A Comparative Study on Pasting and Hydration Properties of Native Rice Starches and Their Mixtures

Anastase Hagenimana[1,2] and Xiaolin Ding[1]

Cereal Chem. 82(1):70–76

ABSTRACT

Four rice starches were isolated from waxy and nonwaxy rice cultivars collected from different places in China. Individual rice starches were examined, along with their corresponding mixtures in different ratios, in terms of pasting and hydration properties. Analysis by micro-viscoamylography (MVAG) showed that waxy rice starch and its blends had higher peak viscosity (PV), breakdown (BD), and setback (SB) than the remaining starches and mixtures. Apparent amylose content (AC) was 16.95–29.85% in nonwaxy individual rice starches and 13.69–25.07% in rice starch blends. Incorporating waxy rice starch (25%) significantly decreased the AC. AC correlated negatively with swelling power (SP) (r = –0.925, $P < 0.01$). SP exhibited nonlinear relationship ($r^2 = 0.8204$) with water solubility (WS) and both increased with temperature. The correlation showed that WS is also an index of starch characteristics and the granules rigidity affected the granule swelling potential. The results show that turbidity of gelatinized starch suspensions stored at 4 ± 0.5°C generally increased during storage up to five days.

Rice (*Oryza sativa* L.) is one of the most important foodstuffs for people in many countries, especially in Oriental countries. China is the world's largest rice producer and consumer, with a total annual production of nearly 200 million tonnes in 1998-2000. It grows mostly the long grain type and short/medium grain as well, most of it being consumed in whole grain form. In addition to the above, other rice types are commercially available including waxy (high-amylopectin) rice.

The textural properties of cooked rice affect strongly the economic value of rice both in international and domestic markets. Changes in starch during rice processing contribute to product texture; gelatinization and retrogradation are the most important changes. The retrogradation of starch is one of the undesirable changes in certain physicochemical properties that affect the texture and digestibility of starchy products (Biliaderis and Zawistowski 1990). In fact, it affects the quality, acceptability, and shelf life of starch-containing foods. The range of amylose contents allows a cultivar to be selected to minimize retrogradation. Juliano (1985) reported that the quality of cooked rice is affected by its starch properties, especially the amylose content.

Starch is generally regarded as the most important constituent of rice in terms of pasting behavior and functionality (Juliano 1985). Studies of starch pasting properties are most commonly conducted using either the Brabender Visco-Amylograph (BVA) or the Rapid Visco Analyser (RVA). A number of studies have been published on the pasting behavior of starch suspensions with viscoamylography (Halik and Kelly 1959; Juliano 1982; Doublier 1987; Deffenbaugh and Walker 1989; Aerts and Verspaille 2001). The RVA was developed as an alternative instrument to the BVA; its advantages include shorter time and smaller sample size requirements, and its use has also been reported in recent studies (Deffenbaugh and Walker 1989; Thiewes and Steeneken 1997; Noda et al 2003; Varavinit et al 2003).

A new apparatus, a micro-viscoamylograph (MVAG) designed on principles similar to those of the BVA has been developed and is actually used to conduct studies on pasting properties. However, it differs from the BVA in spindle design, sample size, and testing speed. To date, as far as we know, the only available literature is that of Suh and Jane (2003), who performed a study on starch pasting properties using RVA and MVAG and found that the difference in pasting properties between the two instruments was attributed to the difference in spindle structure.

[1] Department of Food Science, Southern Yangtze University, Wuxi, Jiangsu, P.R. China, 214036.
[2] Corresponding author. E-mail: hagenanas@yahoo.com

DOI: 10.1094/CC-82-0070

The mixing of starches was previously suggested as a possibility to reduce retrogradation (Obani and BeMiller 1997). As the food industry is exploring the use of rice in new foods for domestic and export markets, it is possible that flours or starches from different rice cultivars can be mixed together to obtain products with desired characteristics for a potential world market. Thus, a better understanding of the pasting properties and a monitoring of retrogradation tendency of native rice starches and mixtures was needed and could lead to improvements in the eating quality of rice-related products (particularly textural attributes).

The objectives of the work presented here were to compare the changes in the pasting properties (using MVAG) and the hydration characteristics of a range of native rice starches and their corresponding blends separated from rice cultivars collected in China, and to quantitate turbidometrically their retrogradation in low-concentration pastes.

MATERIALS AND METHODS

Starch Materials

Milled rice samples consisted of four rice cultivars: Xian Mi (XM) long rice; Gong Mi (GM) short rice; Jin You Mi (JYM) long rice, and common waxy rice (NM). They were obtained and collected from different places of China: Hulan (XM and GM); Hubei (JYM), and Jiangsu (NM). Other reagents were of analytical grade and were used without further purification. Starches of the rice cultivars used in this study were isolated by a modified alkaline steeping method (Yang et al 1984). Apparent amylose content (AC) was determined according to Yao et al (2002). Briefly, 100 mg of starch was dissolved in 10 mL of 90% DMSO and then diluted to 50 mL with deionized water. An aliquot of 2 mL was diluted with deionized water to 50 mL, and then 1 mL of iodine regent (0.30% I_2 + 3% KI) was added. After mixing, the absorbance at 600 nm was measured.

Starch Suspension Preparation

Pasting properties of individual rice starches and starch mixtures were determined at least in duplicate using a micro-viscoamylograph (Brabender, Duisburg, Germany) operated at 250 rpm. Rice starch slurry (10 g, db), dispersed in 100 mL of deionized water, was directly placed into a stainless steel measuring bowl and then heated from 30 to 95°C, held for 20 min at 95°C, and cooled to 50°C. Heating and cooling rates were 3°C/min. The parameters were defined by Limpisut and Jindal (2002) as breakdown (BD), the drop in viscosity at the end of cooking with reference to the peak viscosity; setback (SB), the rise or fall in viscosity at the end of the cooling cycle; and consistency (CC) derived from the viscoamylograph. Viscosity was measured in BU.

Hydration Properties

The swelling power (SP) and the water solubility (WS) of individual native rice starches and starch blends were measured according to the method of Schoch (1964) with some slight modifications (Collado and Corke 1999). Starch suspension (0.5 g, dry basis, to which 45 mL of distilled water was added) was heated to 55, 65, 75, 85, and 95°C, respectively, and was kept at that temperature for 30 min. The heated samples were cooled rapidly in ice water bath for 1 min, equilibrated at 25°C for 5 min, and then centrifuged at 3,000 × *g* for 20 min. SP was determined by measuring the sedimented paste weight and WSI (%) = (weight of the dried supernatant/initial weight of the dry starch) × 100.

Turbidometric Analysis

Turbidity of native rice starches and the blends was measured as described by Perera and Hoover (1999). A 2% starch suspension of rice starch or starch blend was heated in a boiling water bath for 1 hr with continuous gentle stirring and then cooled for 1 hr in a 25 ± 0.5°C water bath. The samples were stored for six days at 4 ± 0.5°C and the turbidity was determined by measuring absorbance at 640 nm against a water blank with a UV 755B spectrophotometer. Incubation at 4°C was applied to obtain extensive retrogradation in a short time by favoring nucleation (formation of crystal nuclei).

Statistical Analysis

All analyses were done in duplicate or triplicate unless otherwise indicated. Data were analyzed by analysis of variance using statistical software (v. 8.2; SAS Institute, Cary, NC). The least significant difference (LSD) was used to compare means at the 5% significance level. Pearson correlation coefficients were calculated (SPSS11.0 for Windows, Student Version).

RESULTS AND DISCUSSION

Pasting Properties of Native Rice Starches and Their Blends

Amylose content and pasting characteristics at different reference points are summarized in Table I. Apparent amylose content (AC) of individual rice starches were 16.95–29.79% in nonwaxy rice starches and 13.69–25.07% in rice starch blends. NM was exclusively made of amylopectin and was classified as waxy rice. Figure 1 illustrates the results from selected representative profiles and compares pasting profiles of individual rice starches and their mixtures. All pasting behaviors of rice starch mixtures were dependent on their mixing ratios. The initial pasting temperature (PT) that represents the temperature of initial viscosity increase was 63.4–75.3°C for individual native rice starches and 64.1–75.5°C for rice starch mixtures. Differences in pasting temperature are

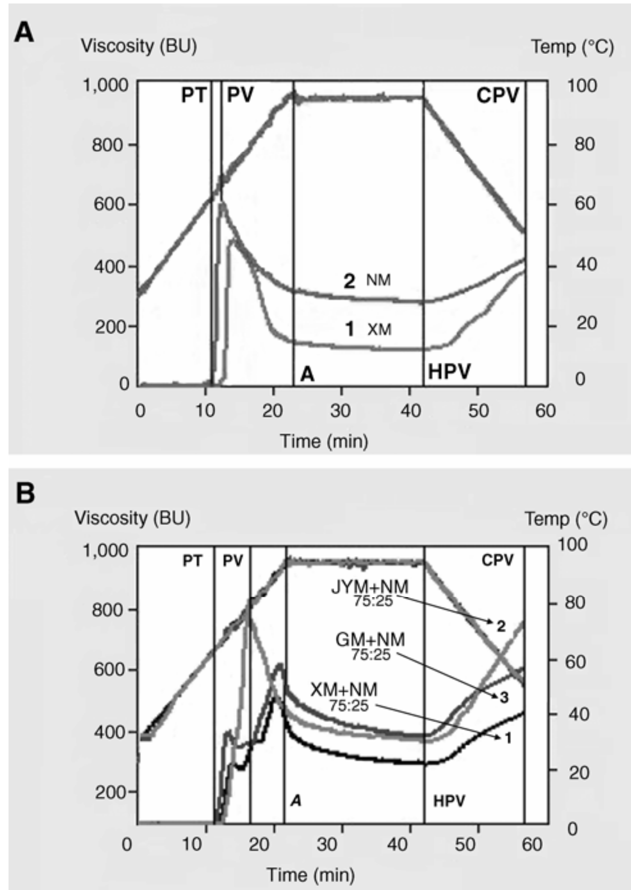

Fig. 1. Representative comparative viscosity profiles of individual native rice starches (**A**) and the corresponding blends (**B**) determined by micro-visco amylography (MVAG). PT, pasting temperature (beginning of gelatinization); PV, peak viscosity (maximum viscosity); *A*, start of holding period; HPV, hot paste viscosity (start of cooling period); CPV, cold paste viscosity (end of cooling period).

TABLE I
Amylose Content and Amylograph Pasting Characteristics[a,b] of Individual Rice Starches and Blends Measured by Micro-Viscoamylography (MVAG)

Starch Sample[c]	PV (BU)	SB (BU)	BD (BU)	CC (BU)	HPV (BU)	CPV (BU)	AC (%)
XM	482.00 ± 1.41d	–104.00 ± 1.41j	357.00 ± 3.53b	254.00 ± 4.94e	124.00 ± 2.12f	378.00 ± 2.82e	16.95 ± 0.48f
GM	434.00 ± 4.24f	–23.00 ± 2.82f	322.00 ± 7.77c	297.00 ± 7.07b	114.00 ± 8.48g	411.00 ± 1.41cd	23.04 ± 0.80c
JYM	347.00 ± 1.41i	50.00 ± 4.94b	214.00 ± 1.41f	268.00 ± 0.00d	133.00 ± 2.82f	401.00 ± 2.82d	29.85 ± 0.21a
NM	597.00 ± 3.24b	–179.00 ± 2.12l	324.00 ± 4.24c	144.00 ± 3.53h	273.00 ± 5.65c	417.00 ± 2.12c	0.04 ± 0.11h
XM+GM 75:25	462.00 ± 2.12e	–116.00 ± 1.41k	328.00 ± 4.24c	212.00 ± 2.82f	134.00 ± 6.36f	346.00 ± 3.53f	20.47 ± 0.36d
XM+GM 50:50	344.00 ± 4.95i	–75.00 ± 2.82i	189.00 ± 2.82g	114.00 ± 5.65i	155.00 ± 2.12e	269.00 ± 7.77g	19.31 ± 0.42e
GM+JYM 75:25	357.00 ± 1.41hi	47.00 ± 0.70b	230.00 ± 1.41ef	277.00 ± 0.70c	127.00 ± 2.82f	404.00 ± 2.12d	25.07 ± 0.93b
GM+JYM 50:50	362.00 ± 9.98e	59.00 ± 1.41a	235.00 ± 4.24e	294.00 ± 2.82b	127.00 ± 5.65f	421.00 ± 8.48c	23.69 ± 0.06c
XM+JYM 75:25	372.00 ± 1.41g	–34.00 ± 4.24g	222.00 ± 2.82f	188.00 ± 1.41g	150.00 ± 4.24e	338.00 ± 5.65f	22.94 ± 0.30c
XM+JYM 50:50	345.00 ± 9.89i	33.00 ± 1.41c	221.00 ± 4.24f	254.00 ± 6.36e	124.00 ± 2.12fg	378.00 ± 8.48e	20.91 ± 1.54d
XM+NM 75:25	465.00 ± 2.82e	–62.00 ± 7.77h	252.00 ± 9.89d	190.00 ± 2.12g	213.00 ± 7.07d	403.00 ± 2.82d	13.69 ± 0.06g
GM+NM 75:25	576.00 ± 5.65c	–9.00 ± 1.41e	262.00 ± 1.41d	253.00 ± 2.82e	314.00 ± 7.07a	567.00 ± 4.24b	17.50 ± 0.52f
JYM+NM 75:25	721.00 ± 11.31a	5.00 ± 2.12d	422.00 ± 4.24a	427.00 ± 2.12a	299.00 ± 7.07b	726.00 ± 9.19a	19.75 ± 0.47de
Mean	451.08	–31.38	275.23	244.00	175.92	419.92	19.48
SD	118.29	73.06	68.86	78.90	72.87	113.57	7.10

[a] PV, paste viscosity; SB, setback; BD, breakdown; CC, consistency; HPV, hot paste viscosity; CPV, cold paste viscosity; AC, apparent amylose. Determined at 10% (w/v) starch suspension.
[b] Data presented are averages at least of two analyses and values are means ± standard deviations. Samples means with different letters in the same column are significantly different at $P < 0.05$.
[c] Chinese rice cultivars Xian Mi (XM) long rice, Gong Mi (GM) short rice, Jin You Mi (JYM) long rice, and common waxy rice (NM).

attributable to the presence of surface lipids and residual hydrophobic proteins that adhere to the granules that should affect the ability of granules to swell.

Figure 1 and Table I show that among individual native rice starches, NM (waxy rice) exhibited a pasting profile typical of a low-amylose starch with the lowest peak temperature (PT), the highest peak viscosity (PV) (Collado and Corke 1997; Zeng et al 1997), and highest cold paste viscosity (CPV) compared with nonwaxy starches. Moreover, it showed lower setback (SB) and consistency (CC) and larger breakdown (BD) than did XM, GM, and JYM. JYM (highest AC) probably had a higher crystallinity level and this may have accounted for lower PV and higher PT. Based on a classification of viscosity patterns of thick-boiling starches (Schoch and Maywald 1968), most of the rice starches and their mixtures displayed a type B pasting curve (characterized by medium peak viscosity during cooking); except that NM and its blends showed a type A pasting curve with a high swelling capacity. The peak viscosity (PV) indicates the water-holding capacity of starch and refers to the maximum viscosity reached during the heating and holding cycle. It can be affected by the molecular structure of amylopectin (Shibanuma et al 1996), starch water concentration, lipids, residual proteins (Whistler and BeMiller 1997), granule size (Fortuna et al 2000), and instrument operating conditions (Batey et al 2000).

The increase in viscosity observed during heating of starch in water was mainly attributed to the swollen granules and also to the amount of solubilized carbohydrates with reference to amylose (Yeh and Li 1996b). However, further continuous heating and shearing at a high temperature (95°C) promotes the weakening and susceptibility of the starch granules to shear damage (disruption) (Thiewes et al 1997). In fact, the sample was subjected to more shear stress due to the high speed of the MVAG (250 rpm). Therefore, this testing condition probably favored the disintegration of swollen granules due to mutual pressure and crowding. A similar reasoning was advanced earlier (Sandhya Rani and Bhattacharya 1995a–c). On the other hand, differences in branch chain length distribution of amylopectin, crystallinity, granular size distribution, and presence of other components likely play an important role in differences in pasting properties among starches. In fact, the presence of lipids in the starch granule could be responsible for the rates of amylose exudation and granule swelling.

Appreciable changes in pasting properties resulting from incorporating of NM (25%) into GM and JYM were observed. In fact, there were increases in peak viscosity and a decrease in SB for all mixtures compared with the controls. The high PV may be the result of a higher SP of NM in the mixture and it is possible that the integrity of GM and JYM were less prone to fragmentation from shear exerted by MVAG than was NM. In waxy starch, the structure of the starch gel was easily disrupted by heating under the high-shear testing condition. The amylose physically interacted with amylopectin and contributed to the resistance of JYM to the effect of shear and heat, indicated by the BD values.

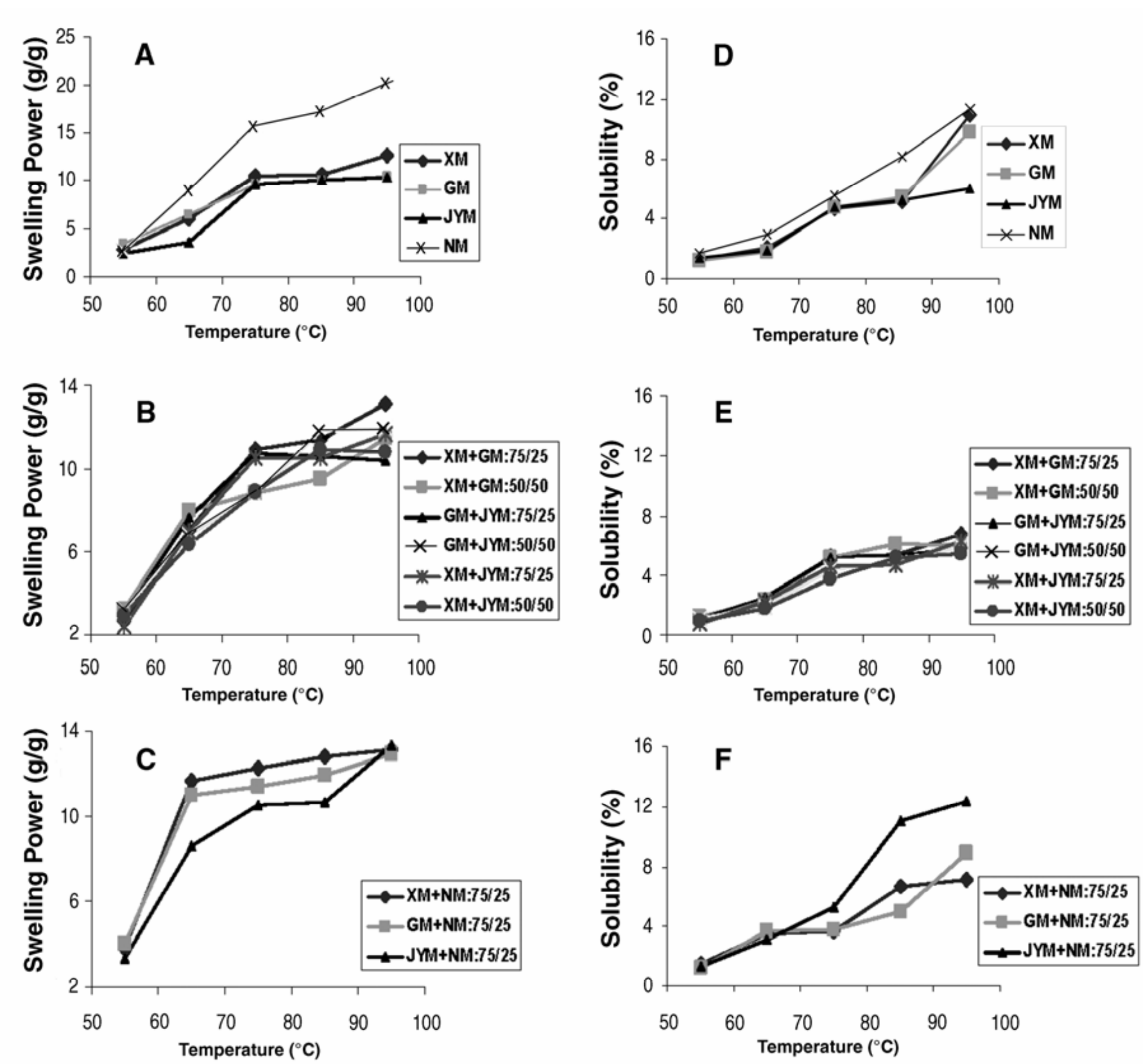

Fig. 2. Swelling power (**A–C**) and water solubility index (**D–F**) patterns of individual native rice starches and the corresponding blends as a function of temperature.

Furthermore, a double peak phenomenon in the pasting profile was observed in mixtures made of NM+XM and NM+GM probably due to the difference in pasting properties between waxy and nonwaxy starches (Fig. 1B). As the gelatinization of waxy starch was lower than that of XM or GM, NM swelled rapidly at the early stages and, when its viscosity started to collapse, XM or GM starches granules kept on swelling. The association between amylose and amylopectin molecules in mixed starches was different from that of individual starches, which induced specific chain interactions (between molecules, starch granules, swollen granules, and granule fragments) during heating, and each starch gelatinized independently of the other, thus providing double peak viscosities. However, this phenomenon was not observed in mixtures made with high-amylose rice starch (JYM) and waxy starch (Fig. 1B) nor between nonwaxy starch mixtures (data not shown).

The breakdown (peak viscosity minus viscosity after holding for 20 min at 95°C [HPV]) is caused by the disintegration of gelatinized starch granule structure during continued stirring and heating (Whistler and BeMiller 1997). The differences among individual rice starch samples and their blends in breakdown are related to differences in rigidity of swollen granules (Sandhya Rani and Bhattacharya 1995a–c; Karim et al 2000). Moreover, amylose has a marked influence on the BD viscosity, which is a measure of the susceptibility of cooked starch granules to disintegration (Lee et al 1995). In contrast to NM starch, JYM showed a stable peak curve with lower BD during heating-cooling cycles, and this indicated restricted swelling of JYM starch granules, probably due to its high amylose content.

The highest setback viscosity (cold paste viscosity minus peak viscosity) was recorded for JYM and its blends with GM, and the lowest was recorded for NM and its blends. The higher the SB, the more syneresis is likely to take place, and this also indicated a higher retrogradation tendency. Higher SB viscosity could result from gel containing more rigid, hydrated structures in the pasted slurry, suggesting the development of network and viscosity during cooling. Thus, SB could reflect the degree of hardening of cooked rice during cooling. Among starch blends, those made of waxy starch developed a low SB compared with other mixtures. Setback varied significantly ($P < 0.05$) among individual native rice starches and the corresponding starch mixtures (Table I). A wide variation in CPV with a mean of 419.92 ± 113.57 BU was observed. The CPV is highly related to the retrogradation tendency of the soluble amylose after cooling or to the ability of the starch paste to form a gel (Olkku and Rha 1978). Another noticeable observation is that the hot paste consistencies are likely of the same order of magnitude for all individual native rice starches and their blends, except those made of NM and its blends. So, HPV patterns depend on the resistance of swollen granules to fragmentation by shear or to dissolution by heat and also on the extent of starch granule swelling. Consistency (cold paste viscosity minus hot paste viscosity) represents the rise in viscosity at the end of the cooling cycle following the cooking of the suspension (Limpisut and Jindal 2002).

Swelling Power and Water Solubility

A comparison showing the change of SP values of native starches and their mixtures during heating is given in Fig. 2. To provide information about the relative strengths of bonding with the granules (Schoch 1964), SP and water solubility of starches were assessed over temperatures of 55–95°C at 10°C intervals. Both the SP and the WS of all starches tested increased as the temperature increased. It has been reported that on the molecular level, the SP and solubility of the starch granule is influenced by many factors, including amylose-to-amylopectin ratio and contents, molecular mass of each fraction, degree of branching, conformation, length of outer branch of amylopectin, and the presence of other components such as lipids and proteins (Leach 1967). Furthermore a combination of granule swelling and solubilization results in a very high increase in viscosity.

Most of the studied individual rice starches exhibited a rapid rise in swelling power from 65 to 75°C, where the gelatinization occurred. However, a slower swelling occurred at temperatures

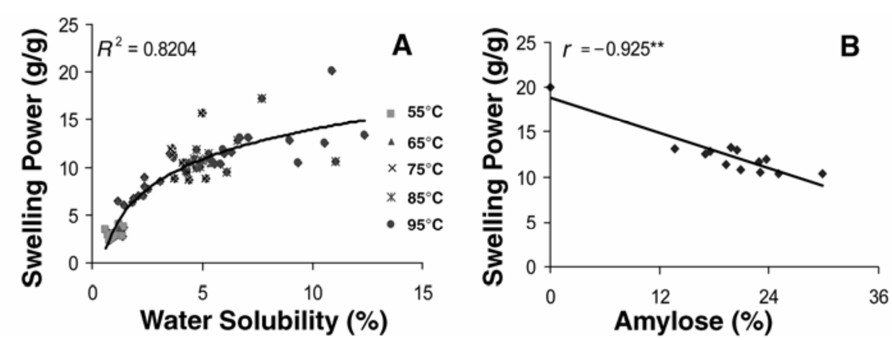

Fig. 3. Correlations between swelling power (SP) and water solubility (WS) (**A**) and relationship between SP and amylose content (AC) (**B**) of individual native rice starches and their mixtures.

TABLE II
Linear Correlation Coefficient Between Physicochemical and Pasting Properties of Rice Starches and Blends[a,b]

	PV	SB	BD	CC	HPV	CPV	WS	SP	AC
PV	1								
SB	–0.371	1							
BD	0.823**	–0.384	1						
CC	0.370	0.596*	0.512	1					
HPV	0.845**	–0.238	0.391	0.118	1				
CPV	0.799**	0.261	0.607*	0.771**	0.724**	1			
WS	0.899**	–0.443	0.886**	0.357	0.622*	0.648*	1		
SP	0.628*	–0.730**	0.425	–0.310	0.617*	0.180	0.570*	1	
AC	–0.556*	0.786**	–0.347	0.432	–0.572*	–0.067	–0.925**	–0.547	1

[a] PV, paste viscosity; SB, setback; BD, breakdown; CC, consistency; HPV, hot paste viscosity; CPV, cold paste viscosity; SP, swelling power; WS, water solubility; AC, amylose content.
[b] Values are correlation coefficients (*r*): **,* significant at 0.01 and 0.05 levels.

higher than 75°C. At 55–95°C, waxy rice exhibited the highest degree of swelling, supporting the idea that reduced amylose content relates to greater swelling. Because the swelling behavior of cereals has been related to amylopectin (Tester and Morrison 1990), the high SP suggested a less rigid granular structure of waxy rice (Wang and Wang 2002) compared with that of nonwaxy rice starches. In fact, Hermanasson and Svegmark (1996) reported that waxy starches have a more open structure that allows rapid water penetration, swelling, and solubility.

Ming et al (1997) reported that greater swelling was associated with higher pasting viscosity and reduction in quantity of free water. Among the four individual rice starches, the lowest swelling power was shown by JYM (high in amylose content) suggesting that the difference in SP among native starches is mainly affected by the amylose content acting as an inhibitor of swelling (Tester and Morrison 1990; Sasaki and Matsuki 1998) and can also be ascribed to the difference in crystallinity of molecular association inside the granules.

Nevertheless, mixtures of 25% NM exhibited a rapid swelling at 55–65°C compared with the remaining ranges of temperatures, followed by a slower swelling from 75 to 95°C. This suggests that NM swells at earlier stages than JYM. Moreover, SP for other starch mixtures behaved differently compared with the respective rice starches, where moderate, slow, and drastic increase of SP was observed at different stages when temperature was increased. Furthermore, the SP apparently took place in two steps (55–75°C and 85–95°C). The difference in SP values obtained among starch mixtures could be attributed to morphological structures, the chemical composition, and the crystallinity of starch granules.

The extent of water solubility for native rice starches and their mixtures is shown in Fig. 2. At >60°C, starting at 65°C, a sharp increase in solubility was observed in individual rice starches. This index increased again at 85–95°C. The same tendency was exhibited by the starch mixtures. In waxy rice starch, the solubility was very high, starting from ≈65°C, and a continuous increase was observed when the temperature was increased and finally resulted in a network of solubilized waxy starch. Among starch mixtures, the JYM+NM 75:25 showed the highest solubility.

Correlation Analysis

Correlation coefficients were calculated to evaluate the relationships between physicochemical properties and pasting characteristics of native rice starches and their mixtures (Table II). Peak viscosity indicated a high positive correlation with BD, HPV, CPV, and WS ($r > 0.79$; $P < 0.01$). Both CC and HPV were correlated with CPV ($P < 0.01$). SP (at 95°C) was negatively correlated with SB ($P < 0.01$) but positively correlated with PV, BD, HPV, and CPV; whereas, solubility showed a significant positive correlation with PV, HPV, and WS. SP range was 10.38–20.1 g/g for all the samples, whereas for WS, the value range was 5.39–12.36% at 95°C. SP exhibited a nonlinear relationship ($r^2 = 0.8204$) with WS, whereas SP correlated negatively with AC ($r = -0.925$) as shown in Fig. 3A and B, respectively. The correlation observed in Fig. 3A shows that WS is also an index of starch characteristics and Fig. 3B indicated that AC had a negative effect on SP as reported by Sasaki and Matsuki (1998). In addition, from the present data, a significant negative correlation was found between the AC and PV ($r = -0.556$; $P < 0.05$), whereas a high positive correlation was found between AC and SB ($r = 0.786$; $P < 0.01$).

Turbidity

It is well known that when starch suspension is heated, leaching of amylose (linear fraction) occurs, and upon cooling, microcrystals are formed and turbidity appears (Craig et al 1989). The increase in turbidity results from changes in density distribution due to phase separation during aging of gelatinized starch solutions (Miles et al 1985). The turbidity of gelatinized rice starch suspensions stored at 4 ± 0.5°C generally increased during storage up to day 5 as shown in Table III. Based on the rates of absorbance changes, the starches could be grouped into three categories: 1) waxy rice with slow increase in initial turbidity; 2) intermediate initial turbidity; and 3) high AC (JYM) with high initial turbidity. Factors responsible for turbidity development in starches during storage have been previously identified by many researchers (Craig et al 1989; Jacobson et al 1997, Jacob and BeMiller 1998) and include aggregates made of leached amylose, amylose, and amylopectin chain lengths, intra- or intermolecular bonding, granule swelling, and granule remnants. Starch gels, being metastable and nonequilibrium states (Biliaderis and Zawistowski 1990), undergo structural transformation in terms of chain aggregation, recrystallization during storage, and these changes are referred to as retrogradation. Short-term development of crystallinity is attributed to molecule organization and crystallization of the amylose fraction (Miles et al 1985).

NM developed a low initial turbidity up to six days because the aggregation and slow crystallization of amylopectin were implicated in the long-term changes. In addition, its lower initial turbidity compared with others also could be attributed to its high swelling power and the absence of granule fragments (Perera et al 1997; Perera and Hoover 1999). JYM developed the highest turbidity due to the molecular associations (especially involving amylose) occurring at the earlier stages of storage from the rapid cooling at low temperature. Furthermore, Perera and Hoover (1999) indicated also that the increase in turbidity was mainly attributed

TABLE III
Turbidity of Gelatinized Starches Suspensions Stored for Six Days at 4 ± 0.5°C[a]

	Turbidity (absorbance at 640 nm)						
Starch Sample[b]	**0 Day**	**1 Day**	**2 Days**	**3 Days**	**4 Days**	**5 Days**	**6 Days**
XM	0.501 ± 0.123bc	0.556 ± 0.002c	0574 ± 0.018c	0.590 ± 0.012c	0.596 ± 0.002d	0.598 ± 0.001d	0.585 ± 0.006de
GM	0.522 ± 0.005bc	0.604 ± 0.004b	0.644 ± 0.009b	0.651 ± 0.010b	0.663 ± 0.005c	0.672 ± 0.009c	0.665 ± 0.008c
JYM	0.759 ± 0.004a	0.817 ± 0.009a	1.022 ± 0.033a	1.262 ± 0.023a	1.279 ± 0.004a	1.489 ± 0.009a	1.506 ± 0.006a
NM	0.331 ± 0.007d	0.336 ± 0.001g	0.339 ± 0.001f	0.342 ± 0.002f	0.346 ± 0.002k	0.345 ± 0.002i	0.345 ± 0.002i
XM+GM 75:25	0.472 ± 0.012bc	0.478 ± 0.012de	0.493 ± 0.006d	0.495 ± 0.006e	0.503 ± 0.005h	0.563 ± 0.036e	0.553 ± 0.033ef
XM+GM 50:50	0.501 ± 0.012bc	0.502 ± 0.006d	0.523 ± 0.052cd	0.521 ± 0.007de	0.537 ± 0.007g	0.577 ± 0.007de	0.573 ± 0.006de
GM+JYM 75:25	0.372 ± 0.042c	0.426 ± 0.006ef	0.488 ± 0.004d	0.496 ± 0.002e	0.507 ± 0.006h	0.530 ± 0.007f	0.526 ± 0.006f
GM+JYM 50:50	0.526 ± 0.014bc	0.541 ± 0.002cd	0.567 ± 0.007c	0.575 ± 0.004c	0.582 ± 0.005e	0.669 ± 0.016c	0.671 ± 0.017c
XM+JYM 75:25	0.436 ± 0.048c	0.453 ± 0.038e	0.453 ± 0.038de	0.473 ± 0.010e	0.480 ± 0.001i	0.489 ± 0.008g	0.488 ± 0.014e
XM+JYM 50:50	0.504 ± 0.016bc	0.511 ± 0.013d	0.531 ± 0.010cd	0.542 ± 0.003d	0.548 ± 0.005g	0.598 ± 0.008d	0.595 ± 0.009d
XM+NM 75:25	0.397 ± 0.030c	0.399 ± 0.012f	0.405 ± 0.008e	0.409 ± 0.002f	0.414 ± 0.004j	0.425 ± 0.001h	0.421 ± 0.002h
GM+NM 75:25	0.533 ± 0.049b	0.536 ± 0.048cd	0.533 ± 0.044cd	0.532 ± 0.041d	0.561 ± 0.010f	0.574 ± 0.019de	0.563 ± 0.013e
JYM+NM 75:25	0.506 ± 0.009bc	0.519 ± 0.012b	0.523 ± 0.006cd	0.533 ± 0.006d	0.733 ± 0.006b	0.845 ± 0.004b	0.851 ± 0.002b

[a] Data presented are averages of three analyses and values are means ± standard deviation determined at 2% (w/v) starch suspension. Sample means with different letters in the same column are significantly different at $P < 0.05$.
[b] Chinese rice cultivars Xian Mi (XM) long rice, Gong Mi (GM) short rice, Jin You Mi (JYM) long rice, and common waxy rice (NM).

to the rapid formation of double helical junction zones upon cooling, resulting from the continued interaction between leached amylose-amylopectin chains through hydrogen bonding. The development of turbidity, opacity, and syneresis of water from the paste occurs during retrogradation, and this phenomenon will depend on starch concentration, storage duration and temperature, presence of solutes, and biopolymers. Meanwhile, the rapid initial rate of retrogradation was related to the loss of networked amylose (Chang and Liu 1991), to the development of amylose aggregates, and the bonding of granule remnants into assemblies by amylose and amylose aggregates (Jacobson et al 1997). It seems logical to mention that starch retrogradation is governed by a consecutive three-step mechanism that involves nucleation, propagation, and maturation. For native rice blends, the lower paste clarity in XM+NM and GM+NM rice mixtures may be explained by the presence of chain polymers that are resistant to retrogradation. In fact, the network of solubilized waxy starch may have retained much of the amylose that leached out of the nonwaxy starch, contributing to the lower paste clarity.

CONCLUSIONS

Apparent amylose content (AC) was 16.95–29.79% in nonwaxy rice starches and 13.69–25.07% in rice starch blends. Both SP and WS of all starches tested increased with temperature; the extent of this increase was more pronounced at >75°C. AC suppresses starch swelling and appears to play a critical role in determining starch pasting properties using MVAG. Waxy rice (25%) mixed with starches isolated from low and intermediate AC showed pasting profile curves with two characteristic peaks and developed viscosities at different temperatures. The rigidity of the granules affected the granule swelling potential. SP of studied starches correlated negatively with AC. The results show that mixtures of native rice starches can be used to improve pasting properties for different purposes, especially in terms of development of new rice food products and also the eating quality of rice. Turbidity of gelatinized starch suspensions stored at 4 ± 0.5°C generally increased during storage up to day 5, and MN developed the slowest turbidity.

The results from this study showed that AC of starch blends can be well adjusted by mixing nonwaxy and waxy rice starches and this should depend on the proportion of each type of starch. Thus, scientists should combine biotechnology with radiation mutation technology to enhance innovation in breeding material and breed new super rice cultivars, as well as new cultivars for food, feed, and industry.

ACKNOWLEDGMENTS

We are thankful to Gu Wen Ying for her constructive advice on this publication.

LITERATURE CITED

Aerts, L., and Verspaille, M. 2001. Absolute rheometry in the Brabender viscograph by mixer viscometry calibration. Starch 53:59-63.

Batey, I. L., and Curtin, B. M. 2000. Effects on pasting viscosity of starch and flour from different operating conditions for the Rapid Visco Analyser. Cereal Chem. 77:754-760.

Biliaderis, C. G., and Zawistowski, J. 1990. Viscoelastic behavior of aging rice starch gels: Effects of concentration, temperature, and starch hydrolysates on network properties. Cereal Chem. 67:240-246.

Chang, S. M., and Liu, L. C. 1991. Retrogradation of rice starches studied by differential scanning calorimetry and influence of sugars, NaCl, and lipids. J. Food Sci. 56:564-567.

Collado, L. S., and Corke, H. 1997. Properties of starch noodles as affected by sweet potatoes. Cereal Chem. 74:182-187.

Collado, L. S., and Corke, H. 1999. Heat-moisture treatment effect on sweet potato starches differing in amylose content. Food Chem. 65:339-346.

Craig, S. A. S., Maningat, C. C., Seib, P. A., and Hoseney, R. C. 1989. Starch paste clarity. Cereal Chem. 66:173-182.

Crosbie, G. B., Lambe, W. J., Tsutsui, H., and Gilmour, R. F. 1992. Further evaluation of the flour swelling volume test for identifying wheats potentially suitable for Japanese noodles. J. Cereal Sci. 15:271-280.

Deffenbaugh, L. B., and Walker, C. E. 1989. Comparison of starch pasting properties in the Brabender Viscoamylograph and Rapid Visco-Analyser. Cereal Chem. 66:493-499.

Doublier, J. L. 1987. A rheological comparison of wheat, maize, faba bean and smooth pea starches. J. Cereal Sci. 5:247-262.

Fortuna, T., Januszewska, R., Juszczak, I., Kielski, A., and Palasinski, M. 2000. The influence of starch pore characteristics on pasting behavior. Int. J. Food Sci. Technol. 35:285-291.

Halik, J. V., and Kelly, V. J. 1959. Gelatinization and pasting characteristics of rice varieties as related to cooking behavior. Cereal Chem. 36:91-98.

Hermansson, A. M., and Svegmark, K. 1996. Developments in the understanding of starch functionality. Trends Food Sci. Technol. 7:345-353.

Hoover, R., Sailaja, Y., and Sosulski, F. W. 1996. Characterization of starches from wild and long grain brown rice. Food Res. Int. 29:99-107.

Jacobson, M. R., Obanni, M., and BeMiller, J. N. 1997. Retrogradation of starches from different botanical sources. Cereal Chem. 74:571-578.

Jacobson, M. R., and BeMiller, J. N. 1998. Method for determining the rate and the extent of accelerated starch retrogradation. Cereal Chem. 75:22-29.

Juliano, B. O. 1982. An international survey of methods used for evaluation of cooking and eating qualities of milled rice. IRRI Res. Paper 77. IRRI: Los Banos, The Philippines.

Juliano, B. O. 1985. Criteria and tests for rice grain qualities. Pages 443-524 in: Rice Chemistry and Technology. Am. Assoc. Cereal Chem.: St. Paul, MN.

Karim, A. A., Norziah, M. H., and Seow, C. C. 2000. Methods for the study of starch retrogradation. Food Chem. 71:9-36.

Leach, H. W. 1967. Gelatinization of starch. Pages 289-307 in: Starch: Chemistry and Technology. R. L. Whistler and E. F. Pascal, eds. Academic Press: New York.

Lee, N. H., Hettiarachchy, N. S., McNew, R. W., and Gnanasambandam, R. 1995. Physicochemical properties of calcium-fortified rice. Cereal Chem. 72:352-355.

Li, J. Y., and Yeh, A. I. 2001. Relationship between thermal, rheological characteristics and swelling power for various starches. J. Food Eng. 50:141-148.

Limpisut, P., and Jindal, V. K. 2002. Comparison of rice flour pasting properties using Brabender Viscoamylograph and Rapid Visco Analyser for evaluating cooked rice texture. Starch 54:350-357.

Lorenz, K., Fong, R. Y., Mossman, A. P., and Saunders, R. M. 1978. Long, medium, and short grain rices—Enzyme activities and chemical and physical properties. Cereal Chem. 55:830-841.

Miles, M. J., Morris, V. J., and Ring, S. G. 1985. The roles of amylose and amylopecton in the gelation and retrogradation of starch. Carbohydr. Res. 135:271-278.

Ming, Z., Morris, C. F., Batey, I. L., and Wrigley, C. W. 1997. Sources of variation for starch gelatinization, pasting, and gelation properties in wheat. Cereal Chem. 74:63-71.

Noda, T., Nishiba, Y., Sato, T., and Suda, I. 2003. Properties of starches from several low-amylose rice cultivars. Cereal Chem. 80:193-197.

Obanni, M., and BeMiller, J. N. 1997. Properties of some starch blends. Cereal Chem. 74:431-436.

Olkku, J., and Rha, C. 1978. Gelatinization of starch and wheat flour starch—A review. Food Chem. 3:293-317.

Perera, C., Hoover, R., and Martin, A. M. 1997. The effect of hydroxypropylation on the structure and physicochemical properties of native, defatted and heat-moisture treated potato starches. Food Res. Int. 30:235-247.

Perera, C., and Hoover, R. 1999. Influence of hydroxypropylation on retrogradation properties of native, defatted and heat moisture treated potato starches. Food Chem. 64:361-375.

Sandhya Rani, M. R., and Bhattacharya, K. R. 1995a. Rhelology of rice-flour paste: Effect of variety, concentration, and temperature and time of cooking. J. Texture Stud. 20:127-137.

Sandhya Rani, M. R., and Bhattcharya, K. R. 1995b. Rheology of rice-flour pastes: Relationship of paste breakdown to rice quality, and simplified Brabender viscograph test. J. Texture Stud. 26:587-598.

Sandhya Rani, M. R., and Bhattacharya, K. R. 1995c. Microscopy of rice starch granules during cooking. Starch 47:334-337.

Sasaki, T., and Matsuki, J. 1998. Effects of wheat starch structure on

swelling power. Cereal Chem. 75:525-529.
Schoch, T. J. 1964. Swelling power and solubility of granular starch. Pages 104-109 in: Methods in Carbohydrate Chemistry. Vol. IV. R. L. Whistler, ed. Academic Press: New York.
Schoch, T. J., and Maywald, E. C. 1968. Preparation and properties of various legumes starches. Cereal Chem. 45:564-573.
Shibanuma, Y., Tekeda, Y., and Hizukuri, S. 1996. Molecular and pasting properties of some wheat starches. Carbohydr. Polym. 29:253-261.
Suh, D. S., and Jane, J.-L. 2003. Comparison of starch pasting properties at various cooking conditions using the Micro Visco-Amylo-Graph and the Rapid Visco Analyser. Cereal Chem. 80:745-749.
Tester, R. F., and Morrison, W. R. 1990. Swelling and gelatinization of cereal starches. I. Effect of amylopectin, amylose, and lipids. Cereal Chem. 67:551-557.
Thiewes, H. J., and Steeneken, P. A. M. 1997. Comparison of the Brabender Viscograph and the Rapid Visco Analyzer. 1. Statistical evaluation of the pasting profile. Starch 49:85-92.
Varavinit, S., Shobsngob, S., Varanyanond, W., Chinachoti, P., and Naivikul, O. 2003. Effect of amylose content on gelatinization, retrogradation and pasting properties of flours from different cultivars of Thai rice. Starch 55:410-415.
Wang, Y.-J., and Wang, L. 2002. Structures of four way rice starches in relation to thermal, pasting, and texture properties. Cereal Chem. 79:252-256.
Whistler, R. L., and BeMiller, J. N. 1997. Carbohydrate Chemistry for Food Scientists. Am. Assoc. Cereal Chem.: St. Paul, MN.
Yang, C. C., Lai, H. M., and Lii, C. Y. 1984. The modified alkaline steeping method for the isolation of rice starch. Food Sci. (Chinese) 11:158-162.
Yao, Y., Zhang, J., and Ding, X. 2002. Structure-retrogradation in relationship of rice starch in purified starches and cooed rice grains: A statistical investigation. J. Agric. Food Chem. 50:7420-7425.
Yeh, A. I., and Li, J. Y. 1996b. A continuous measurement of swelling of rice starch during heating. J. Cereal Sci. 2:277-283.
Zeng, M., Morris, C. F., Batey, I. L., and Wrigley, C. W. 1997. Sources of varietal starch gelatinization, pasting, gelation properties in wheat. Cereal Chem. 74:63-71.

[Received January 27, 2004. Accepted September 13, 2004.]