

# Physicochemical Properties Related to Quality of Rice Noodles

M. Bhattacharya,<sup>1,2</sup> S. Y. Zee,<sup>1</sup> and H. Corke<sup>1,3</sup>

## ABSTRACT

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Eleven rice genotypes with diverse Rapid Visco Analyzer (RVA) pasting characteristics were evaluated for their physicochemical and gel textural characteristics relative to their suitability for making rice noodles. Apparent amylose content (AC) was highly correlated with swelling power ( $r = -0.65$ ,  $P < 0.05$ ), flour swelling volume (FSV) ( $r = -0.67$ ,  $P < 0.05$ ), noodle hardness ( $r = 0.74$ ,  $P < 0.01$ ), gumminess ( $r = 0.82$ ,  $P < 0.01$ ), chewiness ( $r = 0.74$ ,  $P < 0.01$ ), and tensile strength ( $r = 0.72$ ,  $P < 0.05$ ). Solubility

showed an inverse relationship with the pasting parameters and noodle rehydration, and a positive relationship with cooking loss, noodle hardness, and gumminess. FSV and most of the pasting parameters were negatively correlated with noodle hardness. RVA parameters and textural parameters of gels formed in the RVA canister were well correlated with actual noodle texture and may, therefore, be used for predicting rice noodle quality during early screening of genotypes in breeding programs.

Rice noodles are a traditional oriental food, widely consumed in Southeast Asia. Rice protein lacks the functionality of wheat gluten in making a cohesive dough structure. In order to create a uniform matrix in which the starch granules are embedded, it is common to subject at least part of the rice flour to pregelatinization to create a binder for the remaining flour. The conventional process for making rice noodles involves soaking ground rice for several hours, steam cooking the rice slurry to gelatinize the rice starch, kneading the slurry to obtain a cohesive dough, extruding the dough, and, finally, subjecting the extruded noodles to surface gelatinization in boiling water or steam to improve noodle stability and texture (Juliano and Sakurai 1985).

A number of alternative, timesaving methods have been reported for improving and simplifying the process of noodle making. Dry-milled flours have been used instead of wet-milled starch for rice pasta preparation (Resmini et al 1979). Lee and Kim (1981) reported that a flour mixture of rice, popped rice, wheat flour, and xanthan gum could improve the noodle-making properties and cooking quality, and gave a high score in sensory evaluation. Toh (1996) patented a process for producing instant rice noodles by pretreating rice flour with steam to partially gelatinize the starch, mixing the flour with hot water to obtain a dough, extruding the dough to form noodles, steaming the noodles, blanching the steamed noodles in hot water, and, finally, drying the noodles to a moisture content <15% by weight. The noodles had a firm, clean, springy bite, smooth mouthfeel, and low cooking loss.

The degree of pregelatinization of flour plays a very important role in imparting desirable noodle texture. Although some level of gelatinization is required to produce the binding effect during extrusion, excessive gelatinization may cause extremely high extrusion pressures (Juliano and Sakurai 1985). Resmini et al (1979) reported that rice pasta made with 7% pregelatinized rice flour produced much better quality noodles than that with 100% gelatinized or raw rice flour. Increasing the proportion of gelatinized flour from 7% to 10–15% did not further improve the cooking quality and network compactness of the cooked noodles.

Traditionally, rice noodles are made from long-grain rice with intermediate to high amylose content (>22% amylose) (Kohlwey et al 1995). Sanchez (1975) used sensory evaluation to assess the quality of noodles made from different varieties of rice. A highly significant correlation was found between high amylose and general acceptability. Chen and Luh (1980) reported that swelling capacity of starch and amylose-amylopectin ratio are the two major factors

affecting rice noodle quality. Li and Luh (1980) noted that rice varieties with high amylose, low gelatinization temperature, and hard gel consistency were best suited for making noodles. Umali (1981) reported that high amylose rice gave brightest colored noodles with low bulk density due to low swelling capacity, while intermediate amylose rice produced darker noodles with higher bulk density. Mestres et al (1988) studied the structural organization of starch within rice and mung bean noodles and observed that in the absence of gluten, amylose crystallites helped in creating a continuous network by strongly linking to one another by junction zones.

Texture of cooked noodles is the most critical characteristic that determines consumer acceptance of the product. The direct and ultimate method for assessing texture of noodles is by sensory evaluation. However, sensory evaluation is impractical when sample size is limited or when large numbers of lines are to be evaluated in breeding (Edwards et al 1993). Due to the constraints of sensory evaluation, a number of instrumental methods have been developed for measuring the textural properties of pasta (Walsh 1971, Voisey et al 1978, Smewing 1997) and noodles (Chang and Lee 1974, Lii and Chang 1981, Oh et al 1983) that are less time-consuming, more cost-effective, require small sample size, and do not require trained panelists. In an earlier study, we found that the textural parameters of the gels formed in the RVA canister correlated highly with the pasting characteristics of wheat starch, and could be used as an indirect measure of textural quality of wheat noodles (Bhattacharya et al 1997). In this study, we applied similar methodology in evaluating rice noodle quality.

The objectives of the present study were to 1) standardize a laboratory-scale method for making rice noodles, 2) study genotypic variation in physicochemical and pasting properties of rice flour in relation to noodle quality, 3) assess whether texture analysis of the gels formed after RVA analysis could be used for predicting the eating quality of rice noodles, and 4) identify specific characteristics responsible for producing superior quality rice noodles.

## MATERIALS AND METHODS

### Rice Samples

Grain samples of 40 rice genotypes grown under uniform field conditions at the International Rice Research Institute (IRRI), Philippines, were obtained. A subset of 10 were selected covering a wide diversity in pasting profiles. The grain was ground to flour with a cyclone mill (Udy Corp., Fort Collins, CO) fitted with a 0.5-mm sieve. A commercial rice flour sample, purchased from a local supermarket (Park and Shop, Chi Fu Fa Yuen, Hong Kong), was used for comparison. This was a premium quality product with diverse home-cooking uses, including batter-coating for deep-fried foods. All the flour samples were packed in airtight plastic bags and stored at 4°C until further analysis.

<sup>1</sup> Department of Botany, The University of Hong Kong, Pokfulam Road, Hong Kong.

<sup>2</sup> Present address: Dept. Cereal Science, North Dakota State University, Fargo, ND.

<sup>3</sup> Corresponding author. Fax: +852 2858 3477. E-mail: hcorke@yahoo.com

### Proximate Analysis

Flour lipids were extracted with petroleum ether for 4 hr in a Tecator Soxtec System, and the fat content was calculated from the weight of the dried sample after extraction and expressed as a percentage on a dry basis. Apparent amylose content (AC) was determined according to the method of Juliano et al (1981). Moisture content was determined by drying the samples in an air-oven at 105°C to a constant weight.

### Starch Properties

Flour swelling volume (FSV) was determined in duplicate according to the method of Crosbie et al (1992). Flour samples (0.4 g, dwb) were mixed with 12.5 mL of water in 125- × 16-mm Pyrex culture tubes, equilibrated at 25°C for 5 min and then heated to 92.5°C and held at that temperature for 30 min. The samples were cooled in ice water bath for 1 min, equilibrated at 25°C for 5 min and then centrifuged at 1,000 × *g* for 15 min. The swelling volume was calculated by converting the height of the resultant gels to a volume basis, and the results were reported as mL/g of dry flour.

The supernatant was carefully removed and the swollen starch sediment was weighed. Swelling power (SP) was the ratio in weight of the wet sediment to the initial weight of the dry flour. The supernatant was evaporated overnight at 130°C and weighed. Solubility was the ratio in weight of the dried supernatant to the initial weight of the dry flour.

### Thermal Properties

Thermal analyses were performed in duplicate with a Mettler DSC-20 instrument (Mettler-Toledo AG Instruments, Naenikon-Uster, Switzerland) equipped with a Mettler TC11 data analysis station. Rice flour sample (3.0 mg) was weighed directly into a tared aluminum crucible, and distilled water was added to obtain a flour-to-water ratio of 1:3 (w/w, dwb). The crucible was hermetically sealed and allowed to equilibrate for 1 hr before analysis. The samples were heated from 30°C to 110°C at the rate of 10°C/min. An empty crucible was used as a reference. The onset of gelatinization ( $T_o$ ), the temperature at peak ( $T_p$ ), the temperature at the end of gelatinization ( $T_c$ ), and the enthalpy of gelatinization ( $\Delta H$ ) were obtained using the data processing software supplied with the DSC-20 instrument. No measurements were made on the AM-lipid endotherm in the region 95–120°C.

### Pasting Properties

The pasting properties of the rice flour samples were studied using a Rapid Visco Analyser (RVA) model 3D (Newport Scientific, Warriewood, Australia). Flour (3 g, 14% mb) was weighed directly

in the aluminum RVA sample canister, and distilled water was added to a total constant sample weight of 28 g. A programmed heating and cooling cycle was used where the samples were held at 50°C for 1 min, heated to 95°C in 7.5 min at 6°C/min, held at 95°C for 5 min before cooling to 50°C in 7.5 min, and holding at 50°C for 1 min. Peak viscosity (PV), time from onset of pasting to peak viscosity ( $P_{time}$ ), holding strength or hot paste viscosity at the end of holding at 95°C (HPV), breakdown (BD) (PV – HPV), final viscosity at 50°C or cool paste viscosity (CPV), consistency (CPV – HPV), and setback (SB) (CPV – PV) were recorded. All measurements were replicated twice.

### Textural Analysis of RVA Gels

Texture analysis of RVA gels proceeded according to Bhat-tacharya et al (1997). The flour slurry formed in the canister after the RVA cycle was complete was kept at room temperature (≈23–25°C) overnight and allowed to gel. The canister was sealed with paraffin wrap to prevent moisture loss during the storage period. The gel formed in the can (37 mm dia, 20 mm height) was used directly for texture analysis using a TA.XT2i texture analyzer (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK), equipped with a Texture Expert software program (version 5.16). A standard two-cycle program was used to compress the gels for a distance of 10 mm at a crosshead speed of 30 mm/min using a 7-mm cylindrical probe with a flat end. From the force-time curve obtained, textural parameters of hardness (HD, g) (maximum force required to break the gel in cycle 1), gumminess (GU, g) (hardness × cohesiveness), springiness (SP, mm) (height recovered after the first compression), and chewiness (CW, g × mm) (gumminess × springiness) were computed using the software supplied with the instrument. Four repeat measurements were taken of each of the two replicate gels per sample (total of eight readings per sample). The diameter of the gel (37 mm) was such that four unbiased repeat measurements (with puncture) could be made on different areas of the same gel with the probe (7 mm dia).

### Preparation of Rice Noodles

Noodles were prepared from 15 g of rice flour. A portion of the total flour sample (1.05 g) was mixed with 5 g of hot water with constant stirring to completely gelatinize the starch and obtain a slurry. The remaining flour was gradually added to the mixture along with ≈6 g of lukewarm water and mixed thoroughly by hand for 15 min to obtain a smooth dough. The amount of water added was ≈42–45% by weight, based on the total weight of the dough formed. The dough was surface gelatinized by placing it in a bamboo steamer and steaming for 1 min. The dough thus obtained

TABLE I  
Physicochemical Properties of 11 Rice Genotypes<sup>a</sup>

Samples	AC (%)	Fat (%)	Solubility (%)	SP (g/g)	FSV (mL/g)	$T_o$ (°C)	$T_p$ (°C)	$T_c$ (°C)	$\Delta H$ (J/g)	PV (RVU)	$P_{time}$ (min)	HPV (RVU)	CPV (RVU)	BD	SB	Cons
Commercial	15.5	0.17	12.8	16.1	16.4	68.5	75.7	84.0	6.3	232	9.6	145	337	87	105	192
IR5	20.9	0.38	22.4	10.4	9.7	69.0	76.5	87.8	8.5	96	9.0	68	148	28	53	80
IR28	18.1	0.42	19.9	10.4	9.7	62.6	68.0	76.5	3.6	143	9.5	113	248	30	106	136
IR32	19.6	0.54	20.1	11.8	10.9	70.3	77.2	88.2	9.2	128	9.2	80	190	48	62	110
IR34	19.7	0.44	16.0	12.6	11.8	60.8	67.2	77.6	5.5	201	9.8	154	312	48	111	159
IR42	20.7	0.40	17.0	11.3	10.9	59.5	66.7	78.7	5.6	149	9.9	129	267	21	118	138
IR44	23.1	0.36	17.1	11.9	11.0	62.1	68.0	80.2	5.1	182	9.8	139	282	44	100	143
IR46	25.6	0.34	24.4	10.6	9.7	66.4	76.0	88.5	7.4	119	8.8	73	162	47	43	89
IR48	11.9	0.39	18.3	13.8	13.5	59.1	68.7	82.3	6.5	165	9.7	101	207	64	43	107
IR52	21.8	0.35	21.5	9.7	9.0	60.8	68.0	79.5	5.7	95	9.4	79	165	16	70	86
IR68	22.2	0.21	17.7	12.2	11.4	60.8	67.2	80.2	6.6	171	9.7	135	266	36	95	131
Mean	19.9	0.36	18.8	11.9	11.3	63.6	70.8	82.1	6.4	153	9.5	110	235	42	82	124
SD	3.8	0.1	3.2	1.8	2.1	4.1	4.3	4.3	1.5	41.9	0.3	31.0	62.7	19.7	27.9	33.3
LSD	3.5	0.1	0.7	0.5	0.3	1.6	1.3	0.9	0.6	3.4	0.2	3.2	6.2	2.4	4.2	5.0

<sup>a</sup> AC = amylose content; SP = swelling power; FSV = flour swelling volume;  $T_o$ ,  $T_p$ ,  $T_c$  = gelatinization onset, peak, and conclusion temperatures;  $\Delta H$  = gelatinization enthalpy; PV = peak viscosity;  $P_{time}$  = time from onset of pasting to peak viscosity; HPV = hot paste viscosity; CPV = cool paste viscosity; BD = breakdown; SB = setback; Cons = consistency; SD = standard deviation; LSD = least significant difference ( $P < 0.05$ ).

was more pliant in texture and was further kneaded for 15 min to evenly distribute the gelatinized starch. The kneaded dough was placed in a custom-made metal extruder fitted with a die of 1.5-mm diameter pore size, and the dough was extruded slowly into boiling water by applying steady pressure with a piston. Care was taken to minimize movement of the noodle strands in the boiling water to prevent them from disintegrating. The noodles (25–30 cm length, 1.5 mm dia) were scooped out of the boiling water after 2 min, immersed in ice cold water for 1 min to stop the cooking process, drained over a wire sieve, and the excess moisture was blotted from the surface with a paper towel. The noodle strands were individually spread over a rack and air-dried overnight.

**Evaluation of Cooked Noodles**

Cooking loss was measured by evaporating the cooking water to dryness in a 100°C oven and expressed as a percentage of solid loss during cooking (AACC 1995), while the gain in noodle weight after cooking was recorded as a percentage of rehydration. Textural properties (Bourne 1978) and tensile strength (Smewing 1997) of the noodles were analyzed with the texture analyzer after cooking the noodles to optimum, as defined by the disappearance of the white core (≈4–5 min). For testing tensile strength, the cooked noodle strand was wound two or three times around parallel rollers of a spaghetti-noodle tensile grip analyzer (Stable Micro Systems, Godalming, England) to anchor the sample ends and reduce any slippage. The maximum force (g) required to break the noodle strand gives an indication of the sample’s resistance to breakdown, and the distance (mm) to break indicated its extensibility (Smewing 1997). For texture profile analysis (TPA), a single strand of noodle was securely fastened to the platform with adhesive tape and subjected to 75% deformation in a compression mode using a cylindrical probe (38 mm) at a speed of 1.0 mm/sec. From the TPA curve, textural parameters of hardness, gumminess, springiness, and chewiness were obtained. A total of eight repeat measurements were taken of each of the two replicate noodle samples, and all measurements were taken within 20 min of cooking the noodles.

**Statistical Analysis**

The general linear model procedure of the Statistical Analysis System version 6.10 (SAS Institute, Cary, NC) was used for data analysis. Fisher’s least significance difference (LSD) test was used to compare means at the 5% significance level. Pearson’s correlation coefficients were calculated using Statistica for Windows Release 4.5 (StatSoft, Inc., Tulsa, OK).

**Starch Properties**

The flour samples had a mean AC of 19.9%, ranging from 25.6% in IR46 to 11.9% in IR48 (Table I). According to the AC classification by Juliano et al (1990), five of our samples had low AC (10–20%), five had intermediate AC (20.1–25%), while only IR46 had high AC (>25%). The mean crude fat content was 0.36%, ranging from 0.54% in IR32 to 0.17% in the commercial sample (Table I). The range was comparable to that reported by Juliano (1971) (0.30–0.55%) and Maniñgat and Juliano (1980) (0.03–0.44%). Maniñgat and Juliano (1980) observed that high AC rice tended to have less starch lipids than the intermediate AC rice, while the low AC rice had lipid contents intermediate between those of waxy and intermediate AC rice. However, our study did not show any such distinct trend, as illustrated by the fact that the samples showing the highest and the lowest fat content were both low in AC (Table I).

When starch is heated to a critical temperature in the presence of excess water, the granules imbibe water, swell, and some starch leaches out into the solution. The degree of swelling and the amount of solubilization depend on the extent of chemical bonding within the granules (Tian et al 1991). Presence of strong intermolecular bonds and high AC reduce the extent of swelling by forming an extensive network (Rasper 1969). Amylose is believed to restrict swelling, and starch granules show complete swelling only after amylose has been leached out of the granules. Waxy starches have a more open structure that allows rapid water penetration, swelling, and solubility (Hermansson and Svegmak 1996). Swelling power and solubility of starches are often assessed over a range of temperatures to provide information about the relative strengths of bonding within the granules (Schoch 1964). However, when assessing starches in relation to noodle quality, swelling and solubility tests at a temperature of 92.5°C provide a good simulation of the actual noodle-making process and have been used as rapid, small-scale methods to predict the eating quality of wheat and starch noodles (Crosbie et al 1992, Collado and Corke 1997). The mean swelling volume and swelling power of the different rice genotypes were 11.3 mL/g and 11.9 g/g, respectively, ranging from 9.0 mL/g and 9.7 g/g in IR52 to 16.4 mL/g and 16.1 g/g in the commercial sample (Table I). IR46, which had the highest AC among the genotypes, also had the highest solubility (24.4%), while the commercial sample showed the lowest solubility (12.8%). No correlation was found between the AC of the genotypes and the solubility results, while both the swelling volume and the swelling

**TABLE II**  
Correlation Between Gelatinization, Physicochemical, Pasting, and Cooking Properties of 11 Rice Genotypes<sup>a</sup>

	<i>T</i> <sub>0</sub>	<i>T</i> <sub>p</sub>	<i>T</i> <sub>c</sub>	$\Delta H$	AC	Fat	Solubility	SP	FSV	PV	<i>P</i> <sub>time</sub>	HPV	BD	CPV	SB	Cons	CL
<i>T</i> <sub>p</sub>	0.95***																
<i>T</i> <sub>c</sub>	0.81**	0.93***															
$\Delta H$	0.90***	0.98***	0.98***														
AC	0.01	0.05	0.14	0.09													
Fat	0.05	0.03	0.05	0.04	-0.01												
Solubility	0.21	0.31	0.45	0.38	0.50	0.37											
SP	0.09	0.12	0.03	0.08	-0.65*	-0.45	-0.81**										
FSV	0.10	0.13	0.03	0.08	-0.67*	-0.49	-0.80**	0.99***									
PV	-0.15	-0.21	-0.33	-0.28	-0.41	-0.43	-0.91***	0.86***	0.83***								
<i>P</i> <sub>time</sub>	-0.72*	-0.79**	-0.79**	-0.81**	-0.40	-0.17	-0.80**	0.44	0.43	0.66*							
HPV	-0.41	-0.54	-0.64*	-0.61	-0.20	-0.36	-0.89***	0.58	0.56	0.90***	0.83**						
BD	0.32	0.39	0.30	0.35	-0.55	-0.34	-0.54	0.91***	0.89***	0.72*	0.10	0.33					
CPV	-0.25	-0.38	-0.55	-0.48	-0.27	-0.37	-0.93***	0.67*	0.66*	0.93***	0.75**	0.98***	0.46				
SB	-0.33	-0.54	-0.73**	-0.65*	0.01	-0.20	-0.71*	0.22	0.23	0.60	0.70*	0.85***	-0.06	0.84***			
Cons	-0.09	-0.22	-0.44	-0.34	-0.32	-0.37	-0.92***	0.72*	0.72*	0.93***	0.65*	0.91***	0.54	0.98***	0.81**		
CL	-0.17	0.04	0.22	0.13	0.09	0.06	0.70*	-0.38	-0.37	-0.54	-0.45	-0.65*	-0.14	-0.68*	-0.72*	-0.69*	
Rehydration %	0.04	-0.13	-0.34	-0.24	-0.22	-0.60	-0.74**	0.57	0.59	0.67*	0.46	0.66*	0.39	0.75**	0.66*	0.79**	-0.54

<sup>a</sup> *T*<sub>0</sub>, *T*<sub>p</sub>, *T*<sub>c</sub> = gelatinization onset, peak, and conclusion temperatures;  $\Delta H$  = gelatinization enthalpy; AC = amylose content; SP = swelling power; FSV = flour swelling volume; PV = peak viscosity; *P*<sub>time</sub> = time from onset of pasting to peak viscosity; HPV = hot paste viscosity; CPV = cool paste viscosity; BD = breakdown; SB = setback; Cons = consistency; CL = cooking loss. \*, \*\*, \*\*\* = significant at *P* < 0.05, *P* < 0.01, *P* < 0.001, respectively.

power showed negative correlation with AC ( $r = -0.67$  and  $-0.65$ , respectively,  $P < 0.05$ ) (Table II). Flour swelling power and swelling volume tests were highly correlated with each other ( $r = 0.99$ ,  $P < 0.001$ ), and negatively correlated with solubility ( $r = -0.81$  and  $-0.80$  respectively,  $P < 0.01$ ). The correlation results suggest that as AC increases, it restricts the swelling capacity of the starch granules, which in turn limits the amount of starch exudates leaching into the solution. Genotype IR46 showed a very high solubility value despite its high AC, indicating that there are other factors controlling the swelling and solubility of starch granules. Jin et al (1994) reported that it is the insoluble amylose, and not the total amylose, that restricts granular swelling, reduces cooking loss, and enhances the cooking tolerance of starch-noodles. Much is still unknown regarding the chemical basis of cooking and eating qualities of rice. Even though a relationship exists between AC and starch pasting properties, the actual underlying mechanism still remains ambiguous.

### Thermal Properties of Rice Flour

The overall gelatinization temperature range of the flour samples was 59.1–88.5°C (Table I), which was comparable to the range (59.2–83.8°C) reported by Normand and Marshall (1989). The mean onset temperature was 63.6°C, ranging from 59.1°C in IR48 to 70.3°C in IR32. The  $T_p$  ranged from 66.7°C in IR42 to 77.2°C in IR32, with a mean of 70.8°C, while final temperature showed an average of 82.1°C, ranging from 76.5°C in IR28 to 88.5°C in IR46 (Table I). Gelatinization enthalpy ( $\Delta H$ ) varied from 3.6 J/g in IR28 to 9.2 J/g in IR32, with a mean of 6.4 J/g, which was much lower than the values of 9.5–11.2 J/g reported by Normand and Marshall (1989). Juliano (1998) reported that low net enthalpy value for nonwaxy starches may be due in part to the enthalpy of amylose-lipid complex formation during heating. IR5, IR32, and IR46 displayed the highest gelatinization and enthalpy values among the genotypes, but while the  $T_p$  and  $T_c$  values of these genotypes were similar, their  $\Delta H$  values were significantly different from one another. Champagne et al (1990) reported that starch gelatinization is affected by the degree of milling and the percentage of non-starch lipids present in the rice sample. Tester and Morrison (1990) proposed that the crystallites within the amylopectin molecule and the molecular weight and shape of the whole amylopectin molecule determine the onset of swelling and gelatinization.

### Pasting Characteristics

Pasting properties are dependent on the rigidity of starch granules, which in turn affect the granule swelling potential (Sandhya Rani and Bhattacharya 1989) and the amount of amylose leaching out in the solution (Morris 1990). The rice genotypes displayed a broad variation in all their pasting parameters, and nearly all of the genotypes had statistically different PV (except IR5 and IR52) and HPV (except IR32 and IR52) (Fig. 1, Table I). Most of the genotypes displayed a type B pasting curve, as characterized by a low to medium peak viscosity and low shear thinning during cooking (Schoch and Maywald 1968). The average peak viscosity was 153 RVU, and ranged between 95 RVU in IR52 to 232 RVU in the commercial sample (Table I). The hot paste viscosity ranged from 68 RVU in IR5 to 154 RVU in IR34, while the cold paste viscosity varied from 148 RVU in IR5 to 337 RVU in the commercial sample. Hot paste viscosity is influenced by the rate of amylose exudation, amylose-lipid complex formation, granule swelling, and competition between exudated amylose and remaining granules for free water, while the cold paste viscosity is largely determined by the retrogradation tendency of the soluble amylose upon cooling (Olkku and Rha 1978). A high HPV generally represents low cooking loss and superior eating quality, while high CPV relates to high resistance to shear (Jin et al 1994). The commercial sample displayed the highest PV, CPV, breakdown, and consistency. Genotypes IR5, IR42, and IR52 showed very low breakdown values, which were statistically different from one another, but unlike IR5 and IR52, which also showed very low PV and setback, IR42 displayed an intermediate peak, and a fairly high CPV and setback (Table I). AC is believed to have a marked influence on the breakdown viscosity (which is the measure of susceptibility of cooked starch granules to disintegration) and the setback viscosity (which is the measure of recrystallization of gelatinized starch during cooling) (Lee et al 1995). Quite interestingly, all the three genotypes were very similar in their AC and crude fat content, clearly indicating that other minor components of flour (e.g., nonstarch polysaccharides or proteins) may have also interacted in varied proportions and contributed to the granular integrity. Hamaker and Griffin (1993) reported that certain rice proteins with disulfide bonds restrict starch granule swelling during gelatinization and make the swollen granules less susceptible to breakdown by shear. The use of purified starch instead of flour might have

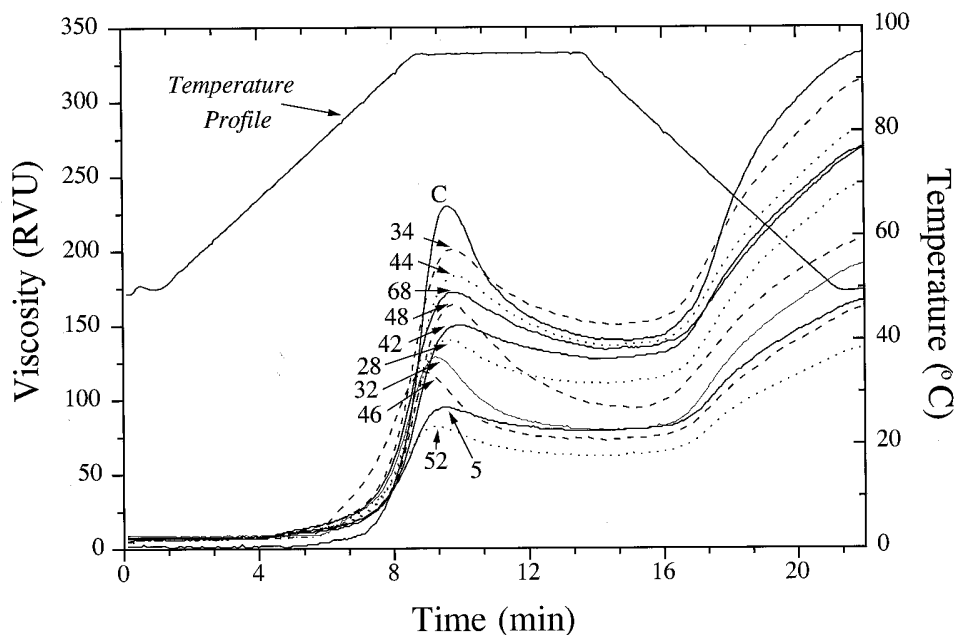


Fig. 1. Rapid Visco Analyser pasting profiles of flour of 11 rice genotypes using IRRI numbers. C = commercial flour.

eliminated this variation in pasting behavior, but when screening rice genotypes for noodle quality, it is more practical to use flour samples for predicting end-use quality because it more closely simulates the actual product processing.

Correlations among the pasting characteristics and the physico-chemical properties of the rice genotypes were calculated (Table II). Except for breakdown, most of the pasting parameters correlated very highly with one another.  $P_{time}$  showed a negative correlation with GT and enthalpy. Solubility was significantly negatively correlated with PV,  $P_{time}$ , HPV, CPV, setback, and consistency, while the swelling power and FSV showed a positive significant correlation with PV, breakdown, CPV, and consistency. Studies on wheat noodle quality have also shown similar significant correlation between swelling power, swelling volume, peak viscosity, and wheat noodle texture, and have established these parameters as rapid, alternative measurements for predicting wheat noodle quality (Toyokawa et al 1989, Crosbie 1991). In this study, the RVA parameters gave a broader insight about the gelatinization behavior and eating quality of the rice genotypes. Other studies have also pointed out the suitability and advantages of viscoamylography in rice breeding programs for discriminating and selecting desirable rice genotypes on the basis of different pasting parameters (Bhattacharya and Sowbhagya 1979, Blakeney et al 1991, Okadome et al 1996, Juliano 1998) for eating quality.

### Textural Properties of RVA Gels

The main criterion for assessing the overall quality of cooked noodles is based on the evaluation of texture. The texture of a cooked noodle is perceived as the resistance of the noodle to chewing and the mouthfeel of its surface (Oh et al 1983). Several instruments have been used for measuring noodle texture as an alternative to sensory evaluation (Oh et al 1985, Lee et al 1987). These methods, although fairly well correlated with sensory results, have the disadvantages of being laborious and time-consuming, and they become a major bottleneck in breeding programs where sample availability and sample size are the major constraints. In this study, the gels formed in the canister after the flour samples were cooked in the RVA were subjected to texture analysis. The gels had a mean hardness of 23.1 g, ranging from 32.1 g in IR68 to 9.1 g in IR48 (Table III). Springiness varied narrowly between 0.87 and 0.92 mm, gumminess varied from 4.4 to 14.9 g, and chewiness ranged from 3.8 to 13.8 g × mm. Genotype IR68 showed the highest textural parameters, followed by IR46, while IR48 had the lowest values. All gel textural parameters were significantly positively correlated with AC, and negatively with swelling power, FSV, and breakdown (Table IV). No significant correlations were found among gel texture, HPV, CPV, and setback, contrary

to the results of our previous study with wheat landraces (Bhattacharya et al 1997). Moreover, in the case of the rice gels, the FSV showed a very significant negative correlation with all the textural parameters, and PV showed a negative relation with springiness (Table IV), while the textural parameters of the wheat gels showed no correlations with the FSV and PV. This discrepancy could be attributed to a large extent to the different nature of the raw material used (rice flour vs. wheat whole meal). The gluten present in the wheat, as well as certain proteins associated with the wheat starch granule, influence the gelatinization properties of starch granules, which in turn affect the texture of the final food product (Seguchi 1986).

On the other hand, the viscoelastic and textural properties of rice are predominantly influenced by the AC and the structure of the amylopectin molecule (Juliano et al 1987). The correlation results in this study indicate that the AC, solubility, FSV, and RVA breakdown are good indicators of cooked gel texture and could be used as indirect measures of rice noodle texture in the early stages of rice breeding (Table IV). In a similar study, Tungtrakul (1998) reported that rice genotypes with high amylose, high consistency, and low retrogradation values are suitable for noodle manufacture, as they give high hardness, have high tensile strength, and deform easily without breakage. These are desirable features during production, operation, and packaging of rice noodles.

### Cooking Quality of Rice Noodles

Cooking loss and degree of swelling are two important factors influencing the cooking quality of noodles. High cooking loss is undesirable as it represents high solubility of starch, resulting in turbid cooking water, low cooking tolerance, and sticky mouthfeel. Low degree of swelling on the other hand indicates low water-holding capacity, resulting in hard, coarse noodles (Jin et al 1994). The cooking loss in this study was extremely low, ranging from 0.27% in the commercial sample to 0.74% in IR46. On the other hand, the rehydration after cooking was very high, ranging between 248.3% in IR46 to 296% in the commercial sample, indicating that the noodles had good cooking tolerance (Table III). As expected, the cooking loss showed a positive correlation with solubility ( $r = 0.70, P < 0.05$ ), while rehydration showed a negative relationship ( $r = -0.74, P < 0.01$ ) (Table II). Rehydration was positively correlated with PV, HPV, CPV, setback, and consistency, while cooking loss was negatively correlated with all the parameters except PV.

Tensile testing assessed the elasticity and breaking strength, as these properties give an indication of how the sample holds together during cooking, which in turn reflects on the cooking tolerance and cooking quality of the noodles. The mean maximum force required to break the noodle strand was 14 g, ranging from

TABLE III  
Textural Parameters of Rapid Visco Analyser (RVA) Gels, and Texture and Cooking Quality of Rice Noodles Made from 11 Rice Genotypes<sup>a</sup>

Samples	RVA Gel Texture				Noodle Texture and Cooking Quality						
	Hardness (g)	Springiness (mm)	Gumminess (g)	Chewiness (g × mm)	TN (g)	Hardness (g)	Springiness (mm)	Gumminess (g)	Chewiness (g × mm)	CL (%)	RH (%)
Com	10.9	0.87	5.4	4.8	12.0	414	0.93	259	243	0.27	296
IR5	30.1	0.91	13.7	12.5	15.6	920	0.76	496	377	0.39	250
IR28	21.8	0.90	10.4	9.4	11.0	826	0.75	418	312	0.49	274
IR32	17.5	0.91	8.5	7.7	16.6	1,001	0.84	502	424	0.38	264
IR34	25.3	0.89	11.1	9.9	16.8	631	1.01	399	406	0.28	262
IR42	24.6	0.91	11.9	10.8	14.8	697	0.82	371	303	0.33	264
IR44	24.0	0.91	12.1	11.0	13.5	835	0.77	439	342	0.38	270
IR46	30.5	0.92	14.0	12.9	20.2	1,019	0.84	522	441	0.74	248
IR48	9.1	0.87	4.4	3.8	8.3	481	1.01	258	262	0.66	254
IR52	28.4	0.92	13.2	12.2	12.3	846	0.79	462	365	0.61	263
IR68	32.1	0.92	14.9	13.8	12.7	743	0.89	419	376	0.41	283
Mean	23.1	0.90	10.9	9.9	14.0	765	0.86	413	350	0.45	266
SD	6.3	0.03	3.1	3.0	3.2	201	0.1	92.9	83.0	0.2	14.5
LSD	1.6	0.04	1.2	1.2	1.7	108.6	0.2	70.1	112.1	0.2	13.3

<sup>a</sup> TN = tensile strength; CL = cooking loss; RH = rehydration; SD = standard deviation; LSD = least significant difference ( $P < 0.05$ ).

TABLE IV  
Correlation Between Textural Parameters and Physicochemical and Pasting Properties of Rice<sup>a</sup>

	Texture Analysis of RVA Gels				Texture Analysis of Cooked Noodles				
	HD	SP	GU	CW	HD	SP	GU	CW	TN
Texture of cooked noodles									
HD	0.62*	0.84***	0.63*	0.65*	1.00				
SP	-0.48	0.68*	-0.54	-0.54	-0.68*	1.00			
GU	0.75**	0.88***	0.75**	0.76**	0.97***	0.62*	1.00		
CW	0.68*	0.72*	0.65*	0.66*	0.80**	-0.19	0.88***	1.00	
TN	0.54	0.50	0.52	0.51	0.62*	-0.16	0.70*	0.80**	1.00
Physicochemical and pasting properties									
AC	0.88***	0.88***	0.90***	0.90***	0.74**	-0.55	0.82**	0.74**	0.72*
Fat	-0.06	0.10	-0.06	-0.07	0.47	-0.15	0.40	0.39	0.25
Solubility	0.53	0.65*	0.51	0.52	0.81**	-0.50	0.77**	0.62*	0.41
SP	-0.74**	-0.81**	-0.75**	-0.75**	-0.81**	-0.72*	-0.81**	-0.59	-0.35
FSV	-0.75**	-0.82**	-0.75**	-0.76**	-0.83***	-0.67*	-0.84***	-0.65*	-0.38
PV	-0.49	-0.67*	-0.49	-0.50	-0.76**	-0.61*	-0.71*	-0.48	-0.26
P <sub>time</sub>	-0.30	-0.46	-0.28	-0.29	0.71*	-0.38	-0.68*	-0.58	-0.58
HPV	-0.20	-0.43	-0.18	-0.20	-0.66*	-0.41	-0.57	-0.40	-0.25
BD	-0.73**	-0.74**	-0.75**	-0.75**	-0.60*	-0.65*	-0.61*	-0.39	-0.16
CPV	-0.32	-0.51	-0.30	-0.32	-0.67*	-0.4	-0.61*	-0.46	-0.24
SB	0.02	-0.13	0.05	0.03	-0.38	-0.02	-0.31	-0.31	-0.14
Cons	-0.42	-0.55	-0.40	-0.42	-0.66*	-0.37	-0.62*	-0.49	-0.21
CL	0.18	-0.08	0.17	0.15	0.29	-0.09	0.20	0.15	-0.05
Rehydration	-0.38	-0.40	-0.36	-0.37	-0.48	-0.09	-0.47	-0.48	-0.40

<sup>a</sup> RVA = Rapid Visco Analyser; HD = hardness; SP = springiness; GU = gumminess; CW = Chewiness; TN = tensile strength; AC = amylose content; SP = swelling power; FSV = flour swelling volume; PV = peak viscosity; P<sub>time</sub> = time from onset of pasting to peak viscosity; HPV = hot paste viscosity; CPV = cool paste viscosity; BD = breakdown; SB = setback; Cons = consistency; CL = cooking loss. \*, \*\*, \*\*\* = significant at  $P < 0.05$ ,  $P < 0.01$ ,  $P < 0.001$ , respectively.

20.2 g in IR46 to 8.3 g in IR48 (Table III), and showed a positive correlation with AC ( $r = 0.74$ ,  $P < 0.05$ ) (Table IV). Tensile strength showed no correlation with the RVA gel texture but showed significant positive relation with noodle TPA. The mean distance to break was 13.7 mm, ranging from 23.9 mm in IR46 to 5.2 mm in IR48. It showed a negative correlation with noodle springiness ( $r = -0.64$ ,  $P < 0.05$ ) and a positive correlation with noodle gumminess ( $r = 0.62$ ,  $P < 0.05$ ). It also showed a positive correlation with solubility ( $r = 0.61$ ,  $P < 0.05$ ), and a negative relationship with P<sub>time</sub> ( $r = -0.75$ ,  $P < 0.01$ ).

Based on the TPA results, a wide variation in textural parameters was observed among the noodle samples. The average hardness varied between 1019 g in IR46 and 414 g in the commercial sample (Table III). The mean springiness was 0.86 mm, gumminess was 413 g, and chewiness was 350 g × mm. Hardness (or firmness) of the noodles showed very significant correlation with noodle springiness ( $r = -0.68$ ,  $P < 0.05$ ), gumminess ( $r = 0.97$ ,  $P < 0.001$ ), chewiness ( $r = 0.80$ ,  $P < 0.01$ ), and tensile strength ( $r = 0.62$ ,  $P < 0.05$ ). All the noodle TPA parameters showed a negative relationship with the swelling power and FSV, and all except springiness showed a positive correlation with AC and solubility of starch (Table IV). It was observed the noodle hardness correlated better than gel hardness with the RVA pasting parameters (such as PV and CPV), although the gel texture parameters were well correlated with noodle texture parameters. Moreover, the noodle TPA results correlated very significantly with the RVA gel TPA (Table IV), indicating that cooked gels from the RVA could be used as an alternative method in predicting the quality of rice noodles during the early stages of breeding when sample size is insufficient for making noodles.

## CONCLUSIONS

The broad variation in physical and chemical properties of this set of rice samples had a marked influence on the textural quality of the cooked noodle. Amylose content was the major factor affecting the pasting and textural properties of rice genotypes, although solubility and swelling behavior of the flour samples also had a significant effects. The RVA pasting properties as well as the texture of the gels formed in the RVA canister correlated very highly with

the cooking and textural properties of rice noodles. The use of RVA in conjunction with the small-scale physicochemical tests could provide rice breeders with a simple, rapid, and accurate tool predicting the textural quality of noodles. Additional research is needed to understand the precise role of amylose and other minor components of rice flour on the pasting and textural properties, which will further provide breeders and noodle manufacturers with the information to help them in the selection of better genotypes for high quality noodles and related rice products.

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