Varietal Differences in Amylopectin Staling of Cooked Waxy Milled Rices

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ABSTRACT

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Varietal differences in amylopectin staling of cooked waxy milled rices were demonstrated in rices with both low and high gelatinization temperatures (GTs) by accelerated staling and using the Instron hardness value with an Ottawa texture measuring system extrusion cell. Cooked high-GT rices had harder cooked rice on accelerated staling than cooked low-GT rices, but significant differences were observed also among some low-GT pairs. Hardness of staled cooked rice correlated negatively with number degree of polymerization of amylopectin for the 12 low-GT waxy rices. The Rapid Visco Analyzer complements the amylograph in measuring the pasting viscosity of waxy rice flour.

Earlier studies have demonstrated that waxy rices with high gelatinization temperature (GT) have harder rice products than low-GT rices, particularly after aging, such as in waxy rice cake *suman* (Antonio et al 1975) and flattened parboiled rice *pinipig* (Antonio and Juliano 1974). The high-GT Thai variety RD4 was not as acceptable as the low-GT RD6 (Kongseree 1979). Intermediate-high-GT waxy starch had higher gel viscosity than low-GT starch (Perdon and Juliano 1975). The higher molecular size of high-GT over low-GT waxy rice starch was confirmed by gel filtration (Juliano and Villareal 1987).

Differences in texture of boiled rice and of rice products have also been reported among low-GT waxy rices. In the Philippines, consumers have reported that IR29 and IR65 are not as tacky on processing as the traditional japonica variety, Malagkit Sungsong. In Taiwan (China), indica waxy rices are used for different rice products than japonica waxy rices (Y. C. Teng, *personal communication*, 1981). Because of its tenderness, indica waxy rice is used in rice tamale (bamboo-leaf-wrapped rice or *tsongtsu*), rice pudding, and a product called oil glutinous rice cooked with pork, dried shrimp meat, red onion, etc. Taiwanese japonica waxy rice is used for sweetened rice cake (*nenkau*) and balls of glutinous rice and is selected for stickiness. Varietal differences are also reported among low-GT Japanese waxy rice varieties for use in rice cakes (*mochi*) (Palmiano and Juliano 1972).

The time-dependent changes in network properties of aqueous starch gels have been studied by small-strain oscillatory shear measurements (0.2 Hz and 2% strain) and differential scanning calorimetry (Biliaderis and Zawistowski 1990). Storage modulus (G')-time profiles revealed a biphasic gelation process: an initial rapid rise in G' due to amylose retrogradation, followed by a phase of slower G' development from amylopectin recrystallization (Biliaderis and Tonogai 1991). The method, however, could not be applied to extremely soft gels, like waxy rice starch. Varietal differences in swelling and gelatinization properties of waxy rice starches have been reported (Tester and Morrison 1990).

Bread staling is now generally accepted to be due in part to amylopectin, rather than to amylose retrogradation, and to gluten-starch interaction (Martin et al 1991). Accelerated aging or staling was achieved by cooling bread or cooked rice at 2–4°C for >4 hr for crystallite formation, followed by 4 hr at 42°C to complete the amylopectin crystallization (Slade et al 1987). Waxy rice would be a suitable rice model system to study amylopectin staling, using Instron hardness values with an Ottawa texture measuring system cell with a perforated base as an index (Perez and Juliano 1979). A preliminary report of this study of amylopectin staling of cooked waxy rice, reporting the mean chain length ($\overline{CL}$ and molecular size (mean number degree of polymerization [$\overline{DP}_n$]) of purified amylopectins, has been published (Juliano et al 1991).

The objectives of the present study were to verify the varietal differences in amylopectin aging of boiled waxy milled rices known to differ in cooked rice texture, using the Instron hardness value as an index, and to compare other properties of milled rices and starches—including aqueous solubility characteristics (Tester and Morrison 1990) and the molecular properties of their amylopectin using the methods of Takeda et al (1987)—with their amylopectin staling after cooking. The companion study on amylopectin staling of cooked milled nonwaxy rices has been published (Perez et al 1993).

MATERIALS AND METHODS

Rice Samples

Waxy rice samples of specific varieties known to differ in processing quality were obtained from various sources: Malagkit Sungsong from the market at Calamba, Laguna; Tapol from a market in Cebu City; IR29 from the IRRI farm; Niaw San Pahtawng, RD4, and RD6 from Pathum Thani Rice Research Center, Thanyaburi, Pathumthani, Thailand; Sinseonchalbyeo and Hangangchalbyeo from Crops Research Station, Rural Development Administration, Suweon, Korea; Mochi Gome and Calmochi-101 through the USDA Western Regional Research Center, Albany, CA; Tainan Glutinous Yu 7 and Tainung Sen Glutinous 2 from Taiwan Agricultural Research Institute, Wufeng, Taichung, Taiwan (China); and Taichung Glutinous 70 and Taichung Sen Glutinous 1 from Taichung District Agricultural Improvement Station, Tatsuen Hsiang, Changhua, Taiwan.

Milled Rice Properties

Aged rough rice was dehulled in a Satake THU-35A dehuller and milled in a Satake TM-05 abrasive mill. Milled rice translucency was measured in duplicate with a Riken Sanno rice meter (brown rice model, T. Igarashi, Koriyama, Fukushima, Japan). The coefficient of variation was 6%. Whiteness was measured with a Kett model C-3 whiteness meter (Kett Electric Laboratory, Tokyo, Japan). The coefficient of variation was 3%. Gelatinization temperature of starch was confirmed by the alkali spreading value on duplicate six grains soaked 23 hr in 10 ml of 1.4% KOH, according to Little et al (1958).

Milled rice was cooked for 20 min in 150-ml beakers in automatic cookers with a water-rice ratio of 1.3; the cooked rice was left undisturbed for 10 min, cooled for 1 hr, and then tested for hardness and stickiness (Perez and Juliano 1979). Duplicate 17-g portions of cooked rice were placed in the Ottawa texture-measuring system (OTMS, Canners Machinary Ltd., Simcoe, Ontario, Canada) extrusion cell (10 cm^2) and pressed with a 145-g weight for 1 min before extrusion. Hardness was the maximum force (kilograms per 7 cm^2) needed to extrude the rice through the cell's perforated base in an Instron food tester, model 1140 (Instron Ltd., High Wycombe, Bucks, England) at a crosshead and chart speed of 10 cm/min using the 0- to 50-kg load cell. For the stickiness test, cooked rice (17 g) was pressed onto the platform with the OTMS plunger (6.9 × 6.9 cm) for 10 sec with

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a clearance of 0.4 mm. This allowed the rice to squeeze out around the edges. Stickiness, expressed in gram-centimeters, was the product of the force in grams required to lift the plunger and the distance in centimeters that the plunger traversed and was measured directly by planimetry from the chart paper using the 0- to 5-kg load cell. The chart speed was 100 cm/min, and the crosshead speed was 5 cm/min.

Amylopectin staling was done by storing cooked rice in the same 150-ml beakers with plastic covers overnight at 2–4°C and then heating it in a 42°C oven at 70% rh (water bath inside) for 4 hr (Slade et al 1987). This resulted in minimal moisture loss. Hardness estimation was then performed in the Instron unit (Perez et al 1993).

Milled rice was ground in a Udy cyclone mill with a 40-mesh sieve and analyzed in duplicate for crude protein by a micro-Kjeldahl method (Perez and Juliano 1979), for apparent amylose content by iodine colorimetry (Juliano et al 1981), for gel consistency of 100 mg of rice flour in 2 ml of 0.2*N* KOH (Cagampang et al 1973), and for pasting viscosity of 3 g of rice in 25 ml of water in a Rapid Visco Analyzer (RVA, Newport Scientific Pty., Ltd., Narrabeen, Australia), model 3D (1.5 min at 50°C, heating to 95°C at 12°C/min, 2.5 min at 95°C, and cooling to 30°C at 12°C/min; Blakeney et al 1991). Unreplicated amylograms were also run in a Brabender Visco-Amylograph with a 700-g·cm sensitivity cartridge using 40 g of milled rice flour and 360 ml of water (Juliano et al 1985). In addition to peak viscosity, breakdown, setback, and consistency were calculated. Amylograph viscosity was reproducible to within 40 BU.

Starch Properties

Starch was prepared from milled rice by soaking in water, homogenizing to a fine flour, and treatment with alkaline protease (Maniñgat and Juliano 1980). The purified starches were analyzed in duplicate for neutral gel consistency and viscosity of 150 mg of starch in 2 ml of water (Juliano and Villareal 1987). The test for aqueous gel consistency used 100 mg of starch and 25 mg of defatted IR29 milled rice flour in 2 ml of 0.1*N* phosphate buffer (pH 6.9) and 0.2 ml of ethanol with dye in 13- × 100-mm test tubes boiled in the presence of one 4-mesh alumina granule (Hengar, Fisher Scientific Co., Fair Lawn, NJ) (Maniñgat and Juliano 1982). Gel length in millimeters was measured in 13- × 100-mm test tubes after 1 hr of standing in a horizontal position. Gel viscosity was measured with a Wells-Brookfield cone-plate microviscometer RVT-C/P (Brookfield Engineering Laboratories, Inc. Stoughton, MA). With a 1.565° cone at 2.5 rpm at 25°C. Preliminary tests showed that these gel concentrations were optimum for differentiating waxy rice starches. The swelling factor of starch at 80°C was determined according to Tester and Morrison (1990), and solubles at 80°C were also determined. The standard deviation was shown to be 2 for swelling factor (Tester and Morrison 1990).

For alkaliviscography, a 1.8% suspension of waxy starch or 2.25 g of dry matter was placed in a tall 400-ml beaker containing 125 g of water, including the moisture in the starch, and a 5.0 ± 0.05*N* KOH solution was added to this suspension from a burette, starting at 0.20*N* and using 0.01*N* increments thereafter (Suzuki and Juliano 1975). After each KOH addition, the suspension was stirred with a glass stirrer for 30 sec, and the viscosity was measured at the fourth minute by a Brookfield LV viscometer with a no. 2 rotor at 60 rpm (500 cP range). This test was performed in duplicate. Gelatinization normality was the normality that coincided with the first viscosity reading above 22.5 cP. Other reported values are peak viscosity and normality at peak viscosity.

Amylopectin was prepared from the waxy starches and characterized for CL and DP_n, according to Takeda et al (1987).

RESULTS AND DISCUSSION

The properties of the six pairs of low-GT and two high-GT milled waxy rices are summarized in Table I. Their GT classification was verified by alkali spreading value: 6–7 for low-GT rices and 3 for high-GT rices. Indica rices were generally longer- and narrower-grained than japonica rices. Translucency values were all low, because of endosperm opacity from the waxy gene. Kett whiteness values were 45–57%, except 32% for the purple rice Tapol, which contained traces of purple pigment.

Crude protein was 6–8% in most samples except the two Taiwan indica waxy rices (9%) and the two high-GT rices RD4 and Tapol (Table I). Among the Taiwanese rices, indica rice had higher protein content than japonica rice. Apparent amylose content was about the usual value of 2% in most samples, except for the commercial varieties Malagkit Sungsong and Tapol and the Thai RD4. Gel consistency was soft (61–100 mm) for most samples and medium (57 mm) for Tapol (Table I). High-GT samples were confirmed to have harder gel consistency than low-GT waxy rices (Antonio and Juliano 1974).

Pasting Viscosity of Milled Rice Flour

Amylograms were similar for the Malagkit Sungsong-IR29, Niaw San Pahtawng-RD6, and Mochi Gome-Calmochi-101 pairs (Table II). But in the three other pairs of low-GT rices, the japonica rice had lower amylograph viscosity than the indica or indica/japonica sample. Taiwan indica waxy rices are reported to have higher amylograph viscosity than japonica waxy rices (A. N. Hsu, Taichung Agricultural Improvement Station, Tatsuen Hsiang, Changhua, Taiwan, *personal communication*, 1991). The two high-GT samples had higher amylograph peak viscosity and consistency than the low-GT samples.

The RVA was evaluated as a possible replacement of the amylograph for screening the pasting viscosity of waxy rice flours. RVA viscosity values were similar for the pairs Malagkit Sungsong-IR29, Niaw San Pahtawng-RD6, and Mochi Gome-Calmochi 101, but differences in peak viscosity were less for the three other low-GT pairs, as compared to amylograph peak viscosity (Table II). RD6, RD4, Niaw San Pahtawng, and Tapol had the highest peak viscosity, and Tainan Glutinous Yu 7 and Sinseonchalbyeo had the lowest. Differences in amylograph peak viscosity and consistency between high-GT and low-GT rices were not evident in the RVA results; the RVA probably had more shear than the amylograph but also had the advantage of using less sample and taking less time to run. Similar results were observed on nonwaxy rice flours (Perez et al 1993). Differentiation of RVA setback and consistency of the samples were obtained at both 50 and 30°C, but more positive values were obtained at 30°C.

Amylopectin Staling of Cooked Rice

Instron stickiness values of freshly cooked rice overlapped among indica and japonica rices (Table III). Japonica rices were not necessarily more sticky than indica rices, even when the four Taiwan waxy rices were considered. High-GT Tapol had the least sticky cooked rice, but the other high-GT rice, RD4, had the highest stickiness value.

Instron hardness values of freshly cooked rice also overlapped among indica and japonica rices (Table III). Indica rices were not necessarily softer (lower hardness values, more tender) than japonica rices, even among Taiwan waxy rices. The South Korean and Thai rices were softest. Tapol had the hardest cooked rice. All paired low-GT samples had similar hardness values, except for the pairs Mochi Gome-Calmochi-101, and Tainan Glutinous Yu 7-Tainung Sen Glutinous 2. Calmochi-101 had quality inferior to that of Mochi Gome; indica and japonica waxy rices also differ in quality in Taiwan.

When Instron hardness values of staled cooked rice were analyzed, varietal differences in amylopectin staling became apparent, as indexed by increases in hardness value for Malagkit Sungsong-IR29 and Taichung Glutinous 70-Taichung Sen Glutinous 1 and further increased differences in hardness for Mochi Gome-Calmochi-101 and Tainan Glutinous Yu 7-Tainung Sen Glutinous 2 (Table III). IR29 is known to be inferior in quality to Malagkit Sungsong. Niaw San Pahtawng and RD6 had similar hardness values, and RD6 has been a substitute for the traditional Thai waxy variety Niaw San Pahtawng (RRI 1982). The Korean waxy rices Sinseonchalbyeo and Hangangchalbyeo had similar hardness values and the least amylopectin staling (i.e., increase in hardness). With the two pairs of Taiwanese rice, indica (sen or native) rices showed more hardening on amylopectin staling than japonica rices. The two high-GT rices RD4 and Tapol had the hardest staled cooked rices, in agreement with earlier results on *pinipig* (Antonio and Juliano 1974) and *suman* (Antonio et al 1975). RD4 was not as acceptable as RD6 in Thailand (Kongseree 1979). Starch gels of RD4 had higher retrogradation (indexed by differential scanning calorimetry melting enthalpy) and higher storage modulus than those of IR29 (Gudmundsson and Eliasson 1992).

Molecular Properties of Amylopectin

The amylopectins of waxy rice starch showed varietal differences in $\overline{DP}_n$ and overlapped among indica and japonica samples (Table III). Amylopectins of indica IR29, Tainung Sen Glutinous 2, and Taichung Sen Glutinous 1 had lower $\overline{DP}_n$ than their paired japonica samples. The sample with the smaller amylopectin size did not necessarily have more amylopectin staling, based on hardness of staled cooked rice in the other samples (Niaw San Pahtawng-RD6 and Sinseonchalbyeo-Hangangchalbyeo pairs), and a critical $\overline{DP}_n$ was not suggested. A negative relationship between amylopectin sedimentation constant and *mochi* quality was observed earlier among low-GT Japanese waxy rice starches (Palmiano and Juliano 1972).

The two high-GT waxy rices had amylopectin $\overline{DP}_n$ values similar to those of the low-GT waxy rices (Table III), in contrast to the findings of an earlier study based on the sedimentation constant of amylopectin, wherein amylopectin of the high-GT sample had higher $S_{20,w}$ values than that of low-GT waxy starches (Antonio and Juliano 1974).

The mean chain lengths ($\overline{CL}$) of amylopectin differed among the samples and overlapped among indica and japonica waxy rices (Table III). Longer $\overline{CL}$ is expected to increase amylopectin staling, as in the Malagkit Sungsong-IR29, Mochi Gome-Calmochi 101, and Taichung Glutinous 70-Taichung Sen Glutinous 1 pairs. The Niaw San Pahtawng-RD6 pair had similar hardness and amylopectin $\overline{CL}$ of staled cooked rice. But Tainan Glutinous Yu 7-Tainung Sen Glutinous 2 showed a difference in hardness of staled rice, even though their amylopectin $\overline{CL}$s were similar. Amylopectins of high-GT waxy starch had $\overline{CL}$s similar to amylopectins of low-GT starch, as previously reported (Antonio and Juliano 1974). The 12 amylopectins had β-amylolysis limits of

TABLE I
Properties of 12 Milled Waxy Rices with Low Gelatinization Temperature (GT) and Two with High GT

Variety	Source[a]	Subspecies[b]	Grain Length (mm)	Grain Width (mm)	Translucency (%)	Kett Whiteness (%)	Crude Protein (%)	Apparent Amylose (%)	Alkali Spreading Value[c]	Gel Consistency (mm)
Malagkit Sungsong	Ph	J	4.9	2.8	12	50	7.4	4.4	6.0 (L)	96
IR29	Ph	I	6.6	2.1	18	45	7.6	2.0	6.0 (L)	89
Niaw San Pahtawng	Th	I	6.9	2.2	8	55	6.5	1.9	6.0 (L)	100
RD6	Th	I	6.5	2.1	10	54	6.1	1.9	6.0 (L)	96
Sinseonchalbyeo	S. Korea	J	4.6	2.8	14	48	7.6	1.7	6.0 (L)	100
Hangangchalbyeo	S. Korea	I/J	6.0	2.6	26	49	6.7	1.8	6.0 (L)	100
Mochi Gome	U.S.	J	5.0	2.9	16	57	6.3	2.5	6.8 (L)	100
Calmochi-101	U.S.	J	5.0	2.8	26	55	6.2	2.0	6.7 (L)	100
Tainan Glu.[d] Yu 7	Taiwan	J	4.7	3.0	28	50	8.2	1.8	7.0 (L)	100
Tainung Sen Glu. 2	Taiwan	I	5.5	2.8	20	50	9.0	2.4	6.9 (L)	100
Taichung Glu. 70	Taiwan	J	4.4	3.0	22	55	7.9	2.1	7.0 (L)	100
Taichung Sen Glu. 1	Taiwan	I	6.2	2.3	30	51	9.1	2.2	6.8 (L)	100
RD4	Th	I	6.9	2.3	15	53	10.5	5.5	3.0 (H)	75
Tapol	Ph	I	6.6	2.2	17	32	10.0	9.2	3.0 (H)	57
SD			0.04	0.02	2	1	0.2	0.5	0.2	5

[a] Ph = Philippines, Th = Thailand.
[b] J = japonica, I = indica.
[c] Starch gelatinization temperature type in parentheses: L = low, H = high.
[d] Glutinous.

TABLE II
Amylograph and Rapid Visco Analyzer Pasting Viscosities of 14 Milled Waxy Rice Flours

Variety	Amylograph Viscosity, BU: Peak	Breakdown	Setback	Consistency	Rapid Visco Analyzer Viscosity,[a] SNU: Peak	Breakdown	Setback at 50°C	Consistency at 50°C	Setback at 30°C	Consistency at 30°C
LGT[b]										
Malagkit Sungsong	320	160	−110	50	202 ± 0	83 ± 1	−66 ± 1	16 ± 1	−34 ± 4	48 ± 5
IR29	340	135	−90	45	196 ± 0	78 ± 1	−64 ± 1	14 ± 2	−28 ± 6	50 ± 6
Niaw San Pahtawng	540	335	−265	70	253 ± 13	114 ± 1	−90 ± 5	24 ± 4	−58 ± 7	56 ± 6
RD6	520	315	−255	60	256 ± 1	85 ± 1	−53 ± 1	32 ± 3	−20 ± 6	65 ± 7
Sinseonchalbyeo	145	105	−90	15	118 ± 2	60 ± 1	−50 ± 1	9 ± 0	−30 ± 1	29 ± 1
Hangangchalbyeo	550	365	−300	65	236 ± 8	118 ± 5	−102 ± 4	18 ± 1	−67 ± 4	52 ± 0
Mochi Gome	160	105	−95	10	206 ± 0	70 ± 2	−60 ± 1	10 ± 1	−28 ± 1	42 ± 1
Calmochi-101	145	85	−65	20	188 ± 4	69 ± 0	−60 ± 4	10 ± 4	−34 ± 1	34 ± 1
Tainan Glu.[c] Yu 7	70	25	−15	10	112 ± 5	32 ± 5	−20 ± 7	12 ± 1	2 ± 7	34 ± 2
Tainung Sen Glu. 2	445	280	−215	65	162 ± 4	52 ± 4	−42 ± 1	10 ± 2	−11 ± 2	41 ± 1
Taichung Glu. 70	105	50	−30	20	153 ± 4	44 ± 1	−30 ± 1	13 ± 1	−6 ± 0	39 ± 1
Taichung Sen Glu. 1	395	245	−195	50	206 ± 2	50 ± 1	−20 ± 1	29 ± 1	14 ± 1	64 ± 2
HGT[b]										
RD4	920	415	−275	140	256 ± 2	110 ± 8	−97 ± 4	13 ± 8	−68 ± 3	42 ± 7
Tapol	840	315	15	330	253 ± 1	115 ± 1	−108 ± 1	7 ± 2	−73 ± 2	42 ± 2

[a] Mean ± SD (n = 2). Three grams of flour in 25 ml of water; 1.5 min at 50°C, heated to 95°C at 12°C/min, 2.5 min at 95°C, and cooled to 30°C at 12°C/min. SNU = swelling number units, 1 SNU = 10 cP
[b] LGT = low gelatinization temperature, HGT = high gelatinization temperature.
[c] Glutinous.

55.9–59.9% and blue values at 680 nm of 0.02–0.05 absorbance units (*unpublished data from our laboratory*).

The phosphate ester content of rice amylopectin is probably not a factor in varietal differences in amylopectin staling of cooked waxy rice. Reported values are 9–15 ppm for japonica waxy rice starch (low GT) and 19 ppm for an indica high-GT waxy rice starch (Tabata et al 1975, Hizukuri et al 1983).

Properties of Waxy Rice Starch

The purified starches of indica and japonica rices had similar iodine affinities; the highest was for Tapol (Table IV). Amylose contents were lower than in milled rice in some samples because translucent nonwaxy grains had been discarded before starch preparation. Protein content overlapped among indica and japonica rices.

Alkaliviscogram gelatinization normality (gel *N*) and peak normality (peak *N*) showed lower values for low-GT starches than for high-GT starches (Table IV), as reported earlier (Suzuki and Juliano 1975). Alkaliviscogram peak viscosity was highest for Malagkit Sungsong and lowest for Mochi Gome. Three of the low-GT pairs showed differences in peak viscosity, with the indica second sample being higher; these were Sinseonchalbyeo-Hangangchalbyeo, Mochi Gome-Calmochi-101, and Tainan Glutinous Yu 7-Tainung Sen Glutinous 2. Peak viscosity of indica and japonica samples overlapped. The two high-GT starches had peak viscosity similar to that of low-GT samples, as in the RVA, in contrast to amylograph peak viscosity (Table II).

Neutral gel consistency and viscosity in 0.1*N* phosphate buffer, at a previously determined optimum starch concentration, differed among the starches (Table IV). Differences among the paired samples were not consistent, and values of indica and japonica starches overlapped. High-GT RD4 had the hardest consistency, but not the highest viscosity; the most viscous was Taichung Sen Glutinous 1. An earlier study showed harder gel consistency for high-GT than for low-GT waxy rice starches (Antonio et al 1975).

Aqueous gel consistency of starch was 29–66 mm and gave better differentiation among the low-GT starches than neutral gel consistency (Table IV), probably because the solvent (water)

TABLE III
Stickiness and Hardness of Cooked Waxy Milled Rices and Molecular Properties of Their Amylopectins

Variety	Cooked Rice Instron Value			Amylopectin[b]	
		Hardness, kg/7 cm^2			
	Stickiness (g·cm)	Freshly Cooked	Staled[a]	$\overline{DP}_n$ (10^3 glc)	$\overline{CL}$ (glc)
LGT[c]					
Malagkit Sungsong	152 ± 2	4.8 ± 0.6	5.9 ± 0.5	12.8 ± 0.8	18.6 ± 0.4
IR29	200 ± 13	4.9 ± 0.4	7.9 ± 0.4	9.6 ± 0.9	21.3 ± 0.5
Niaw San Pahtawng	199 ± 14	3.6 ± 0.5	5.4 ± 0.4	18.4 ± 0.4	20.7 ± 0.4
RD6	190 ± 2	3.7 ± 0.5	5.2 ± 0.3	15.7 ± 0.9	20.6 ± 0.5
Sinseonchalbyeo	136 ± 4	3.3 ± 0.3	4.4 ± 0.3	16.8 ± 0.4	20.1 ± 0.7
Hangangchalbyeo	181 ± 17	3.2 ± 0.2	4.5 ± 0.6	11.4 ± 0.4	21.0 ± 0.3
Mochi Gome	132 ± 12	3.9 ± 0.2	4.7 ± 0.4	16.6 ± 0.9	18.3 ± 0.3
Calmochi-101	127 ± 10	5.2 ± 0.6	6.6 ± 0.1	12.4 ± 0.3	19.3 ± 0.1
Tainan Glu.[d] Yu 7	118 ± 2	4.0 ± 0.2	5.4 ± 0.5	10.3 ± 0.9	20.5 ± 0.4
Tainung Sen Glu. 2	146 ± 10	5.2 ± 0.2	7.5 ± 0.5	7.6 ± 0.3	20.0 ± 0.2
Taichung Glu. 70	128 ± 18	4.9 ± 0.4	5.3 ± 0.5	17.5 ± 0.5	18.5 ± 0.5
Taichung Sen Glu. 1	128 ± 9	5.0 ± 0.3	6.6 ± 0.6	13.4 ± 1.3	21.0 ± 0.5
HGT[c]					
RD4	205 ± 6	5.6 ± 0.7	22.4 ± 2.8	13.3 ± 0.9	20.6 ± 0.5
Tapol	95 ± 11	7.9 ± 0.6	27.4 ± 1.7	10.3 ± 1.0	21.3 ± 0.6

[a] Cooked rice was stored overnight at 2–4°C, reheated at 42°C for 4 hr, and cooled to 25°C in 1 hr. Mean ± SD.
[b] Values are for mean number degree of polymerization ($\overline{DP}_n$) and mean chain length ($\overline{CL}$) in glucose (glc) units.
[c] LGT = low gelatinization temperature, HGT = high gelatinization temperature.
[d] Glutinous.

TABLE IV
Properties of Purified Waxy Rice Starches

Variety	Iodine Affinity (% db)	Amylose (% db)	Crude Protein (%)	Alkaliviscogram Gel *N*	Alkaliviscogram Peak Viscosity (cP)	Alkaliviscogram Peak *N*	Neutral Gel Consistency (mm)	Neutral Gel Viscosity (cP)	Aqueous Gel Consistency (mm)	Aqueous Gel Viscosity (cP)	Swelling Factor at 80°C	Solubles at 80°C (%)
LGT[a]												
Malagkit Sungsong	0.023	1.2	0.6	0.45	>500	0.52	100	848	33	2,660	39.9	9.6
IR29	0.020	2.0	0.2	0.45	494	0.49	92	877	48	1,340	39.3	9.9
Niaw San Pahtawng	0.027	1.2	0.3	0.40	380	0.47	84	1,126	31	1,970	34.3	7.7
RD6	0.023	1.4	0.2	0.41	360	0.47	72	1,107	29	1,710	35.8	8.5
Sinseonchalbyeo	0.021	1.3	0.2	0.44	331	0.49	100	861	47	1,450	40.5	12.8
Hangangchalbyeo	0.028	1.0	0.3	0.42	458	0.50	93	768	29	2,510	33.5	6.9
Mochi Gome	0.037	1.8	0.5	0.42	136	0.47	100	771	66	774	43.2	17.7
Calmochi-101	0.028	1.6	0.6	0.42	208	0.47	100	1,024	46	2,610	41.7	10.2
Tainan Glu.[b] Yu 7	0.022	1.4	0.3	0.42	258	0.47	64	1,174	44	1,370	50.9	9.9
Tainung Sen Glu. 2	0.026	1.2	1.0	0.46	428	0.55	57	1,082	31	2,970	34.4	7.9
Taichung Glu. 70	0.015	1.6	0.2	0.45	216	0.49	96	1,181	52	1,270	42.3	10.8
Taichung Sen Glu. 1	0.039	1.8	0.4	0.44	218	0.49	82	1,267	36	1,260	41.3	9.9
HGT[a]												
RD4	0.034	2.1	0.8	0.55	476	0.59	48	1,168	45	1,050	20.6	25.6
Tapol	0.040	2.4	1.0	0.54	328	0.57	56	1,088	45	922	15.9	9.7
SD	0.006	0.5	0.2	0.02	20	0.02	4	29	3	30	1.9	1.5

[a] LGT = low gelatinization temperature, HGT = high gelatinization temperature.
[b] Glutinous.

was used also for cooking the milled rice. Differences in gel consistency showed the expected ranking in four of the six pairs, but not for Malagkit Sungsong-IR29 and Niaw San Pahtawng-RD6. Aqueous gel viscosity rankings were consistent with gel consistency differences, except for Taichung Glutinous 70-Taichung Sen Glutinous 1. The high-GT rices RD4 and Tapol were not the hardest in consistency, despite the harder gel consistency of their milled rice (Table I). Their higher milled-rice protein content (Table I) probably contributed to their harder gel consistency values in 0.2*N* KOH.

The swelling factor at 80°C was not necessarily higher for low-GT japonica waxy rice than for indica rices (Table IV). It was highest for Tainan Glutinous Yu 7 and lowest for Hangangchalbyeo. Among the 12 low-GT waxy starches, only in the pairs Malagkit Sungsong-IR29, Sinseonchalbyeo-Hangangchalbyeo, and Tainan Glutinous Yu 7-Tainung Sen Glutinous 2 did the second (indica) sample show a lower swelling factor. The swelling factors of Malagkit Sungsong, IR29, and RD6 were similar to previously reported values (Tester and Morrison 1990). The high-GT RD4 and Tapol had lower swelling factors at 80°C than the low-GT starches and were lower than those reported earlier (Tester and Morrison 1990).

The values for percent solubles at 80°C overlapped among indica and japonica starches and did not always follow those of swelling factor (Table IV). Although Hangangchalbyeo, with the lowest swelling factor, also had the lowest percent solubles, Mochi Gome, not Tainan Glutinous Yu 7 (highest swelling factor), had the highest percent solubles among the 12 low-GT waxy starches. Despite a low swelling factor, high-GT RD4 had surprisingly more solubles at 80°C than did the other starches, even low-GT starches and the other high-GT sample Tapol.

Correlations of Rice Properties with Stickiness and Hardness

The various quality factors were correlated with cooked rice stickiness and hardness, with emphasis on hardness of staled cooked rice. Stickiness of freshly cooked rice correlated positively with milled rice alkali spreading value; gel consistency; amylograph peak viscosity, breakdown, and consistency; and RVA peak viscosity, breakdown, and consistency at 30°C. It correlated negatively with milled rice amylograph setback, RVA setback at 50 and 30°C, starch alkaliviscograph peak, and swelling factor (Table V).

By contrast, hardness of freshly cooked rice correlated significantly positively only with hardness of staled cooked rice, which in turn correlated negatively with amylopectin $\overline{DP}_n$ (Table V). Analysis of other molecular properties of these 12 amylopectins may provide additional indications of other factors affecting the rate of amylopectin staling of cooked waxy rice. Although the hardness of freshly cooked waxy milled rice may be affected by grain fractions besides starch, the staling effects are probably due mainly to starch (amylopectin) retrogradation (Slade et al 1987, Perez et al 1993). Cooking milled rice by boiling in water results mainly in gelatinization and swelling of starch and denaturation of protein bodies, with much of the cell walls still intact. Differential scanning calorimetry of nonwaxy starch-water systems shows this amylopectin staling, with a peak melting temperature of about 45–60°C (Biliaderis and Juliano, *in press*).

It is tedious to routinely run Instron tests of hardness of staled cooked rice and freshly cooked milled rice to measure amylopectin staling. An aqueous gel consistency type of test to measure amylopectin retrogradation in milled-rice gels via gel length would facilitate measurement of amylopectin staling in a waxy-rice breeding program.

TABLE V
Correlation of Rice Properties with Cooked Rice Stickiness and Hardness of 12 Waxy Rices with Low Gelatinization Temperature

Property	Correlation Coefficient[a] with Stickiness	Hardness: Fresh Cooked	Hardness: Staled
Milled rice			
Cooked rice stickiness	1.00	−0.32	0.11
Cooked rice hardness, staled	−0.32	0.82**	1.00
Apparent amylose	−0.10	0.37	0.15
Alkali spreading value	−0.78**	0.50	0.17
Gel consistency	−0.62*	−0.22	−0.51
Amylograph			
Peak viscosity	0.77**	−0.21	0.13
Breakdown	0.67*	−0.31	−0.01
Setback	−0.64*	0.37	0.08
Consistency	0.72**	−0.04	0.27
Rapid Visco Analyzer			
Peak viscosity	0.71*	−0.19	−0.02
Breakdown	0.79*	−0.49	−0.24
Setback at 50°C	−0.69*	0.46	0.23
Setback at 30°C	−0.60*	0.52	0.33
Consistency at 50°C	0.45	−0.18	−0.07
Consistency at 30°C	0.60*	−0.04	0.14
Starch			
Alkaliviscograph peak	−0.56*	−0.08	0.28
Swelling factor at 80°C	−0.71**	0.17	−0.08
Solubles at 80°C	−0.49	−0.06	−0.30
Neutral gel consistency	−0.09	−0.08	−0.31
Neutral gel viscosity	0.49	0.36	0.26
Aqueous gel consistency	−0.48	0.10	−0.13
Aqueous gel viscosity	0.17	0.22	0.28
Amylopectin			
Mean $\overline{DP}_n$	0.02	−0.44	−0.66*
Mean chain length	0.54	−0.26	0.24

[a] * = $P < 0.05$, ** = $P < 0.01$.

Other Correlations

Amylograph and RVA viscosities were highly correlated, except for RVA setback at 30°C. Starch neutral gel consistency and viscosity did not correlate significantly with other quality parameters. Starch aqueous gel consistency correlated negatively with alkaliviscograph peak viscosity ($r = -0.64$, $P < 0.05$). Swelling factor at 80°C correlated positively with amylograph and RVA setbacks and starch aqueous gel consistency and negatively with amylograph and RVA peak viscosity and breakdown, amylograph consistency, and alkaliviscograph peak viscosity. Percent solubles of starch at 80°C correlated positively with starch aqueous gel viscosity and negatively with amylograph peak viscosity, breakdown, and consistency; alkaliviscograph peak viscosity; and starch aqueous gel viscosity.

CONCLUSIONS

Amylopectin staling of cooked rice is a useful indicator of processed waxy rice product texture, as measured by Instron hardness values, even among low-GT waxy rices. The differences are due in part to differences in amylopectin $\overline{DP}_n$. The RVA complements the amylograph in measuring the pasting viscosity of waxy milled rice flours.

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