Laboratory Parboiling Procedures and Properties of Parboiled Rice from Varieties Differing in Starch Properties[1]

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ABSTRACT

Differences in rate of water absorption during steeping and steaming of rough rice due to differences in starch gelatinization temperature (GT) may be minimized by soaking for 8 hr at 60°C and steaming for 10 min at 1.0 kg/cm^2 steam pressure (120°C) or 30 min at 100°C. The water content of parboiled rice was higher for low-GT rice than for intermediate-GT rices steamed at 100°C only. In 12 rices parboiled at 100, 120, and 127°C, apparent amylose content was the major factor influencing parboiled rice properties such as brown rice bending hardness, head rice yield, equilibrium water content, gel consistency and viscosity, and cooked rice hardness and stickiness. Gelatinization temperature was an important factor only in rices parboiled at 100°C, probably because it affected parboiling rate at that temperature. Differences in degree of parboiling because of differences in GT resulted in different relations between parboiled rice properties and raw rice quality factors in samples parboiled at 100, 120, and 127°C. Thus, raw rice quality factors, particularly apparent amylose content, may be used in breeding programs as an index of parboiled rice quality. Gel consistency of brown and milled rice in 0.2*N* KOH was confirmed to soften on parboiling.

Parboiled rice is the staple food in Bangladesh and Sri Lanka and accounts for more than half of the rough rice produced in India and Nepal and a large proportion in Pakistan (Bhattacharya 1985). It is popular in parts of Africa, especially West Africa, in other parts of Asia, and in Caribbean countries, particularly among descendants of Indian immigrants. It is estimated that about one-fifth of the world's rice is parboiled (Gariboldi 1984).

Defining varietal characteristics associated with good quality in parboiled rice is a research priority (IRRI 1985). Some scientists consider that breeding for raw rice quality will take care of breeding for parboiled rice quality (IRRI 1979). However, in the United States, rice selections are assessed for both raw rice quality and parboil-canning stability (Webb 1985). Some national programs, such as those in Bangladesh and Nigeria, perform quality tests only on laboratory-parboiled samples. Laboratory parboiling methods are usually arbitrary and do not fully account for varietal differences in starch properties, particularly starch gelatinization temperature (GT). Resultant grains often are not fully translucent or gelatinized, suggesting incomplete parboiling.

Traditionally, the local varieties used for parboiling in Bangladesh and Sri Lanka are high-amylose (>25%) rices (Breckenridge 1979, Choudhury 1979). By contrast, the U.S. long-grain varieties used for parboiling are mainly intermediate (20–25%) amylose type (Webb 1985). Varietal differences in the properties of parboiled rice have been reported that relate to amylose content (Raghavendra Rao and Juliano 1970, Antonio and Juliano 1973, Alary et al 1977, Kato et al 1983, Chinnaswamy and Bhattacharya 1984, Burns and Gerdes 1985, Villareal and Juliano 1987).

Although traditional parboiling consists of steeping rough rice in ambient temperature water for a few days followed by steaming or boiling at 100°C and sun-drying (Gariboldi 1984, Bhattacharya 1985), a hot water soak and pressure parboiling are becoming more popular. However, pressure-parboiled rice requires a longer cooking time and cooks harder than traditional parboiled rice (Ali and Bhattacharya 1982). In addition, pressure-parboiled rice also undergoes aging or storage changes just like raw rice (Ohta et al 1985).

Based on these considerations, a suitable soaking and steaming procedure was developed using high-amylose rices with low and intermediate GT and rices differing in amylose content and GT. These were laboratory-parboiled at 100, 120, and 127°C and their properties correlated with raw rice quality factors.

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MATERIALS AND METHODS

Samples of IR rough rices were obtained from the 1985 and 1986 crops of the International Rice Research Institute farm and Bangladesh rices from the Bangladesh Rice Research Institute 1986 transplanted *aman* crop (July–September transplanting, November harvest). The samples were aged or had been harvested at least three months before parboiling.

Laboratory Parboiling Method

IR42 and IR62 rough rice (10.0 ± 0.01 g) in tared wire baskets was soaked in duplicate in 60 and 70°C water for 1–10 hr, quickly withdrawn, surface-dried with blotting paper, and immediately weighed. Water content was rechecked by drying to constant weight at 105°C and expressed on dry basis. Initial moisture content was measured with a Kett model PB-10 dielectric moisture meter.

The soaked rough rices were steamed for 25, 30, and 35 min at 0 kg/cm^2 gauge pressure (100°C) and for 10 min at 111°C (0.5 kg/cm^2), 120°C (1.0 kg/cm^2), 127°C (1.5 kg/cm^2), and 131°C (1.8 kg/cm^2) in a Hirayama model HA-24 autoclave. The samples were cooled and dried in trays at 20–25°C to 12–13% moisture.

Based on the results obtained for IR42 and IR62, 260-g batches of rough rices were soaked for 8 hr at 60°C and parboiled for 30 min at 100°C or for 10 min at 120 and 127°C. Solids loss during soaking was determined.

Analytical Methods

Rough rice was dehulled with a Satake THU-35A sheller, and percent hull was calculated based on rough rice weight. Brown rice (180–200 g) was milled in a Satake TM-05 pearler with no. 5330 abrasive disk at 1,730 rpm to approximately 8% bran-polish removal for all samples. Brokens were manually separated and total milled rice and head rice yields calculated as percentage of rough rice. Brown rice length and width were measured on duplicate 10-grain samples using a photoenlarger set at 10×. Brown rice bending hardness used the three-point bending cell described by Nguyen and Kunze (1984) on 20 individual grains with an Instron model 1140 food tester with 5–50-kg load cell, a crosshead speed of 10 cm/min, and chart speed of 40 cm/min. An Ottawa Texture Measuring System bite cell was fitted with a 6-mm-thick base plate with two edges 1-mm thick, 2-mm high, and 4-mm apart, and the crosshead had one center edge 1-mm wide and 2-mm high parallel to the base plate. Brown rice was ground in a Udy cyclone mill with 60-mesh sieve and analyzed for gel consistency according to Cagampang et al (1973). Gel viscosity was determined on 1 ml of the resulting gel using a Wells-Brookfield model RVT-CP cone-plate microviscometer with 1.565° cone at 2.5 rpm at 25°C.

Translucency of milled rice was measured with a brown-rice rice meter (Mitsui & Co. Ltd., Tokyo, Japan) and whiteness with a Kett whiteness meter model C-3. Alkali spreading value was determined by the method of Little et al (1958) using duplicate samples of six grains soaked for 23 hr in 10 ml of 1.7% KOH at 30°C. Alkali reaction test for degree of parboiling (Ali and Bhattacharya 1972) consisted of soaking six grains in 10 ml of 1.0% KOH for 4 hr. Equilibrium water content was measured by soaking duplicate 2-g samples of milled rice in 20 ml of water in a covered 50-ml beaker for 24 hr, thoroughly blotting dry with filter paper, and weighing (Bhattacharya 1979). Moisture content was calculated and expressed on dry basis.

Cooked rice samples were prepared in duplicate by soaking 10 g of milled rice for 30 min (150-ml beakers) in a predetermined amount of water, based on apparent amylose content (13 ml for waxy, 17 ml for low amylose, 19 ml for intermediate amylose, and 21 ml for high amylose) and cooking four samples simultaneously for 20 min in a Toshiba RC-4B automatic electric cooker with 200 ml of water in the outer pot. After standing 10 min, the cooked rice was drained and transferred into polyethylene bags to cool for 1 hr. The cooled rice (17 g) was placed into a 10-cm^2 Ottawa Texture Measuring System cell with a perforated base and pressed with a 145-g weight for 1 min before extruding in an Instron model 1140 food tester with a 5–50-kg load cell at crosshead and chart speeds of 20 cm/min (Perez and Juliano 1979). Hardness was determined as the maximum force needed to extrude the rice through the perforated base. Cooked rice (5 g) was also pressed onto the Instron platform with the 3.6-cm diameter plunger at a constant pressure of 4 kg for 20 sec. Stickiness was calculated as the product of the force (g) required to lift the plunger and the distance (cm) the plunger traversed, measured by planimetry. The 5–50-kg-load cell was used at a crosshead speed of 5 cm/min and chart speed of 100 cm/min.

Milled rice flours were prepared with a Udy cyclone mill with a 60-mesh sieve, but a 40-mesh sieve was used for amylography and a 50-mesh sieve for the rapid gel test. Apparent amylose content was determined by iodine colorimetry at 620 nm using potato amylose-waxy rice starch standard mixture (Juliano et al 1981), together with hot-water-soluble amylose using an AutoAnalyzer (Juliano 1971). Crude protein was measured by microKjeldahl digestion of 50 mg of flour, followed by colorimetric estimation of ammonia in the Kjeldahl digest as indophenol blue after reaction with NaOCl and alkaline phenol in an AutoAnalyzer (Juliano and Pascual 1980). Gel consistency of 100 mg of flour in 2 ml of 0.2*N* KOH in 13 × 100 mm culture tubes was determined by the procedure of Cagampang et al (1973), and gel viscosity was also measured at 25°C. Degree of parboiling was measured by the rapid gel test of Pillaiyar (1984a) whereby 100 mg of 50-mesh flour was thoroughly mixed with 4 ml of 1.25% KOH in rubber-stoppered 13 × 100 mm test tubes for 3 min and centrifuged at 250 × *g* for 5 min, and the gel length measured. Final gelatinization temperature of starch was measured photometrically on 0.5% milled rice flour dispersions in water at 525 nm with a Bausch & Lomb Spectronic 20 with a heated 18-mm tube adapter and magnetic stirrer (Ignacio and Juliano 1968).

Amylograph pasting characteristics were determined on 40 g of rice flour in 360 ml of water with a Brabender Viscoamylograph with 700 g·cm sensitivity cartridge at 75 rpm by heating at 1.5°C/min between 30 and 95°C, 20 min cooking at 95°C, and cooling at 1.5°C/min to 50°C (Juliano et al 1985). Amylograph consistency was calculated as viscosity cooled to 50°C minus final viscosity at 95°C. Setback was final viscosity cooled to 50°C minus peak viscosity.

RESULTS AND DISCUSSION

Laboratory Parboiling Method

Steeping IR42 and IR62 rough rice in water at 60°C rapidly increased water absorption during the first hour and leveled water content in 7–8 hr (Table I). Differences in water content between IR42 and IR62 during 10 hr of soaking were not significant except at 7 and 8 hr of soaking. In water at 70°C, IR42 and IR62 absorbed in 4 hr the same level of water they absorbed in 8 hr at 60°C. However, both samples continued to absorb water on further soaking, particularly the low-gelatinization temperature (GT) sample, IR42. Excessive water absorption at 70°C in IR42 was accompanied by starch gelatinization, brown rice swelling, and hull splitting. No hull opening was observed in IR62. A soaking method of 8 hr in 60°C water was adapted for the laboratory parboiling method because it was less subject to excessive water absorption inherent at 70°C for low-GT rices such as IR42. Bhattacharya and Subba Rao (1966) also reported that soaking raw rough rice at 60°C or lower did not affect the quality of the resulting parboiled rice.

Steaming presoaked IR42 and IR62 rough rices at 100°C (0 kg/cm^2 gauge pressure) for 25 min resulted in uneven hull opening in IR62, but IR42 had uniform hull opening. Uniform hull opening was observed in 30-min parboiling in both IR42 and IR62, but 35-min steaming caused significant brown rice swelling and excessive hull opening, particularly in IR42. Corresponding water content of parboiled rice was always higher in IR42 than in IR62 for all steaming periods (Table II). Degree of parboiling indexed by alkali reaction in 1% KOH confirmed the complete parboiling of all samples, except IR62 steamed for 25 min. This sample had an ungelatinized white core, reflecting incomplete parboiling. Thus, a steaming time of 30 min at 100°C may be used to represent the traditional parboiling method, although the low-GT sample IR42 absorbed more water than the intermediate-GT sample IR62.

Pressure parboiling for 10 min at 111, 120, 127, and 131°C completely gelatinized steeped IR42 and IR62 rough rice, but not IR62 at 111°C which still showed a white core. Water content of rough rice parboiled at 111°C was also lower than that of rough

TABLE I
Hydration Characteristics of High-Amylose Rough Rices with Low (IR42) and Intermediate (IR62) Gelatinization Temperature in Water at 60 and 70°C

Soaking Period (hr)	Water Content[a] (% dry basis) at 60°C IR42	60°C IR62	70°C IR42	70°C IR62
0	13.3	13.6	13.3	13.6
1	28.0	29.4	30.4	30.1
2	34.1	34.0	35.4	35.3
3	36.4	36.6	41.7	38.7
4	39.2	39.0	44.5	41.0
5	40.7	39.9	47.2	42.0
6	41.8	40.7	49.1	42.5
7	43.4	40.9	53.5	43.5
8	43.4	41.2	59.4	45.1
9	43.9	42.6	65.2	46.1
10	44.0	42.9	77.0	47.3

[a] LSD (5%) = 1.2%.

TABLE II
Effect of Parboiling Time and Pressure Parboiling Temperature on Water Content of IR42 and IR62 Rough Rices (soaked 8 hr at 60°C) and Their Degree of Parboiling Indexed by Alkali Reaction of Milled Rice in 1% KOH[a]

Parboiling Temperature and Time	IR42 Water Content (% dry basis)	IR42 Alkali Reaction	IR62 Water Content (% dry basis)	IR62 Alkali Reaction
Control[b]	43.4	2.3	41.2	2.0
100°C/25 min	62.2	5.9	59.1	4.0
100°C/30 min	79.0	6.0	66.2	5.2
100°C/35 min	88.8	6.0	71.3	5.5
111°C/10 min	71.6	5.9	64.7	4.5
120°C/10 min	80.0	6.0	77.8	6.0
127°C/10 min	80.4	6.0	78.0	6.0
131°C/10 min	80.9	6.0	78.5	6.0
LSD (5%)	2.6	0.2	1.2	0.7

[a] Ali and Bhattacharya (1972).
[b] Soaked 8 hr at 60°C.

rice parboiled at higher temperatures, particularly IR62 (Table II). Degree of parboiling indexed by alkali reaction in 1% KOH (Ali and Bhattacharya 1972) was also low for IR62 parboiled at 111°C. By contrast, at 127 and 131°C endosperm contents leached out and there was excessive discoloration. Water contents of parboiled IR42 and IR62 rough rice were similar at 120–131°C. Differences in gelatinization and cooking rates of milled rice are known to decrease at cooking temperatures higher than 100°C (Juliano and Perez 1986). The coarser grain of IR62 relative to IR42 (Table III) may have also contributed to its longer cooking time. Thus, subsequent pressure parboiling of different rices utilized 10 min steaming at 120°C (1.0 kg/cm^2 pressure) after soaking rough rice for 8 hr at 60°C.

Varietal Differences

The nine IR varieties selected by apparent amylose content and GT and three high-amylose Bangladesh varieties were mainly of low GT but five were intermediate (Table III). Values for apparent amylose content, GT, and alkali spreading value were comparable to previous values (Khush and Juliano 1985, Juliano and Pascual 1980). Hot water-soluble amylose increased with apparent amylose content but tended to be higher for the Bangladesh rices. Gel consistency of 100 mg of flour tended to be harder for all samples; IR36, IR64, and IR48 showed hard (26–40 mm) gel instead of medium (41–60 mm) gel, and IR24 and IR62 showed medium gel instead of soft (61–100 mm) gel. Protein contents of the samples were average for all samples, except the high value for BR4. Translucency values were high for translucent nonwaxy milled rices (45–66%), low for white-core rices IR8 (25%) and IR5 (42%), and lowest for opaque waxy grain IR65 (12%) at similar degrees of milling. Apparent amylose, water-soluble amylose, and GT were positively correlated. Apparent amylose and gel consistency were negatively correlated, but water-soluble amylose and gel viscosity were also negatively correlated. GT and alkali spreading value were also correlated with gel viscosity.

Equilibrium water content of rough rice after the 8 hr soaking at 60°C was highest for waxy rice IR65 (51.4%) and lowest for high-amylose rices (41.4–42.8%). Water content tended to be lower for intermediate GT high amylose rices (41.4–47.8%) than for low GT high-amylose rices (43.1–49.2%). White-core rices IR8 and IR5, particularly IR8, showed higher water content than translucent rices as earlier reported (Antonio and Juliano 1973, IRRI 1980). The Bangladesh rices showed higher water content (47.4–49.2%) than high-amylose IR rices (41.4–45.2%). Water content of steeped rough rice correlated negatively with amylose content ($r = -0.68$, $P < 0.05$) and positively with alkali spreading value ($r = 0.64$, $P < 0.05$).

Corresponding solids loss during this soaking step of parboiling ranged from 0.37 to 0.66% of rough rice weight. BR11 had the highest weight loss and IR48 the lowest. Solids loss correlated positively with GT ($r = 0.65$, $P < 0.05$) and negatively with alkali spreading value ($r = -0.77$, $P < 0.01$).

Indexes of Degree of Parboiling

Four indexes of degree of parboiling were compared. Milled rice alkali reaction in 1.0% KOH increased with parboiling and was higher on pressure parboiling than at 100°C (Table IV). Similar results were obtained for equilibrium water content of milled rice at 25°C except for similar values under various parboiling conditions for the IR42 (74–79% dry basis) and IR8 (63–73%) and for the Bangladesh rices (59–69%). Waxy IR65 had the largest increase in water content, from 103% to 325–330% on pressure parboiling. Water content tended to be less in the intermediate-GT samples (51–69%). Alkali gel length (Pillaiyar 1984a) showed higher values for parboiled samples, but not necessarily higher for pressure-parboiled rices, except for intermediate-GT rices. Pillaiyar (1984b) demonstrated a positive correlation between gel length and severity of parboiling of rice. Water content of rough rice after parboiling at 100°C for 30 min was higher for low-GT rices (62–81%) than for intermediate-GT samples (53–62%), consistent with earlier data on IR42 and IR62 (Table II). However, water content values after parboiling rough rice 10 min at 127°C were lower than those observed for IR42 and IR62. Among the Bangladesh rices, Pajam had a lower water content after parboiling, both at 100 and 127°C (53%), than BR4 (62–66%) and BR11 (59–63%), which was consistent with Pajam's higher GT (Table III).

Among these four indexes of degree of parboiling only alkali reaction value in 1% KOH of milled rice parboiled at 100°C, but not at 120 and 127°C, correlated with raw rice GT ($r = -0.69$, $P < 0.05$), alkali spreading value ($r = 0.74$, $P < 0.01$), and gel viscosity ($r = 0.73$, $P < 0.01$). Equilibrium water content of parboiled milled

TABLE III
Some Characteristics of Low and Intermediate Gelatinization Temperature (GT) Milled Rices Arranged in the Order of Increasing Apparent Amylose Content and Their Correlation Coefficients with Milled Rice Properties

Variety	Amylose	GT	Apparent Amylose[a]	Water-Soluble Amylose[a]	Final Gel. Temp. (°C)	Alkali Spreading Value	Gel Consistency (mm)	Gel Viscosity (cP)	Protein Content[a]
IR65	waxy	low	1.0	0.2	64.5	6.7	91	1,270	8.4
IR24	low	low	15.0	9	64.0	6.8	58	1,020	7.3
IR48	int.	low	21.8	13	64.5	7.0	34	870	7.7
BR4	high	low	25.2	12	68.0	6.6	26	1,720	10.2
BR11	high	low	25.5	18	69.5	7.0	30	902	7.6
IR42	high	low	25.7	11	66.5	7.0	26	1,290	8.9
IR8	high	low	26.3	11	66.0	7.0	28	1,540	7.0
IR64	int.	int.	21.9	12	73.0	4.0	39	736	8.6
IR36	high	int.	25.7	12	72.5	4.0	28	938	8.8
IR5	high	int.	26.2	16	72.5	4.0	78	707	7.5
Pajam	high	int.	26.6	13	72.0	5.4	26	1,290	8.2
IR62	high	int.	26.9	16	73.5	4.0	54	698	7.6
LSD (5%)			0.4	0.4	1.9	0.4	6.4	136	0.2
Correlation coefficients (n = 12)									
Apparent amylose				0.93**[b]	0.62*	−0.39	−0.67*	0.29	−0.03
Water-soluble amylose					0.69*	−0.52	−0.42	−0.59*	−0.22
Gelatinization temperature						−0.95**	−0.24	−0.70*	0.14
Alkali spreading value							−0.10	0.75**	−0.23
Gel consistency								−0.19	−0.27
Gel viscosity									−0.07

[a] % dry basis.
[b] *, $P < 0.05$; **, $P < 0.01$.

rice correlated negatively with apparent amylose (r = −0.74 to −0.96, $P < 0.01$) and hot-water-soluble amylose contents (r = −0.79 to −0.91, $P < 0.01$) and with GT of raw rice (r = −0.58, $P < 0.05$, to −0.84, $P < 0.01$). Only equilibrium water content of rices parboiled at 120 and 127°C correlated positively with raw rice gel consistency (r = 0.68–0.72, $P < 0.05$). Alkali gel length did not correlate significantly with any raw rice quality factor except gel consistency (r = −0.66, $P < 0.05$) and viscosity (r = 0.5, $P < 0.05$) for rice parboiled at 100°C. Water content of rough rice parboiled at 100°C only correlated with raw rice GT (r = −0.72, $P < 0.01$) and alkali spreading value (r = 0.64, $P < 0.01$), but water content rough rice parboiled at 127°C only correlated positively with gel viscosity of raw rice (r = 0.77, $P < 0.01$).

Effects on Rough and Brown Rice Properties

Parboiling had no effect on grain dimensions. Parboiling did not result in a consistent decrease in rough rice and hull weights. Brown rice weight was also not consistently affected by parboiling. IR42 had the lightest (15 mg) and shortest (5.8 mm) brown rice among IR rices but not the narrowest. Pajam was the lightest (13 mg) among the three Bangladesh rices. Brown rice length ranged from 5.4 to 7.1 mm and width from 2.0 to 2.6 mm. Length-width ratio ranged from 2.3 to 3.5.

Parboiling at 100°C significantly increased Instron bending hardness of brown rice, including waxy rice (Table IV). Pressure parboiling improved hardness values further except for waxy rice. Increase in parboiling temperature from 120 to 127°C did not affect hardness of low-GT rices but improved hardness of IR36 (from 1.7 to 2.1 kg) and IR5 (from 2.0 to 2.4 kg) grain. Hardness of parboiled brown rice correlated positively with apparent amylose content of raw rice only at 120 and 127°C (r = 0.85, $P < 0.01$) but consistently correlated with raw rice water-soluble amylose (r = 0.69, $P < 0.05$, to 0.90, $P < 0.01$) regardless of parboiling temperature. Breaking and crushing hardness values were reported improved by parboiling for 14 min at 100°C (Raghavendra Rao and Juliano 1970).

Effects on Milled Rice Properties

Total milled rice yield was not significantly affected by parboiling (Table IV), except in IR65 and IR5, where endosperm contents oozed out particularly at 127°C. Degrees of milling, based on bran-polish weight, were similar for raw and parboiled rices. The exudate was included with the hull fraction during dehulling. Parboiling increased head or whole-grain rice yield of all rices (Table IV), although some raw rices such as IR64, IR36, Pajam, and BR4 already have high head rice yields (65–67%). Although both IR8 and IR5 had white core endosperm, only IR8 had low raw head rice yield (33%) compared to IR5 (60%). IR42 also had low raw head rice yield (40%) but is prone to cracking (IRRI 1986). Parboiled rices had low percent brokens because total and head rice yields were almost the same. Again, the lower head rice yields in pressure-parboiled IR65 (66 vs. 70%) and IR5 (66–70 vs. 72%) were due to loss of exudate with the hull fraction. Total and head milled rice yields of rices parboiled at 100 and 120°C, but not of raw rice or rice parboiled at 127°C, correlated positively with raw rice apparent amylose and hot-water-soluble amylose content (r = 0.65, $P < 0.05$, to 0.73, $P < 0.01$). Only total and head milled rice yields of raw rice (r = 0.71, $P < 0.01$) and rice parboiled at 100°C (r = 0.66, $P < 0.05$) correlated positively with raw rice GT.

All samples decreased progressively in milled rice whiteness with increased parboiling temperature (Table IV). Milled rice translucency increased on parboiling but tended to decrease on pressure parboiling due to endosperm discoloration at more severe parboiling. The lower translucency values obtained for pressure-parboiled milled rices must be due to interference of grain color to translucency values. Similar effects of severity of parboiling on milled rice whiteness and translucency have been reported (Bhattacharya and Subba Rao 1966, Ali and Bhattacharya 1982).

Apparent amylose content showed a mean 1% decrease on parboiling, and hot-water-soluble amylose content decreased progressively with severity of parboiling (Table IV). Raw rice hot-water-soluble amylose was highest for BR11 (18%) and soft-gel IR5 and IR62 (16%) and lowest for waxy IR65 (0.2%). The

TABLE IV
Properties of Rough, Brown, and Milled Rices Before and After Parboiling 30 min at 100°C or 10 min at 120 or 127°C

Property	Ranges of Values[a]					Mean Values[a]			
	Raw (n = 12)	100°C (n = 12)	120°C (n = 9)	127°C (n = 12)	LSD (0.05)	Raw (n = 12)	100°C (n = 12)	120°C (n = 9)	127°C (n = 12)
Degree of parboiling tests									
Alkali reaction value	1.8–3.0	4.2–5.4	5.1–6.2	6.0–6.8	0.6	2.3	4.8	5.8	6.2
Equilibrium water content, % db	19–33	51–103	59–330	59–325	13	23	69	99	90
Alkali gel length, cm	0.5–0.8	1.2–2.0	1.6–2.4	1.7–2.4	0.1	0.6	1.7	2.0	2.2
Rough rice water content, % db	···	53–81	···	50–66	3	···	65	···	55
Brown rice wt, mg	13–23	13–24	16–24	13–23	0.3	19	19	20	19
Brown rice hardness, kg	0.4–0.8	1.0–1.9	1.0–2.2	1.0–2.4	0.3	0.6	1.1	1.8	1.9
Total milled rice yield, %	70–74	70–76	68–75	67–74	2	72	73	72	71
Head rice yield, %	33–67	70–75	66–75	66–74	3	56	72	71	71
Degree of milling, %	7.9–8.6	8.1–8.9	8.0–8.4	8.2–9.1	0.6	8.2	8.3	8.2	8.6
Milled rice whiteness, %	38–48	24–30	20–26	15–21	1	42	28	23	18
Milled rice translucency, %	12–66	>100	81–>100	70–>100	0.3	49	>100	98	87
Apparent amylose content, % db	1–26	1–25	1–26	0–26	0.4	21	20	20	20
Water-soluble amylose, % db	0.2–18	0.2–14	0.1–10	0.1–9	0.4	12	9	6	5
Alkali spreading value	4.0–7.0	4.3–7.0	6.0–7.0	6.0–7.0	0.3	5.9	5.5	6.5	6.9
Brown rice gel consistency, mm	26–84	38–99	38–100	41–100	7	36	65	76	81
Brown rice gel viscosity, cP	938–2,360	579–2,560	454–2,450	412–2,150	165	1,420	1,170	1,060	904
Milled rice gel consistency, mm	26–91	42–100	44–100	49–100	6	43	67	80	86
Milled rice gel viscosity, cP	698–1,720	400–2,490	392–2,370	390–2,070	136	1,080	1,110	1,010	873
Amylograph viscosity, BU									
Peak	460–900	···	···	···	19	710	···	···	···
Final at 95°C	355–680	140–540	55–175	20–240	2	510	330	115	90
Cooled to 50°C	400–1,680	200–840	80–540	50–460	22	895	560	180	145
Consistency	45–1,000	60–420	25–220	10–220	22	390	230	65	55
Setback	−200–780	···	···	···	25	185	···		···
Cooked rice hardness, kg/7 cm^2	7.1–10.0	6.4–12.2	7.0–12.2	5.8–11.8	0.9	8.6	10.0	10.1	9.9
Cooked rice stickiness, g·cm	39–666	0–636	0–591	0–485	36	245	171	156	136

[a] n = 11 instead of 12 for amylograph viscosity (excluding BR4); n = 5 for rice stickiness (IR65, IR24, IR48, IR64 and IR5); excluding three Bangladesh rices at 120°C (n = 9).

reduction of water-soluble amylose was greatest for hard gel IR8 (from 11 to 3–6%) and IR42 (from 11 to 4–7%). Hot-water-soluble amylose of parboiled rices correlated positively with apparent and hot-water soluble amylose ($r = 0.74$, $P < 0.05$, to 0.95, $P < 0.01$) and GT ($r = 0.75$–0.80, $P < 0.01$), and negatively with gel viscosity ($r = -0.75$, $P < 0.05$, to -0.85, $P < 0.01$) of raw rice. Defatting of milled rice with refluxing 95% ethanol did not substantially increase the amylose content of parboiled rice, suggesting that nonstarch lipids content of the raw and parboiled rices were similar at similar degrees of milling. Nonstarch lipids reduce the apparent amylose content of milled rice (Juliano 1971, Juliano et al 1981). Decrease in hot-water-soluble amylose on parboiling was been reported earlier (Raghavendra Rao and Juliano 1970, Pillaiyar and Mohandoss 1981).

Alkali spreading value of rice parboiled at 100°C was similar to that of raw rice but increased with pressure parboiling (Table IV). Hence, alkali spreading value in 1.7% KOH for 23 hr cannot be used to measure degree of parboiling when parboiled at 100°C, although alkali value in 1% KOH for 4 hr was sensitive even with samples parboiled at 100°C.

Brown and milled rice gel consistency softened progressively with parboiling temperature (Table IV), except for IR65 and IR24. Gel consistency of IR65 brown rice was 84 mm in raw rice, 46 mm in rice parboiled at 100°C, 45 mm in rice parboiled at 120°C, and 53 mm in rice parboiled at 127°C. For IR24 brown rice, gel consistency was 34 mm in raw rice, 38 mm in rice parboiled at 100 and 120°C, and 41 mm in rice parboiled at 127°C. The softening in gel consistency was usually accompanied by a decrease in gel viscosity. Because brown and milled rices changed similarly in gel consistency and viscosity, the change was not due to differences in residual lipids of raw and parboiled milled rices. Extending dispersion time at 100°C from the usual 8 min to 15 min did not harden the gels further. Because the decrease in gel viscosity was still observed even after defatting or dispersing the flour in dimethyl sulfoxide (IRRI, *unpublished data*), the changes must be due to starch degradation during parboiling. The degradation, however, was not extensive enough to reduce the apparent amylose content of parboiled rice (Table IV).

Milled rice and brown rice gel consistency of parboiled rice correlated positively with apparent and hot-water-soluble amylose content of raw rice ($r = 0.73$, $P < 0.05$, to 0.83, $P < 0.01$), except with apparent amylose for rices parboiled at 100°C. Gel viscosity of parboiled milled and brown rices correlated negatively with raw rice apparent and hot-water-soluble amylose without exception ($r = -0.86$ to -0.98, $P < 0.01$). Raw rice gel consistency and viscosity were less correlated to apparent and hot-water-soluble amylose content than those in parboiled rices. GT correlated negatively with gel viscosity of rices parboiled at 100°C ($r = -0.78$, $P < 0.01$) reflecting possible interaction of gel viscosity with degree of parboiling at this lower temperature.

Amylograph peak viscosity of raw flour was lowest for waxy IR65 and highest for Pajam. Softer gel intermediate GT high-amylose rice IR5 and IR62 had lower peak viscosity (525 and 630 BU) than the other five high-amylose rices (745–900 BU). Peak viscosity disappeared on parboiling at 100°C except for the peak viscosity of 650 BU for low amylose IR24 flour. Final viscosity on cooking 20 min at 95°C decreased on parboiling at 100°C except IR24 (from 460 to 540 BU) and IR64 (from 380 to 460 BU) and was lower than raw rice peak viscosity. However, amylograph final viscosity at 95°C was lower in all rices parboiled at 120 and 127°C than in raw rice flour (Table IV). IR24 had the highest viscosity among pressure parboiled rices. Viscosity on cooling at 50°C decreased on parboiling at 100°C except also for IR24 and IR64, and were lower in rices parboiled at 120 and 127°C. Amylograph consistency was generally lower for rices parboiled at 100°C than for raw rice except for IR65, IR24, IR48, IR64, and IR36. For IR24, amylograph consistency was 170 BU for raw rice, 230 BU for rice parboiled at 100°C, and 220 BU for rices parboiled at 120 and 127°C. The other rices had amylograph consistency of 25–80 BU on parboiling at 120°C, and 10–55 BU on parboiling at 127°C.

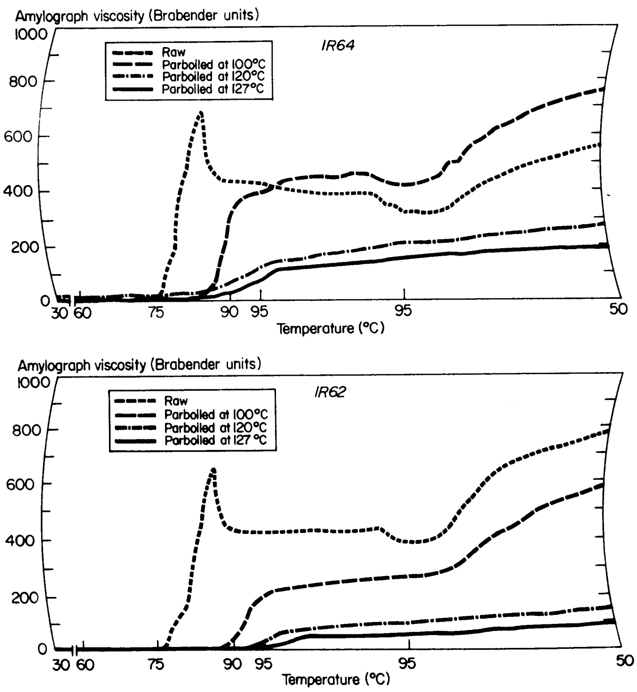

Fig. 1. Effect of parboiling temperature on the amylograph pasting viscosity of IR64 (intermediate amylose) and IR62 (high amylose) milled rice.

TABLE V
Analysis of Variance Mean Squares of Some Properties of Raw and Parboiled Rices

Property	Mean Squares from Sources of Variation: Treatment (T) (2–3)[a]	Variety (V) (8–11)[a]	T × V (19–30)[a]	Error (33–45)[a]	Coefficient of Variation (%)
Hull content, % of rough rice	3**[b]	16**	0.8**	0.07	1.2
Total milled rice yield, %	3**	11**	0.7**	0.2	0.7
Head milled rice yield, %	1,876**	96**	95**	1.2	1.7
Brown rice hardness, kg	8**	0.2**	0.1**	0.02	12.2
Gel viscosity of brown rice, cP	1,001,049**	1,693,622**	350,768**	6,724	6.9
Equilibrium water content, %	22,656**	14,358**	3,469**	43	9.9
Amylose content, %	2**	518**	0.6**	0.05	1.1
Hot-water-soluble amylose, %	116**	102**	3**	0.03	2.3
Gel consistency, mm	5,598**	1,081**	783**	10	5.1
Gel viscosity, cP	188,957**	1,763,081**	167,726**	4,531	6.6
Whiteness, %	2,249**	28**	14**	0.4	2.0
Cooked rice Instron hardness, kg	12**	14**	1**	0.2	4.9
Cooked rice stickiness, g·cm	22,781**	493,669**	2,932**	311	10.0

[a] Degrees of freedom in parenthesis.
[b] ** $P < 0.01$.

Setback could not be calculated for parboiled rices because of the absence of a distinct peak. Amylograph viscosity of waxy IR65 and particularly low-amylose IR24 were less affected by parboiling at 100, 120, and 127°C than the other higher amylose rices, in agreement with observations on rices parboiled at 100°C (Raghavendra Rao and Juliano 1970). Amylograph viscosity also decreased progressively with parboiling time at 100°C for an Indian rice variety (Ali and Bhattacharya 1980). The decrease in amylograph viscosity with increasing parboiling temperature was consistent with the use of the amylograph to measure the extent of cooking of steamed rice (Ferrel and Pence 1964).

In the raw rice amylograph, peak viscosity, final viscosity at 95°C, viscosity cooled to 50°C, and consistency correlated negatively with gel consistency ($r = -0.65$, $P < 0.05$, to -0.80, $P < 0.01$) but not positively with gel viscosity. However, on parboiling, no amylograph property correlated with raw rice quality factors. Thus, amylography of parboiled rice does not provide much varietal differentiation. The lower amylograph viscosity is a reflection of the decreased swelling ability of gelatinized and dried starch as compared with raw starch (Priestley 1976, Ali and Bhattacharya 1980).

Parboiling significantly increased the cooked rice hardness of milled rice (Table IV) except for IR65 (from 7.6 kg/7 cm^2 to 5.8–7.0 kg) and IR24 (from 7.1 kg/7 cm^2 to 7.6–7.9 kg). Surprisingly, pressure parboiling did not substantially increase cooked rice hardness over that of parboiling at 100°C (Table IV), except for IR64 (from 9.6 kg/7 cm^2 to 11.0–11.3 kg). Some samples even showed lower hardness values than rices parboiled at 100°C such as IR42, IR8, and BR4 (from 11.0–12.2 kg/7 cm^2 to 9.3–10.6 kg). The softer cooked rice of intermediate-GT rices with intermediate and high amylose content over those with low GT were still shown after parboiling at 100°C (9.3–10.8 kg/7 cm^2 vs. 9.4–12.2 kg), except BR11, but masked by pressure parboiling. Cooked rice hardness of parboiled rice, but not of raw rice, correlated significantly with apparent and hot-water-soluble amylose content of raw rice ($r = 0.75$–0.88, $P < 0.01$). The correlation with gel consistency was significant only for rices parboiled at 100°C ($r = -0.63$, $P < 0.05$), probably because gel consistency softened on parboiling particularly at higher temperatures. Cooked rice stickiness of five samples was reduced by parboiling, except for IR65, particularly by parboiling at 100°C. Stickiness of cooked raw and parboiled rices correlated negatively with apparent and hot-water-soluble amylose ($r = -0.97$ to -0.99, $P < 0.01$) and positively with gel viscosity of raw rice ($r = 0.94$–0.97, $P < 0.01$). Kato et al (1983) also reported that parboiling made the cooked rice harder and less sticky.

General Discussion

Analysis of variance showed that parboiling treatment, variety and their interaction significantly affected grain properties—hull content, total and head milled rice yields, brown rice hardness and gel viscosity, milled rice equilibrium water content, apparent and hot-water-soluble amylose, gel consistency and viscosity, whiteness, and cooked rice hardness and stickiness (Table V). Variation in head rice yield, brown rice hardness, and milled rice gel consistency and whiteness were mainly due to treatment, whereas variation in hull content, total milled rice yield, amylose content, milled rice gel viscosity, and cooked rice stickiness were due mainly to variety. Other properties were affected to similar extents by parboiling temperature and variety.

Differences in starch properties and grain thickness make it difficult to prepare parboiled rices with similar degrees of parboiling from different varieties. Although soaking for 8 hr in 60°C water followed by parboiling 30 min at 100°C (0 kg/cm^2 steam pressure) or 10 min at 120°C (1.0 kg/cm^2 steam pressure) minimized these differences, these two parboiled rices have different properties (Table IV) as judged by their different relationships with raw rice quality factors. Both apparent amylose content and starch final GT affected the water content of steeped rough rice, but GT had a greater effect on the rate of parboiling at 100°C than at 120 and 127°C (Juliano and Perez 1986), as evident by the closer range of water content of pressure-parboiled rough rice (Table IV). The residual starch crystallinity in rices parboiled at 100°C (Biliaderis et al 1986) probably influenced the properties of the resultant milled rice. The V-type X-ray pattern of parboiled rice reported by Priestley (1976) must be due to amylose-lipid complex, which reforms on cooling of gelatinized starch (Russell and Juliano 1983, Biliaderis et al 1986).

Methods for measuring degree of parboiling were mainly qualitative, except for equilibrium water content and parboiled-rice water content (Table IV). Intermediate-GT rices tended to have lower values for all methods, except probably for alkali gel length. A low-GT, medium-grain U.S. rice also showed a higher degree of parboiling than an intermediate-GT, long-grain rice at 100°C and higher temperature (Sesay and Verma 1985).

Most of the physical properties of parboiled rices showed significant correlation with apparent and hot-water-soluble amylose content of raw rice, which was not affected significantly by parboiling (Table I). They include equilibrium water content, brown rice hardness and head rice yield parboiled at 100 and 120°C, gel consistency and viscosity, and cooked rice hardness and stickiness (Table IV). Amylograph pasting viscosity was not useful in discriminating among parboiled milled rices. Earlier workers have observed the importance of apparent amylose content on parboiled rice properties (Raghavendra Rao and Juliano 1970, Alary et al 1977). Gel consistency in 0.2*N* KOH, however, was softened by parboiling, probably due to starch degradation.

CONCLUSIONS

The study showed that raw rice properties may be used to predict parboiled rice quality in a breeding program and only advanced lines need to be assessed for actual parboiling quality. Apparent amylose content seems to be the most dominant quality factor for parboiled rice quality as in raw rice quality (IRRI 1979), and GT was also a factor in rice parboiled at 100°C. Gel consistency and viscosity of raw rice are also important factors. Relationships with grain properties were demonstrated to also be affected by parboiling temperature. Thus, no special tests need to be done for parboiled rice quality in a breeding program already screening for raw rice quality such as in IRRI (Khush and Juliano 1985).

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