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AN INTERNATIONAL SURVEY OF METHODS USED FOR EVALUATION OF THE COOKING AND EATING QUALITIES OF MILLED RICE

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ABSTRACT

A survey of methods used by rice scientists for the evaluation of the cooking and eating qualities of milled rice was made in 1981. This report represents the reply of 41 scientists in 27 countries. Thirty-six respondents cooked rice for texture evaluation; of those, 20 used sensory evaluation, 11 used instruments, and 5 used both. Details of the methods are discussed and compared. Of the 41 respondents, 30 determined amylose, 27 determined alkali spreading value, and 17 screened for gel consistency. Most respondents were interested in cooperative testing of cooking methods. Possible areas for cooperative testing were comparative hardness of rice cooked to 75% water content by cooker and excess-water methods, single-grain vs bulk cooked rice for hardness estimation by instruments, grain elongation during cooking, and amylography.

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AN INTERNATIONAL SURVEY OF METHODS USED FOR EVALUATION OF THE COOKING AND EATING QUALITIES OF MILLED RICE

Rice is cooked in various ways throughout the world. Batcher et al (1963a) classified cooking methods into: oven method, small amount of water, medium amount of water, large amount of water, steaming, steaming with oil added, and cooking in water with oil added. Taste panel scores of the rice prepared by different methods suggested that the palatability characteristics of the cooked product from a given sample or region were similar regardless of cooking method used (Batcher et al 1963a,b).

The 1978 IRRI International Workshop on Chemical Aspects of Rice Grain Quality recommended the characters of cooked rice as the first priority research problem area (Barber et al 1979). Also recommended were international cooperative tests on four areas -- amylose content, alkali test, gel consistency, and instrument methods for cooked-rice texture (Webb and Blakeney 1979). The resulting cooperative tests showed good reproducibility among laboratories for amylose (Juliano et al 1981a), alkali spreading value (Juliano et al 1982), and gel consistency (Juliano et al 1980). A cooperative study on texture methods using 10 rices differing in amylose content, but cooked by the same excess-water method to optimum degree of cooking (minimum cooking time plus 2 minutes), showed better sensitivity for instrument methods for cooked-rice hardness and stickiness than for the taste panel scores (Juliano et al 1981b).

Several reviews on cooking quality methods applicable to world rices have been published. These include those of Borasio (1965), Refai (1962), Simpson et al (1965), Hampel (1968), and IRRI (1979a). They did not indicate, however, the relative adaption of these methods in various rice quality laboratories in the world.

In 1980 the International Association for Cereal Chemistry organized the Study Subgroup 21b "Cooking Properties of Rice" with the IRRI Chemist as chairman. Its mandate was to try to standardize the current methodology for assessing the cooking properties of milled rice. To determine the various methods currently in use, a mail survey on cooking quality evaluation by various laboratories throughout the world was done as a basis for formulating international ring tests.

In 1981 a letter to 68 rice scientists in 37 countries requested details of the methods they use to determine, test, or evaluate:

- cooking characteristics of milled rice,
- texture of cooked rice,
- amylograph for rice flour, and
- elongation for elongating or Basmati-type rices.

Details of other methods, including indirect methods, amylose content, alkali spreading value, and gel consistency were also requested.

Respondents were requested to indicate their possible interest in cooperative testing on specific cooking tests and to suggest other scientists who might join the study group.

Based on replies to the first survey letter, a summary table of methodology was compiled and sent to the respondents in June 1981 for verification. In addition, respondents were asked to name the popular aromatic varieties in their country or region.

DIRECT METHODS FOR TESTING RICE COOKING QUALITY

A summary of direct tests for cooking quality of milled rice used by the 41 respondents is presented in Table 1. The summary includes methods for which they showed interest for cooperative testing. Most respondents showed interest on cooperative tests within the limits of equipment and staff availability.

Minimum cooking time

Eighteen respondents reported the measurement of minimum cooking time in their laboratory in connection with the cooking of milled rice in excess water. The method followed was that of Ranghino (1966) or that of Bhattacharya and Sowbhagya (1971) in which about 10 grains were pressed between 2 glass plates every minute until at least 90% no longer had opaque centers. That time was considered as minimum cooking time but was called optimum cooking time by some respondents. The samples were not presoaked in room-temperature water but were dropped directly into a boiling water bath. Fagade/Amubode sampled rice every 3 minutes after an initial 20 minutes of boiling; they reported that cooking time had been useful in predicting the protein quality of rice varieties.

Volume expansion and water absorption during cooking

In addition to Crisostomo and Vega, who determined volume expansion as the ratio of height of cooked rice to that of raw rice in the rice cooker pan used for sensory evaluation, seven other respondents reported determining volume expansion ratio, all in boiling water, with either a wire basket, a cloth sack, or in a perforated glass tube (Table 2). With the direct contact with boiling water, cooking time and boiling time were identical. In cases where the rice was placed in containers with

Table 1. Checklist of direct methods of cooking quality evaluation of milled rice used (+) by 41 respondents (family names given) from 27 countries and methods of interest to them for cooperative testing.

Respondent	Cooking time	Volume expansion ratio	Water absorption ratio	Elongation ratio	Miscellaneous cooking tests	Amylograph viscosity	Texture of cooked rice: Sensory	Texture of cooked rice: Instrument	Aroma	Interest for cooperative testing
Alyoshin/ Romanov					+a/					Test listed
Benedito de Barber								Instron		Test listed
Bhattacharya	+				+b/	+		Various		Not indicated
Blakeney	+			+		+		Instron-Kramer	+	Tests listed
Breckenridge			+ (96° & 60°)				+			Tests listed
Cheigh								Texturometer		Test listed
Choudhury	+			+			+		+	Tests listed
Crisostomo							+			Cooking test
Delgado							+			Test listed, Instron, and Amylograph
Diên		+							+	**Tests listed**
Ebata								Texturometer		Test listed
El Bayâ			+				+			Tests listed
Fagade/Amubode	+		+	+	+c/	+	+	Sieve test		Tests listed
Fossati	+	+		+	+d/	+				Tests listed
Harahap							+			Test listed
Husain	+	+	+				+			Tests listed, Texturometer, and Amylograph
Iwasaki						+	+	Texturometer		Tests listed, Single-grain vs bulk texture
Kongseree	+	+	+	+		+	+		+	Tests listed
Kurasawa		+	+		+c/	+	+	Various		Tests listed
Laignelet	+							Viscoelastograph		Tests listed
Launay	+							Instron		Tests listed
Lodh		+	+ (77°)	+			+		+	Tests listed
Mendes	+	+				+				Tests listed
Milev	+	+	+	+			+			Little interest
Mossman/Nishita and Bean						+		Instron		Tests listed
Paule				+			+		+	Tests listed
Perez	+			+		+		Instron		Tests listed
Pillaiyar	+		+ (90° & 60°)		+b/		+	Various		Tests listed for parboiled and raw rices
Reginatto										Indirect methods only
Schneeweiss							+			Test listed
Sekhon	+		+	+		+	+			Tests listed
Sekin						+	+			Tests listed
Siddiq	+	+		+			+		+	Tests listed
Siwi/Damardjati				+			+			Tests listed
Suzuki	+						+	Texturometer		Relation between Instron and Texturometer
Tsuji	+							Tensipresser		Little interest
Tun	+			+						Elongation ratio
Vega							+			Test listed
Victoria							+			Test listed
Vidal	+						+		+	Tests listed
Webb			+ (77°)		+e/	+		Pabst texture tester		Tests listed
Total	19	9	11	13	7	13	24	16	8	

a/ Resistance to overcooking. b/ Equilibrium water content of raw grain at room temperature. c/ Solids content and starch-iodine blue value of cooking gruel (Kurasawa et al 1962). d/ Solubles in cooking water and apparent solubility of cooked rice (Priestley 1976). e/ Parboil-canning stability (Webb 1979).

Table 2. Details of volume expansion (VE) and water absorption (WA) tests during cooking of milled rice.

Respondent	Rice weight (g)	Water weight (g)	Water-rice ratio	Cooking time [a] (minutes)	Cooking temperature (°C)	Details of test
Breckenridge	20	42	2.1	21	Boiling	WA. Weight increase in rice cooker with 200 ml in outer pot.
Crisostomo	200	360-390	1.8-1.95	Therm.	Boiling	VE and WA. Increase in height and weight of rice in cooker with 40 ml in outer pot (del Mundo 1979).
Diên	10	XS	-	10-20	Boiling	VE. Increase in volume by displacement; cooked in cloth sack.
El Bayâ	8	160	20	20	Boiling	WA. Weight increase of rice in perforated cylinder.
Fagade/Amubode	5	40	8	23	Boiling	WA (swelling capacity). Increase in weight of rice in beaker (Dimopoulos and Muller 1972). Also solids in cooking water.
Fossati	5	100	20	30	Boiling	VE. Increase in volume by displacement in graduated cylinder (Refai and Ahmed 1961).
Husain	25	200	8	20	Boiling	VE and WA. By volume displacement and weight increase of rice in wire cage.
Kongseree	8	160	20	20	Boiling	VE and WA. Increase in height and weight of rice in tared wire basket. Moisture content of cooked rice determined 8 hours at 130°C.
	8	16	2	20	Boiling	VE and WA. In 25 mm x 200 mm culture tube with glass marble cover instead of wire basket.
Kurasawa	8	180	22.5	20	Boiling	VE and WA. Increase in height and weight of rice in 7.5 cm x 4 cm diam wire basket, prewashed twice and presoaked overnight (Kurasawa et al 1962).
Lodh	5	15	3	20	Boiling	VE. By displacement in 100-ml graduated cylinder (Verghese 1950).
	2	10	5	45	77	WA. Decrease in volume of cooking water of 30 minutes presoaked rice and filtered; expressed per 100 g rice (Halick and Kelly 1959).
Milev	100	750	15	14-20	Boiling	VE and WA. Volume displacement and weight increase in Buehler cooker to optimum cooking time (Borasio 1965, Milev 1964).
Pillaiyar	2	20	10	20	60 and 98	WA. Weight increase after heating. Water content ratio at 60 and 98°C as index of degree of parboiling (Bhattacharya 1979a, Pillaiyar and Mohandoss 1981a).
Sekhon	2	20	10	Min	Boiling	WA. Weight increase on cooking.
Siddiq	1 grain	1	>30	15	Boiling	VE. By displacement in graduated hypodermal syringe.
Vega	200	360-390	1.8-1.95	Therm.	Boiling	VE and WA. Increase in height and weight of rice in cooker with 40 ml in outer pot (del Mundo 1979).
Vidal	100	180	1.8	Min	Boiling	VE and WA. Increase in height and weight in 400-ml beaker.
Webb	2	14	7	45	77	WA. Decrease in volume of cooking water of 30 minutes presoaked rice and filtered; expressed per 100 g of rice (Halick and Kelly 1959).

[a] Min = minimum cooking time, Therm. = thermostat control.

water and immersed in a boiling water bath, cooking time and boiling time were not the same, unless the time was considered from the time the cooking water in the container started boiling. In such a case, some degree of presoaking was involved.

Volume of raw and cooked rice was measured either as bulk volume (4 respondents) or as displacement volume (6 respondents). Bulk volume has practical value, but displacement volume has more theoretical importance. Volume expansion was mostly expressed as the ratio of volume of cooked rice to volume of raw rice but Siddiq expressed it as the increase in volume by subtracting the value of 1 from this ratio.

The conditions used for water absorption or uptake were similar to those for volume expansion (Table 2). A source of error was the blotting step to remove free water from the cooked-rice surface. Another source of error was the solids extracted from the rice cooked in excess water. A few determined the solids in cooking liquid or actually the dry matter/moisture content of the cooked rice to correct for this solids loss. Of course, the method did not distinguish between absorbed and adsorbed water in the cooked grains.

The purposes for determining volume expansion and water absorption of rice varied and were affected by differences in cooking time among varieties. Water uptake at 77°C used by Lodh and Webb continued to identify high starch gelatinization temperature (GT) rices in view of their low water uptake so close to their GT. With an arbitrary cooking time of 20 minutes, for example, water absorption will relate not only to amylose content but also to rates of cooking. If cooking time was adjusted to optimum cooking time, as done by Sekhon and Vidal, all rices will have absorbed similar amounts of water -- about 75% (Bhattacharya and Sowbhagya 1971). However, the method remains a means of checking if the cooking of samples for texture evaluation has proceeded normally. For parboiled rices, water absorption at 60°C and at 90-96°C was used by Breckenridge and Pillaiyar to measure degree of parboiling (Indudhara Swamy et al 1971). The ratio of apparent water uptake at 60°C to that close to boiling water temperature increased proportionately with severity of parboiling (Bhattacharya 1979a).

Solids in cooking water during cooking

In addition to volume expansion and water absorption, tests on the cooking water were made by some respondents. Fagade/Amubode determined solids in residual cooking water (Table 2) by drying at 120°C. Kongseree determined solids in cooking water by drying 10 ml in a tared moisture can at 130°C for 8 hours.

Kurasawa determined starch iodine blue value (Kurasawa et al 1962) and solids in cooking gruel (Table 2). A 5-ml aliquot of the measured cooking water was diluted with water and 2 ml of 0.2% iodine in 2% potassium iodide to 100 ml and the absorbance read at 530 or 580 nm after 30 minutes. Solids were determined on a 10-ml aliquot dried at 130°C for 8 hours (Ishimura et al 1979).

Webb determined canning stability on 5 g parboiled rice in 100 ml water, precooked 20 minutes at 95°C, cooled to room temperature with tap water, autoclaved for 1 hour at 121°C (1.05 kg/cm^2 gauge pressure), and cooled to room temperature with tap water (Webb 1979). Solids loss, as the decrease in dry weight from the starting parboiled rice, was determined by collecting cooked rice over 1.6-mm wire screen and drying it at 70°C overnight in a forced draft oven, and weighing.

Fossati determined solubles in cooking water and apparent solubility (Priestley 1976). Rice (1 g) was added to 20 ml boiling distilled water in a boiling tube fitted with a condenser. After 12 minutes of boiling, the cooking water was drained, its volume measured, and the grains were rinsed with 20 ml cold water. The volume of drained cooking water was replaced by an equal volume of cold water, the grains were macerated 20 seconds using a tissue homogenizer (Ultra-Turrax) at 20,000 rpm, and the homogenate was transferred into a 50-ml centrifuge tube with 15 ml water used for rinsing. A 20-ml sample of the aliquot and an aliquot of the pooled cooking water and rinsing were evaporated on a steam bath and dried for 4 hours at 105°C. The weight of the solubles in cooking water and soluble material released by macerating the kernels were calculated as a percentage of the dry weight of the sample. Maningat and Juliano (1978) found apparent solubility (Priestley 1976) to be better related to amylose content than to alkali digestibility pattern of Bhattacharya and Sowbhagya (1972).

Grain elongation during cooking

Fourteen respondents did elongation tests on rice with 0-30 minutes presoaking and a boiling time ranging from 10 to 30 minutes, or for a length of time corresponding to the minimum cooking time in excess water (Table 3). If presoaked, the grains were placed directly into boiling water either by direct dropping or in a wire cage or basket Or the container of presoaked rice and water was placed into the vigorously boiling water bath. The use of minimum cooking time erased the differences in rate of cooking among the samples.

Basmati-type rice tended to curl and disintegrate on overcooking so that undercooked rice was preferred to overdone rice in the elongation test (Baloch, 1980, unpublished data at IRRI).

Most respondents measured only the mean length of cooked and raw grains (Table 3). Siddiq considered the increase of length-breadth ratio during cooking of rice a sensitive indicator of the elongation characteristics of the rice grain (Sood and Siddiq 1980). Most respondents measured the cooked grains immediately after cooling but Fossati dehydrated the rice 24 hours in absolute ethanol and air-dried them before measuring.

Table 3. Details of elongation tests for milled rice.

Respondent	Presoaking time (minutes)	Boiling/Heating time[a] (minutes)	Remarks
Blakeney	0	Min	20 grains in test tubes with 20 ml water placed in boiling water bath.
Choudhury	0	Min	5 g in 135 ml boiling water in 250-ml beaker with watch glass; 10 grains measured.
Fagade/Amubode	0	23	20 grains measured for length and breadth (expansion ratio).
Fossati	0	30	5 g in graduated tube with 100 ml hot water placed in boiling water bath; dehydrated 24 hours in ethanol and airdried before measuring.
Kongseree	30	15	20 grains in wire basket in boiling water bath; 10 grains measured.
Lodh	0	20	5 g in tubes with 15 ml water placed in boiling water bath; 6 grains measured.
Milev	0	20-25	100 g in 750 ml in Buehler cooker.
Paule	10	15-18	25 grains in test tube with 20 ml water placed in boiling water bath; cooled in ice bath, kept overnight on moist filter paper; all grains measured.
Perez	30	15	Boiled in wire basket; 10 grains measured.
Pillaiyar	0	Min	20 grains measured.
Sekhon	0	Min	2 g in test tube with 20 ml water placed in boiling water bath; 10 grains measured.
Siddiq	10	15	1 grain in 5 ml water or 10 grains in 10 ml water in tubes placed in boiling water bath; measured after 5 minutes cooling.
Siwi/Damardjati	30	10	25 grains in glass cylinder with wire bottom placed in boiling water bath, cooled 24 hours, and 20 grains measured.
Tun	30	10	25 grains in test tube with 20 ml water placed in boiling water bath.

[a] Min = minimum cooking time.

Amylography

The Brabender Visco/Amylograph is basically a recording-cup torsion viscometer for measuring and recording apparent viscosity at fixed temperatures or at temperatures varied at a uniform rate usually 1.5°C /minute (Suzuki 1979a, Shuey and Tipples 1980). Although Amylograph originally referred to the instrument without a cooling accessory, the term is more popularly used for the Viscograph or the Visco/Amylograph, which has a cooling accessory (M. Brabender, 1979, pers. comm.)

Fifteen respondents had Amylographs (Table 4). In the original method the Wiley mill with a 0.5-mm screen was used to prepare the rice flour (Halick and Kelly 1959). The respondents used different grinding mills. Aside from particle size, the degree of starch damage during milling may differ among the various mills and has been shown to affect amylograph viscosity (Nishita and Bean 1982). Webb ground the sample not more than 1 day in advance.

Viscosity curve. The procedure of Halick and Kelly (1959) for determining viscosity dispersed 50 g rice flour in 300 ml water for 1.5 minutes in a Waring blender at medium speed and an additional 150 ml of water (total volume of 450 ml) was used to facilitate the transfer of the adhering flour from the blender into the Amylograph bowl (Simpson et al 1965). Blakeney used a milk shake machine with stirrer motor above the solution for the dispersion step (Table 4). Perez and Bhattacharya used a total slurry weight of 400 g (40 g rice flour/360 ml water) instead of 500 g without apparent change in Amylograph curves (Juliano and Pascual 1980; Bhattacharya and Sowbhagya 1981). Bhattacharya, Fossati, and Iwasaki used dry weight of rice flour in determining the weight of rice to use, thus requiring predetermination of the moisture content of the flour.

Bhattacharya and Sowbhagya (1979) recommended the running of several (5) Amylographs (5-16% dry basis) per sample or at least 2 at 6% and 11% dry basis. They suggested recently a reduction of paste weight from 500 g to 400 g (Bhattacharya and

Sowbhagya 1981). Results were expressed as a fraction of peak viscosity. From the plot of viscosity with paste concentration, values of various viscosity ratios at peak viscosity of 1000 BU were considered to give much more definitive information.

The cooking program of Halick and Kelly (1959) was heating from 30°C to 95°C at 1.5°C/minute (43.3 minutes), cooking at 95°C for 20 minutes, and cooling from 95°C to 50°C at 1.5°C/minute (30 minutes) for a total running time of 93.3 minutes/Amylogram. Variations from this program are given in Table 4 by Bhattacharya, Blakeney, Fagade/Amubode, Iwasaki, Kongseree, and Nishita/Bean. Japanese workers had a cooking time of only 10 minutes and cooled the paste back to 30°C (Tani et al 1969). To save time, Blakeney started his Amylograph 50°C. Similarly, Bhattacharya started at a 60°C setting for the thermoregulator during heating, reducing the heating cycle to 95°C to 23.3 minutes, reducing the cooking time at 95°C to 10 minutes, and cooling to 50°C with the thermoregulator initially set at 70°C (13.3 minutes) (Bhattacharya and Sowbhagya 1981). The total time was halved (about 47 minutes instead of 93 minutes) without appreciably altering the curve pattern. Previously, a similar abridged Amylogram had been proposed by Webb et al (1963) wherein heating started at 60°C, the cooking period was reduced to 10 minutes, and the cooling phase was deleted.

Data of interest are peak viscosity, final viscosity on cooking at 93-97.5°C, and viscosity on cooling to 50 or 30°C. From these three values, setback and consistency were calculated. Setback is viscosity cooled to 50 or 30°C less peak viscosity. Consistency is viscosity cooled to 50 or 30°C less final cooking viscosity at 93-97.5°C. Nishita/Bean recommended that a copy of the actual Amylogram, together with the data, be reproduced.

Webb and Kongseree kept the cooling probe down throughout the run, but turned on the cooling water only during the cooling phase, evidently to avoid the sudden drop in viscosity when the cooling probe was brought down into the paste during the start of cooling (Shuey and Tipples 1980). However, the Brabender Visco/Amylograph procedure recommended that the cooling probe be brought down only during the cooling phase.

Final gelatinization temperature. Final GT of rice starch was reported to be determined by using double the flour concentration of the regular Amylograph, according to Halick et al (1960) (Table 4). Final GT corresponded to the temperature of initial viscosity increase of the 100 g flour/400 ml

Table 4. Summary of details of rice Amylograph procedures.[a]

Respondent	Flour mill[b] sieve opening (mm)	Homogenizer used	Rice wt (g)	Water wt (g)	Initial temp (°C)	Max temp (°C)	Cooking time (minutes)	Final cooling temp (°C)
A. Regular method								
Bhattacharya	0.25R	Blender	24[c]	376	60[d]	95	10	50[e]
			44[c]	356	60[d]	95	10	50[e]
Blakeney	0.16B	Milk shake machine	50	450	50	95	20	50
Fagade/Amubode		Blender	50	450	25	92	15	50
Fossati	0.42	Blender	40[c]	400	30	95	10	30
Iwasaki	0.3	Blender	40[c]	450	30	93	10	30
Kongseree	0.42U	Blender	50	450	30[d]	95	20	50
Kurasawa	0.3	Blender	50	450	30	97.5	10	30
Mendes	C	Blender	50	450	25	92	20	n.a.[f]
Nishita/Bean	0.4J	Blender	50	450	30	97	20	50
Perez	0.42U	Blender	40	360	30	95	20	50
Sekhon	0.8F	Blender	50	450	30	95	n.a.[f]	n.a.[f]
Webb	0.5W	Blender	50	450	30[d]	95	20	50
B. Final gelatinization temperature								
Blakeney	0.16R	Milk shake machine	100	400	30			
El Bayâ	0.15	Blender	100	400	30			
Nishita/Bean	0.4J	Blender	100	400	30			
Webb	0.5W	Blender	100	400	30			

[a] Respondents Delgado, Husain, and Sekin recently acquired their Amylographs. [b] R = Raymond high-speed hammer mill, B = Brabender Quadramat roller mill, U = Udy cyclone mill, C = Culatti mill, J = Brabender Quadramat Junior mill no. 46, F = Falling number type 120 mill, W = Wiley mill no. 3. [c] Dry weight basis. [d] Cooling probe in down position throughout the run. [e] Temperature set initially at 70°C during cooling (13.3 minutes instead of 30 minutes). [f] No cooling probe.

of water slurry or equivalent. Nishita/Bean again routinely included a copy of the Amylograph curve with their report. Perez and Kongseree estimated final GT from the 10% Amylograph paste by subtracting 3°C from the temperature of initial increase in viscosity of the 10% paste (Juliano et al 1964b).

Laboratory parboiling

Parboiling tests were implied from the responses of Breckenridge, Pillaiyar, and Webb. Breckenridge steeped rough rice at 60-65°C (below starch GT) for 6 to 7 hours and steamed the steeped rice in an autoclave at 1.05 kg/cm^2 gauge pressure or 121°C for 10 minutes or at 100°C for 15-20 minutes at zero gauge pressure (Raghavendra Rao and Juliano 1970). Pillaiyar used rough rice presoaked at 65°C for 4 hours and parboiled at 70, 80, 90, 100, 110, and 120°C for 5 or 10 minutes (Pillaiyar and Mohandoss 1981a). Webb parboiled samples by treating dry rough rice (15-25 g or more) in cheese cloth bags at a reduced pressure of 25-50 mm mercury for 30 minutes in a retort chamber, steeping it in 60°C water at 5.25 kg/cm^2 air gauge pressure for 2 hours, and draining and blowing out excess water with compressed air. The steeped grain was steamed 10 minutes at 1.05 kg/cm^2 gauge pressure or 121°C and the parboiled samples were dried slowly at 20°C and 55-60% relative humidity (Webb 1979).

TEXTURE EVALUATION OF COOKED RICE

A critical variable in the determination of texture of cooked rice is the method of preparation. In Southeast Asia, housewives cook their rice in an amount of water that is adequate to provide the texture desired, whereas in the Western world, rice is boiled in excess water until the center of the grains is translucent.

Cooking methods with adequate water

Although many respondents used the rice cooker with or without a water jacket thermostat, a cooker was not necessary. Most of the water-rice ratios were below 2.0, except for Bhattacharya and Pillaiyar (Table 5). Waxy and japonica (low-amylose) rices generally had water-rice ratios of 1.5 or lower. Perez and Paule varied the water-rice ratio depending on the amylose content of the raw rice: 1.3 (26 ml/20 g) for waxy rice; 1.7 (34 ml/20 g) for low-amylose rice; 1.9 (38 ml/20 g) for intermediate-amylose rice; and 2.1 (42 ml/20 g) for high-amylose rice (Juliano and Pascual 1980). Respondents used water-rice ratios of 1.5-2.5 for indica rices.

The number of rice washings before cooking varied from 0 to 4 times. Kongseree washed the waxy rice twice before presoaking and twice more before steaming. Presoaking was practiced by many respondents, which reduced cooking time particularly for parboiled rices (IRRI 1980, Desikachar and Subrahmanyan 1961, Santos et al 1980).

Cooking time varied from 7 to 45 minutes, depending on the time required for the water to be completely absorbed by the rice. A few respondents, however, such as Breckenridge, Kurasawa, Paule, Perez, and Pillaiyar used the cooker as a double boiler and boiled the rice for the same period of time. The temperature in the inner pot probably did not exceed the boiling water temperature until the time no free water was present at the bottom of the pan. Actual water absorption of the rice would not depend on other variables such as tightness of the cooker cover, and amount of water in the outer pot.

An important feature of this cooking method which was absent in the excess-water method was the standing time after boiling (Table 5). Presumably further cooking occurred during this period, because rices differing greatly in cooking time in the excess-water method showed comparable texture in the rice cooker method boiled 20 minutes with excess water in the outer pot. Samples for texture determination were usually taken from the center of the cooked mass because the bottom and top portions were not evenly cooked.

To prevent water loss during cooking, Cheigh used sealed 12 mm (inside diameter) x 28 mm brass vessels able to endure 140°C oil bath (Cheigh et al 1978). Webb used Pabst rice cookers with reflux condenser for cooking and weighed the cooked rice to check water absorption.

El Bayâ and Sekin used the 176°C oven method of Batcher et al (1956, 1957, 1963a,b) wherein 100 g rice was cooked in 220-260 ml water in covered glass or aluminum dishes at 176°C for 28 minutes, followed by 5 minutes without a cover. The water required was predetermined from water uptake by boiling 8 g rice in 160 ml boiling water for 20 minutes (Batcher et al 1956). Based on actual water loss during oven heating of 0.35 g water/g rice, El Bayâ calculated that for a water uptake ratio of 3.15 (2.15 g water/100 g rice), for example, the water-rice ratio for the oven method was 250 g water/100 g rice.

Bhattacharya used a water-rice ratio of 2.5 for 16-18 g rice in a 121 mm diam stainless steel dish with an aluminum cover, which gave a rice layer only 2-3 grains thick. The dish was arranged in a special cooking stand and steamed 45 minutes at zero gauge pressure to attain 73% moisture, which was the moisture content of cooked rice boiled in excess water to minimum cooking time (Bhattacharya et al 1978). The cooked rice was blotted and stirred gently with a glass rod at 0, 5, 15, and 60 minutes after cooking to prevent grain-to-grain adhesion.

Additives were reported on nonwaxy rices by two respondents. Victoria added 5 ml (1 teaspoon) salt and 10 ml (2 teaspoons) oil to the cooking mixture and Webb added 6 g sodium chloride (Table 5).

Harahap precooked 200 g milled rice with 300 ml tap water in a pan for 5 minutes to absorb the water; Siwi/Damardjati washed rice 2-3 times and

boiled 100 g in 150 ml water until all the water was absorbed by the rice. After cooking the undercooked rice was placed in an Indonesian-type perforated pan and steamed for 30 minutes at zero gauge pressure. The samples were removed from the pan, drained, and cooled for 10-15 minutes before serving.

Waxy rices were prepared differently by five respondents. Perez and Tsuji boiled the waxy rice in water but Kongseree presoaked and steamed it and stored it for 45 hours before sensory evaluation. Husain and Vega prepared coconut rice cakes. Husain washed 400 g or less of waxy rice with water, soaked it in water overnight, then drained and steamed it in a steamer until cooked. Coconut milk was added (with a little salt) to the hot rice to the desired consistency and mixed well. Vega washed 237 ml (1 cup) waxy rice with tap water, drained it, and placed it in the inner pot of a rice cooker with 5 ml (1/3 tablespoon) coarse salt and 315 ml (1 1/3 cups) coconut milk (del Mundo 1979) and stirred. The mixture was precooked 15 minutes with 40 ml water in the outer pot and then stirred and left undisturbed for 10 minutes. Cooked rice (23 ml or 1 1/2 tablespoons) was wrapped in wilted banana leaves, arranged in a steamer and steamed for 30-35 minutes, and stored 10-12 hours before serving.

Cooking methods in excess water

Cooking in excess water was done usually up to minimum cooking time to insure that the core of the milled rice had been gelatinized (Table 6). Benedito de Barber used 19 minutes in a 175-180°C oven for Spanish rices, which have low GT or cooking times below 23 minutes (Primo Yufera et al 1960). Schneeweiss used 10-15 minutes but simmered the cooked rice for 15-25 minutes more. With this method, water content of cooked rice was about 73-75%, much higher than most of the methods using a cooker type unit. Only Blakeney added salt to the cooking mixture. The International Cooperative Test on Instrument Methods for Cooked-Rice Texture

Table 5. Details of cooking methods with water the rice absorbs.

Respondent	Water (g)	Rice[a] (g)	Water-rice ratio	Washings (no.)	Presoaking time (minutes)	Outer-pot water (g)	Cooking time[b] (minutes)	Standing time (minutes)	Reference(s)
Bhattacharya	40-45	16-18	2.5	0	0	Steam	45	0	Bhattacharya et al 1978
Breckenridge	42	20	2.1	0	0	200	21	10	
	42	20P	2.1	0	0	240	25	10	
Cheigh	1.4	1.0	1.4	0	30	None[c]	20	0	Cheigh et al 1978
Crisostomo	360-390	200	1.8-1.95	1	0	40	Therm.	15	del Mundo 1979
Ebata	18-21	15	1.2-1.4	2	60	None	Therm.	30	Ebata and Hirasawa 1980
Husain	300	400	1.5	3	0	None	Therm.	10	
Iwasaki	30	20	1.5	0	30	50	Therm.	20	Endo et al 1976,1980
	1.2	0.6	2.0	0	30	50	Therm.	10	
	1200	1000	1.2	Several	30-60	50	Therm.	30	
Kongseree	0	200Wx		2 + 2	720	Steam	40	0	
	340	200	1.7	2	0	50	Therm.	30	
Kurasawa	35	25	1.4	3	30	XS	15		Sumino et al 1979
Mossman	10-12	8	1.25-1.5	0	0	Steam	20	10	Mossman et al 1982
Paule	26-42	20	1.3-2.1	0	0	200	20 (4)	10	Juliano and Pascual 1980
Perez	26-42	20	1.3-2.1	0	0	200	20 (4)	10	Perez and Juliano 1979
Pillaiyar	10-25	5-10	2.0-2.5	0	0	375	7	10	Pillaiyar and Mohandoss 1981c
	10-25	5-10P	2.0-2.5	0	0	375	10		
Suzuki	30	20	1.5	1	60	100	Therm.(3)	15	
	450	300	1.5	1	60	100	Therm.	15	
Tsuji	55-70	50	1.1-1.4	1	30	None	Therm.	10	
	40-55	50 Wx	0.8-1.1	1	30	None	Therm.	10	Tsuji 1980, 1981
Vega	360-390	200	1.8-1.95	1	0	40	Therm.	15	
Victoria	474 ml	237	2 (V/V)[d]	0	0	None	15	35	del Mundo 1979
Vidal	≤180	100	≤1.8	1	0	None	Min	15	
Webb	500	250[e]	2.0	0	0	None	20	0	

[a]P = parboiled, Wx = waxy rice. [b]Therm. = thermostat control of cooking time, Min = minimum cooking time. Figures in parentheses refer to number of samples per run. [c]Cooked in sealed vessels. [d]With 1 tsp salt and 2 tsp oil. [e]With 6 g NaCl in Pabst rice cooker with reflux condenser.

adapted a water-rice ratio of 8 as reported by Benedito de Barber, Blakeney, Launay, Perez, Suzuki, and Webb (Juliano et al 1981b). The cooked rice was usually removed from the cooking water immediately after the minimum or optimum (minimum + 2 minutes) cooking time.

Sensory evaluation of cooked rice

Sensory evaluation of cooked rice reported by 26 respondents were mainly by judges or panel members rather than consumers (Table 7). Kurasawa and Pillaiyar reported assessment on both warm and stored cooked rice, whereas Kongseree reported mainly assessment of cooked waxy rices stored 45 hours. Cooked nonwaxy rices were usually assessed within 1 hour after cooking.

Cooked-rice characteristics frequently assessed were aroma, flavor or taste, tenderness or hardness, cohesiveness or stickiness, appearance, and whiteness or color (Table 7). Kongseree and Pillaiyar used the 7-point scale of Juliano et al (1965). El Bayâ and Sekin used the 9-point scale of Batcher et al (1956, 1957). Iwasaki and Suzuki used 24 panelists with an 11-point score using whole numbers from -5 to +5 (Yoshikawa and Nishimura 1965). When fewer panelists were available, Suzuki used the Wiley et al (1957) procedure of multiple comparison or collaborative panel testing and the data obtained were calculated by rating test. Diên compared the flavor of cooked rice against the standard Vietnamese aromatic rice Tam Thom.

For consumer tests by Crisostomo and Vega, the 6-point scoring system of del Mundo (1979) and del Mundo and Juliano (1981) was used. The ranking scores of Larmond (1977) were used and the samples were presented in a randomized manner. Consumers gave three reasons for choosing the best of up to five samples ranked in the order of decreasing importance based on the scoring system for six properties (Table 7).

Aroma test

In addition to the routine taste panel evaluation for aroma as part of the assessment of cooked rice by several respondents (Table 7), separate aroma tests were reported by seven respondents. The evolution of aroma was facilitated by boiling in water, except for Siddiq, who added 10 ml 1.7% KOH to 2 g brown rice and scored aroma after 10 minutes (Sood and Siddiq 1978). Boiling time ranged from 10 to 20 minutes. Blakeney, however, warmed the rice to 40-45°C for only 5 minutes before scoring (Nagaraju et al 1975). Descriptive scores were either absent, faint, normal, and strong (IRRI 1971) or in comparison with a standard aromatic variety.

Standard aromatic varieties. Lodh, Paule, Sekhon, Siddiq, and Vidal used Basmati 370 as standard; Kongseree used Khao Dawk Mali 105, a Thai variety, as a standard. Indian scientists reported Basmati 370 as a standard aromatic variety. Khao Dawk Mali 105 was used in Thailand; Dulhabhog (BR5) in Bangladesh; Tam Thom in Vietnam; Hieri, Hendoyori, and Eigoh in Japan; Seratus Malam and Rojolele in Indonesia; and Azucena, Milagrosa, and Malagkit Sungsong in the Philippines.

Instrument methods for cooked-rice texture

Twelve methods were reported for instrument determination of cooked-rice texture.

Instron tester. The Instron tester (Instron Ltd., Coronation Road, High Wycombe, Bucks, England) has a mechanical drive system, a load cell for measuring forces generated either in compression or tension, and a recorder. The mechanical drive system is a horizontal crossbar (crosshead) driven vertically.

Of the five respondents who gave details of their Instron method for cooked rice, Benedito de Barber, Blakeney, Launay, and Perez measured hardness; Launay, Mossman, and Perez measured stickiness or adhesiveness of cooked rice (Table 8). Most methods, except the hardness test of Launay, which required only 4 grains/run, required 2 g or more of cooked rice. Actually, single-grain hardness test may be run with the Instron by the texture profile analysis or double-bite technique (Blakeney 1979).

Perez recently changed the stickiness procedure reported earlier based on a fixed compression clearance of 0.4 mm with the OTMS 6.9 cm x 6.9 cm plunger, which overtaxed the 5-kg load cell and resulted also in variable compression pressure among the cooked samples (Perez and Juliano 1979). A constant pressure of 4 kg for 20 seconds was employed using a 3.6 mm diam plunger. The constant compression pressure method was also used by Mossman (Table 8) and Keneaster and Chung (Juliano et al 1981b) and was an adaption of the beam balance stickiness test of Kurasawa et al (1962).

Beam-balance method for stickiness. Kurasawa used a trip-pan counterscale to measure stickiness of cooked rice (Kurasawa et al 1962, Sumino et al 1979). With the left weight pan (A) and the right metal pan (B) balanced, 10 cooked grains (cooked rice stored overnight at room temperature) were arranged on the plywood board and a smooth Bakelite plate (D) was pressed below pan B by putting a 500- or 800-g weight on B for 2 minutes. The weight was removed carefully and a beaker placed on weight pan A and water added to it until plate D was detached from the rice grains. The weight of the beaker plus water was the measure of stickiness. The mean of 10 measurements was reported.

Pabst texture tester. The Pabst Texture Tester (Performance Engineered Products, Inc., 8928 Spring Branch Drive, Unit A 3, Houston, TX 77080, USA) is an instrument for compressive/shear force measurement and force distribution analysis of bite-size food units. Webb used the Pabst TT-2 tester, with a Kramer-type shear cell of 2.54 cm

Table 6. Details of rice cooking methods in excess water.

Respondent	Rice weight[a] (g)	Water (ml)	Cooking time[b] (minutes)	Reference(s)
Benedito de Barber	18	200	19 (175-180°C oven)	Primo Yufera et al 1960
	50	400	Min + 2	Juliano et al 1981b
Blakeney	100	2000[c]	Min + 2	Blakeney 1979
	100	800	Min + 2	
Choudhury	5	135	Min	
Delgado	10	50	25-30	
Diên	20-30 grains	20	10-20	
Fagade/Amubode	5	40	23	Dimopoulos and Muller 1972
Laignelet	2	250	Min + 2 and Min + 12	Laignelet and Feillet 1979
Launay	80	640	Min + 2	Juliano et al 1981b
Milev	100	750	Optimum (Büehler cooker)	Borasio 1965
Perez	50	400	Min + 2	Juliano et al 1981b
Pillaiyar	3	30	Min	Bhattacharya and Sowbhagya 1971
	3P	30	Min + 2	
	10	80	Min	
Schneeweiss	1:10		10-15; simmer 15-25	
	1:10Q		7	
Sekhon	2	20	Min	Bhattacharya and Sowbhagya 1971
Suzuki	25	200	Min + 2	Juliano et al 1981b
Tsuji	50	400	Min + 2	Juliano et al 1981b; Tsuji 1980, 1981
Webb	40	320	Min + 2	Juliano et al 1981b

[a] P = parboiled, Q = quick cooking rice. [b] Min = minimum cooking time (Ranghino 1966). [c] With 4 g NaCl.

along any diagonal and with 16 shear planes of 0.16 cm nominal spacing, for hardness determination using 13 g cooked rice and a 13.6-kg load cell at a test stroke velocity of 0.6 cm/second (Webb 1979, Juliano et al 1981b). Firmness was the maximum force in kilograms obtained in the compression-extrusion curve, which occurred before the onset of extrusion. Test cycle time was 9 seconds. The plunger traveled about 37 mm, of which 23 mm was compression and 14 mm was extrusion. Chart paper advance was also set at 0.6 cm/second.

Texturometer. The General Foods-Zenken Texturometer (Zenken Co., Ltd., Kyodo Bldg, No. 5, 2-Chome Honcho, Nihonbashi, Chuo-Ku, Tokyo 103, Japan) is a denture tenderometer, which simulates the motions of mastication by means of a mechanical chewing arrangement (Suzuki 1979b). It consists of a mechanical masticator, a sensing device placed under the platform supporting the food, a 1/16-hp motor driving the arm holding the plunger, and a high-speed recorder for the force-time curve that indicates the behavior of the test food under the disintegrating action of the plunger. Sample sizes of 1 grain to 20 g cooked rice were used by 5 respondents (Table 9). The plunger was either Lucite or nickel and the lower plate was of aluminum.

From the curve of the first and second chew (Fig. 1), hardness was the height of the first chew normalized to a 1-volt input. Adhesiveness was the area A3, in arbitrary units, of the negative peak below the baseline of the profile after the first

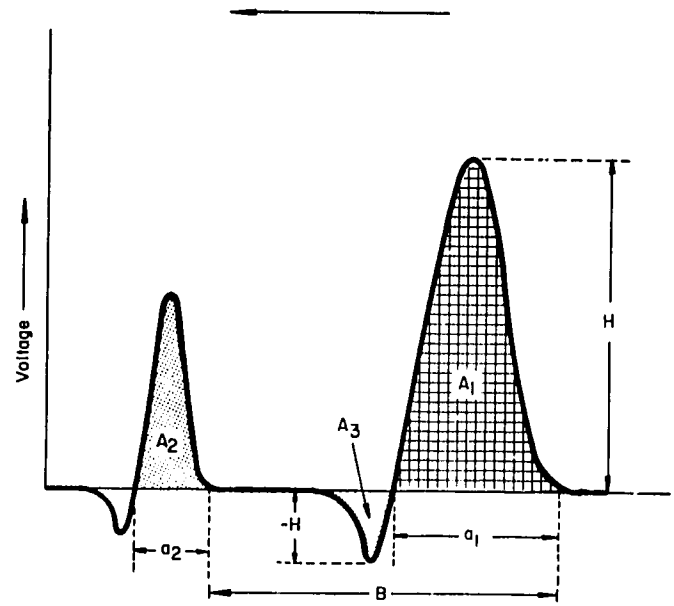

Fig. 1. A Texturometer curve for cooked rice (Ebata and Hirasawa 1980). H = hardness, A_2/A_1 = cohesiveness, A_3 = adhesiveness, -H = adhesive power (stickiness), C-B = springiness, where C = time constant for inelastic material, H x A_2/A_1 = gumminess, H x A_2/A_1 x (C-B) = chewiness.

Table 7. Checklist of sensory evaluation methods of cooked rice.

Respondent	Judges or consumers[a] (no.)	Samples[b] (no.)	Score[c]: Aroma/ smell	Flavor/ taste	Tenderness/ hardness	Cohesiveness/ stickiness	Whiteness/ color	Gloss	Appearance	Overall rating	Other characteristics[d]
Breckenridge	5J	3D			5	5			+	+	Acceptability
Choudhury			8	9	7	9			9		
Crisostomo	30C	5	6	6	6	6	6	6			Acceptability (2)
Delgado			+	+	+	+	+				
Diên				+							
El Bayâ	3-20J	20		9	9	9			9		
Fagade/Amubode	30J	5		+	+	+	+	+		+	Cleanliness, off-flavor
Harahap	15-20J	10								+	
Husain	6J	6	+	+	+	+	+	+	+		Acceptability and ranking
Iwasaki	24J	4		11	11	11			11	11	Palatability (11)
Kongseree	5J	6D[e]	9		9	9	9	9			
Kurasawa	J	4[f]	5	5	5	5	5	5	5	5	
Lodh	J		5	3	3				4	3	Consistency (3), chewiness (3)
Milev	7J	4[g]		3							
Paule	C	4	4		4	4	4	4			
Pillaiyar	5J	12[h]			+						
Schneeweiss	3J		+	+	+		+		+		Uniform swelling and consistency
Sekhon	J		4			4			4		Integrity (4)
Sekin	J			9	9	9			9		
Siddiq	100-200C	3	2			2	2		4		Size and shape (3), expansion (3), splitting (3), curling (3), acceptability (2)
Siwi/Damardjati	8J	5	5	5			5				Hardness-stickiness ratio (5)
Suzuki	24J	4		11	11	11			11	11	Palatability (11)
	10-12J	10Q		5							
Vega	30C	5	6	6	6	6	6	6		+	Acceptability (2)
Victoria						2					Grain separation (2)
Vidal				+	+	+					
Total			13	18	18	18	11	7	12	8	

[a] J = judges, C = consumers. [b] D = duplicate. [c] Numbers refer to number of points in the judging scale. A "+" indicates that property is assessed but the scoring system was not reported by respondent. [d] Figures in parentheses indicate number of points in the scoring scale. [e] Waxy rices are assessed 45 hours after steaming. [f] Assessed twice at 0.25 hours and 24 hours after cooking. [g] Assessed at 0800 hours. [h] Assessed 1 hour and 6 hours after cooking.

Table 8. Details of Instron methods for cooked-rice hardness and stickiness.

Respondent	Details of hardness and stickiness tests
Benedito de Barber	Setback extrusion cell with 50.9 mm diam and 3.15 mm annulus gap. Hardness was the maximum force in kg required for back extrusion of 50 g cooked rice in duplicate at a crosshead speed of 20 cm/minute and a 0- to 50-kg load cell.
Blakeney	Standard Kramer shear cell with 10 3-mm-thick blades, 50-kg load cell. Hardness was the maximum force for compression and extrusion of duplicate 100 g cooked rice at crosshead speed of 10 cm/minute (Blakeney 1979).
Launay	Hardness was calculated from duplicate 4 grains compressed with a plunger at a speed of 0.5 cm/minute as the slope of the force-compression curve (Newton/m) measured at a force of 0.7 Newton (Lisch and Launay 1975). Adhesiveness was measured on 150 g cooked rice in a 6.6-cm diam beaker compressed with a 5.6 cm diam stainless steel plunger at 5 cm/minute until a force of 13.63 Newtons was reached. The position of the plunger was adjusted so that the resultant force was zeroed and made constant. The plunger was raised at 5 cm/minute and the maximum force in Newtons recorded as adhesiveness.
Mossman	CB compression cell. Cooked rice (2 g) pile pressured with crosshead speed of 0.5 cm/minute until 640 g pressure was reached and maintained for 10 seconds (Mossman et al 1982). Crosshead was moved up at 0.5 cm/minute and the area of pulling force with distance in g.cm was stickiness index. Chart speed 25 cm/minute zeroed at middle with ± 1000 g chart range.
Perez	Modified 50-m^2 Ottawa Texture Measuring System cell (perforated plate with 6-mm holes) with 4 spacers and 2.5 cm x 2.6 cm plunger, 0- to 50-kg load cell, crosshead speed 10 cm/minute, duplicate 17 g cooked rice. Hardness was maximum force in kg required for extrusion (Perez and Juliano 1979, Juliano and Pascual 1980). Stickiness was measured using duplicate 2.5 g cooked rice compressed at 10 cm/minute with 3.6 cm diam plunger to constant compression force of 4 kg maintained for 20 seconds. Stickiness was the area in g.cm of the curve of pulling force with distance down to 20 g force at crosshead lifting speed of 10 cm/minute using a 5-kg load cell.

chew and represented the work necessary to pull the plunger from the sample. Adhesive power (stickiness, Okabe 1979) was the height of this negative peak. Cohesiveness was the ratio of the area, in arbitrary units, under the second peak and the area under the first peak (A_2:A_1). Springiness or elasticity was the difference between the distance from the initial sample contact to the contact on the second chew, and the distance for the same measurement made on a completely inelastic standard material such as clay. Gumminess was the product of hardness and cohesiveness, and chewiness was the product of gumminess and springiness or hardness x cohesiveness x springiness.

Differences in clearance between plunger and the aluminum plate, sample height, voltage, and bite speed were evident (Table 9). In addition, definitions of terms were not identical among the respondents. Ebata defined springiness as the ratio of the width of the second-bite curve (a_2) to the width of the first-bite curve (a_1) and used this springiness term to calculate chewiness (Ebata and Hirosawa 1980). Kurasawa defined springiness as B in Figure 1 and called adhesive power (stickiness) as viscousness (Sumino et al 1979). The details of the Texturometer GTX2 parameters of Kurasawa were not described by Sumino et al (1979).

Tensipresser. The Tensipresser TPP-50 (Taketomo Electric Co., 33-5, Takatanobaba-1-chome, Shinjuku-ku, Tokyo 160, Japan) is a tension-compression testing device used by Tsuji wherein at least 10 grains were measured individually for 2 batches of cooked rice at 50 and 90% compression (Tsuji 1980, 1981). The grains were sampled from the center of the upper layer (1-2 cooked layers below the surface) of cooked rice. The 25-mm diam needle plunger had a speed of 240 mm/minute. The thickness of each individual grain was measured and the plunger travel distance was adjusted for each test sample to give the desired compression depth (50 and 90%). Care was needed to have the plunger fully contact the outer surface of the grain. Because rice grains do not have a flat surface, the area of contact with the plunger increased as the compression (or biting) progressed. Data recorded were hardness, cohesiveness, adhesiveness, and springiness at 50 and 90% compression.

Viscoelastograph. The Chopin-INRA Viscoelastograph (Tripette and Renaud, 39, Rue Jean-Jacques-Rousseau, 75038 Paris Cedex 01, France) is used for evaluating the viscoelastic properties of food products. A fixed load is applied perpendicularly to the sample on the sample holder, then the load is removed. The strain of the sample as a function of time is determined by measuring its change through a displacement gauge. Laignelet placed 3 cooked grains in the sample holder (Laignelet and Feillet 1979) and the Viscoelastogram was recorded with a load of 700 g for 40 seconds followed by a recovery time of 20 seconds without load. This gave a strain-time curve showing the change in thickness of the sample relative to the time during and after loading. Equations used:

$$\text{Firmness (F)} = 100 \times (e_1/E)$$
$$\text{Elastic recovery (ER)} = 100\ (e_2-e_1)/(E-e_1)$$

where E = initial thickness (mm), e_1 = thickness (mm) before loading off, and e_2 = final thickness (mm).

Samples used were rices cooked to minimum cooking time plus 2 minutes and to minimum cooking time plus 12 minutes.

Parallel plate plastometer. A Parallel Plate Plastometer (Ueshima Co., Wasedatsurumaki-cho 362, Shinjuku-ku, Tokyo 162, Japan) with temperature regulation at 35 ± 1°C was used by Kurasawa. It measures deformation of a cooked-rice sample between horizontal plates under load, and the recovery when the weight was removed (Chikubu et al 1964). Rice was cooked in a 5 cm diam x 5 cm stainless steel cylinder with removable bottom and was left 1 hour at 38°C before measurement. Nonwaxy rice (10 g) was soaked in 17.5 ml water in the cylinder and cooked in rice cooker with 33 ml of water in the outer pot and then left 10 minutes. Waxy rice (10 g) was soaked in water for 30 minutes in a cylinder with wire matting and steamed with 66 ml water in the outer pot.

The upper and lower parallel plates were first adjusted so that the spindle connected to the upper plate moved freely. Next a gauge as thick as the test material was inserted between the plates and the lower plate gradually raised so that the weight of the load was imposed on the rice when the upper level was horizontal. A balance weight was then shifted to fix the load (200 g, 400 g, 600 g, and instant deformation). The dial gauge was then attached to the top of the shaft by turning the handle at the head. The double door of the plastometer was then closed to raise the temperature to 35°C; the rice was placed with the lever raised. The lever was fixed level with the dial gauge set at zero. When the pressure was given by removing a stopper-pin, the degree of deformation was shown in a dial gauge.

Iwasaki commented that the plastometer required much skill and has poor reproducibility.

Viscolasticity was calculated as follows:

$$\text{Viscosity (poise)} = \frac{k \times 10^6\ W}{mv^2}$$

$$\text{Elasticity (dyne/cm}^2) = \frac{w \times 980}{H}$$

where W = weight of load (kg),
w = weight of load (g),
$m = \frac{b}{a} = \frac{h^4}{t}$ inclination (cm^4/second),
v = volume of test material (cm^3),
h = thickness of test material (cm),
H = distortion of test material (cm), and
k = constant.

Haake consistometer. The Haake consistometer (Dieselstrasse 6, D-7500 Karlsruhe 41, Germany) is a tester for viscosity and hardness measurements on highly viscous materials. The method used by Bhattacharya was as described by Manohar Kumar et al (1976) but using a perforated plunger and measuring body VIIC (Hampel 1968) with minor modification. The test was in a constant-temperature room (27°C). Cooked rice (20 g) was packed uniformly in the cylindrical sample holder (3-5/sample) and kept in a water bath equilibrated with the room temperature (27°C) until used. After fixing a cylinder in the Haake consistometer, the plunger was made to penetrate the rice mass until the dial gauge had a reading of 5 mm at which the plunger was stopped for 1 minute for equilibration. The

Table 9. Texturometer parameters for measurement of texture of cooked rice.[a]

Respondent	Cooked-rice sample	Plunger Material	Plunger Diam (mm)	Voltage (V)	Clearance (mm)	Sample height (mm)	Bite speed (no./min)	Properties measured[b]
Cheigh	1 grain	Lucite	18	1.5	0.25	2.0	24	H
Ebata	3 grains	Nickel	20	1.5-2	0.2	2.0	6	A and AP
	3 grains	Nickel	20	1.5-2	0.5	2.0	6	H, A, S, and consistency
Iwasaki	20 g	Lucite[c]	18	1[d]		19[e]	12	H, C, A, S, and H/A
	0.6 g	Lucite[c]	18	1.5	1.0	10[f]	12	H, A, H/A, AP (stickiness), H/AP, and C
Kurasawa								H, A, AP, elasticity, and C
Suzuki	30-40 grains	Lucite[c]	18	3 ± 1	0.5-1.0	3.5[g]	12	H and AP (stickiness)

[a] Chart speed all at 750 mm/minute. [b] H = hardness, A = adhesiveness, AP = adhesive power, S = springiness, C = cohesiveness. [c] With dual arm (Suzuki 1979b). [d] 15 V for adhesiveness (Endo et al 1980). [e] Aluminum dish 19.5 mm deep and 71 mm in diameter (Endo et al 1976). [f] Aluminum dish 30 mm in diameter, 10 mm high, and 1 mm thick (Endo et al 1980). [g] Aluminum dish 24 mm in diameter and 3.5 mm deep.

requisite load or weight (1-10 kg, usually 5 kg) was then loaded into the lever arm and the plunger released. The time taken for the plunger to travel from the 10-mm to the 25-mm mark on the gauge was recorded, with intermediate readings at 15 and 20 mm. The average time taken by the plunger to travel a distance of 5 mm between the 10- and 20-mm marks was calculated and the consistency (apparent viscosity) of the cooked rice was calculated from the formula

$$\text{Consistency (cps)} = \frac{GTK \times 1000}{S} = 0.4\ GT \times 10^5$$

where G = load (kg),
T = time of penetration (seconds),
S = distance of penetration (5 mm), and
K = plunger constant (200).

Different weights were used for the test to evaluate the effect of the shear force. All the cylinders prepared at a time were read consecutively without washing the plunger.

Extrusion test. Pillaiyar used an improvised extrusion test (Mohandoss and Pillaiyar 1980a). Triplicate cooked parboiled rice (15 g) samples were placed in an extruder consisting of a 5-mm-diam hollow cylinder of anodized aluminum with a movable plunger, and a detachable perforated bottom disc having 36 equally distributed holes of 1-mm diameter. A lever attached to a movable arm with a loaded weight of 5 kg was placed on the plunger, which extruded the rice for exactly 5 minutes. The material that was extruded was collected in a Petri dish below the extruder, weighed, and expressed as grams per gram cooked rice. All sides of the base wherein the Petri dish rested were provided with glass doors. Cooked raw rice and cooked rice previously parboiled at 70 and 80°C were more or less entirely extruded within 5 minutes, but cooked severely parboiled rices were not.

Dropping device method. A simple dropping device test was reported by Pillaiyar to differentiate cooked parboiled rices based on their tenderness (Pillaiyar and Mohandoss 1981d). A cooked sample (15 g) was kept inside a 4 cm x 4 cm x 4 cm box and dropped -- by releasing the bottom flap doors -- from a height of 50 cm onto a 60 cm x 60 cm glass plate. The glass plate had concentric circle markings 5 cm apart. The grains that fell in the inner and outer circles were collected separately and weighed immediately. The cooked severely parboiled rices had more rice in the outer rings whereas cooked rices from raw and mildly parboiled rices occupied the core and second rings. From the percentage of the samples that occupied the two innermost rings and comparing it to that of the reference sample, the texture of the test sample was indicated as soft or hard and the suitability of the sample to various consumer groups was indicated.

Pressing device method. Pillaiyar used a pressing device to compare the degree of cooking of severely parboiled rices (Pillaiyar and Mohandoss 1981b, c). Four to six cooked grains were withdrawn from boiling water bath every 5 minutes, blotted on a filter paper, and immediately placed between 2 10 cm x 10 cm glass plates and pressed by dropping a 2.5-kg load on them. The 2.5-kg load, a round steel shaft 6.5 cm diam x 8.0 cm, was mounted on vertical rails and dropped from a 10-cm height. The presence or absence of opaque core and the time required for its disappearance in samples exhibiting opaque core during the initial stages of cooking were noted. The perimeter of the pressed grains was drawn on tracing paper and the area measured by planimeter. Cooking and pressing of test samples continued until the pressed area approached that of the mildly parboiled reference sample (completely soaked rough rice steamed 10 minutes at zero gauge pressure). The time needed to cook the experimental sample to attain a pressed area similar to the test sample was taken as the absolute cooking time. Pressed area of cooked parboiled samples differed widely (from 1.74 cm^2 to 0.66 cm^2) with the degree of parboiling.

Sieve test for stickiness. Bhattacharya and Fagade/Amubode used the method of Manohar Kumar et al (1976), with modifications, to test stickiness of cooked rice. Wire sieves in the initial procedure were not suitable due to sticking of rice particles and, hence, were replaced by perforated plates. Those were initially stainless steel (Bhattacharya et al 1978) but subsequently brass perforated plates (gauge 16) were cut, built into Bühler sieve frames (27.9-cm diam), and buffed moderately. Two sets of sieves with round perforations of 8.00 and 7.25 mm diameter each were made and a pair was used for 1 test.

Two such pairs, with a collecting plate below each pair, were mounted in a laboratory Bühler sifter type MLU-300 and used simultaneously. Cooked rice (25 g) was weighed into the center of the top (8 mm) sieve and sieving was carried out for exactly 2 minutes at 180 rpm. The grains retained on each sieve were then carefully collected and weighed and the index of stickiness was expressed as percent by weight of rice retained by each sieve. Each sample was run at least twice and the mean value taken. Values of both sieves were used, because although the top 8-mm sieve gave better differentiation among sticky samples, the bottom (7.25 mm) sieve seemed to differentiate the less sticky rices better. Following each test, the sieves were washed thoroughly with water, wiped dry, brushed with ethanol, wiped, and finally dried in air to avoid adherence of particles of cooked rice or of water to the sieve.

Alyoshin/Romanov reported studies to develop a method for firmness and plasticity of cooked rice.

INDIRECT METHODS FOR COOKING QUALITY

A checklist of respondents who reported their indirect cooking quality tests is given in Table 10.

Amylose content

Thirty respondents reported running amylose assay on milled-rice flour based on the intensity of the blue colored complex of amylose with iodine at

neutral to acid pH (Table 10). Most of them followed the method of Williams et al (1958) simplified by Juliano (1971) and Perez and Juliano (1978) either manually or with an AutoAnalyzer at 620 nm on the milled-rice flour (1 mg/ml dispersion) in NaOH. Flour (100 mg) was weighed in duplicate in 100-ml volumetric flasks. Then 1 ml of 95% ethanol was added, taking care to wash down any flour adhering to the sides of the flask, followed by 9 ml of 1 N NaOH. The suspension was either heated for 10 minutes in a boiling water bath or kept at room temperature overnight to gelatinize the starch. After cooling or standing, the samples were diluted to volume with distilled water and mixed well. Amylose content of an aliquot of this dispersion was determined either manually or with an AutoAnalyzer (Juliano et al 1981a). Potato amylose/waxy rice starch mixtures were used for the standard curve to compensate for interference of amylopectin-iodine complex with the assay (Juliano 1979a). Nondefatted rice flours of known amylose content may be used routinely for the day-to-day standard curves.

Variations of this method were reported (Juliano 1979a). Webb used a completely automated system (Webb et al 1979) but returned to an AutoAnalyzer II system with manual sample dispersion to improve total sample output. Samples were also defatted in Soxhlet extractors. Siddiq ran single-grain genetic analysis of breeding lines (Kang 1975, Puri et al 1980). Bhattacharya used the method of Sowbhagya and Bhattacharya (1971, 1979) and also determined water-insoluble amylose (Bhattacharya et al 1978, Shanthy et al 1980). Samples dispersed in alkali were individually neutralized by titration with acid to phenolphthalein end point instead of acetic acid addition. Carbon tetrachloride defatting of the alkaline dispersion was also proposed instead of bulk Soxhlet defatting with 95% ethanol.

Fagade/Amubode determined water-soluble amylose (starch-iodine blue color) of rice flour at 77°C (Halick and Keneaster 1956) and at 100°C (Juliano et al 1968) after heating for 10 minutes using iodine colorimetry in acetate buffer. Bhattacharya, Fagade/Amubode, and Kongseree also measured boiling-water-soluble amylose from rice flours by iodine colorimetry (Juliano et al 1968, Bhattacharya et al 1978). Insoluble amylose was calculated by difference from total amylose obtained by gelatinizing the flour in alkali.

Table 10. Checklist of indirect methods used (+) to evaluate cooking quality of milled rice.

Respondent	Amylose	Alkali spreading value	Gel consistency	Protein	Other qualities
Bhattacharya	+ a/	+			+ b/
Blakeney	+			+	
Breckenridge	+	+ c/		+	
Choudhury	+	+	+		
Crisostomo	+	+	+		
Delgado	+	+	+		
Diên	+	+	+	+ d/	+ e/
El Bayâ	+				
Fagade/Amubode	+ a/	+	+		
Fossati	+	+		+	+ f/
Harahap	+	+			
Husain	+	+	+		
Kongseree	+ a/	+ (1.4 and 1.7%)	+		
Kurasawa	+	+			
Lapis	+	+	+	+	
Lodh	+	+	+	+	
Mossman/Nishita/Bean	+		+	+	
Paule	+	+	+		
Perez	+	+	+	+	
Pillaiyar	+	+ c/	+		
Reginatto	+	+			
Sekhon	+	+			
Sekin	+	+			
Siddiq	+ g/	+	+ 3/		
Siwi/Damardjati	+	+	+		
Suzuki	+	+			
Tun	+	+	+	+	
Victoria	+	+	+		
Vidal	+	+			
Webb	+	+ c/		+	+ h/
Total	30	27	17	10	4

a/ Insoluble or soluble amylose at 100°C also. b/ Equilibrium water content of raw rice at 25-30°C. c/ Also for parboiled rice. d/ Nonprotein N also. e/ Starch and total lipids. f/ Surface area per gram of rice. g/ Single-grain analysis. h/ Surface lipids.

Alkali tests

Twenty-seven respondents performed the alkali test on milled rice, mostly adapted from Little et al (1958) from the original work of Jones (1938) (Table 10). Suzuki cited the method of Kasahara (1941). Six whole milled-rice grains were placed in duplicate square plastic boxes (4.6 cm x 4.6 cm x 1.9 cm) containing 10 ml 1.7% KOH, arranged so that the grains did not touch each other. The boxes were covered and incubated for 23 hours preferably at constant temperature such as 30°C. The appearance and disintegration of the grains were rated visually after incubation based on the numerical scale: 1 = grain not affected; 2 = grain swollen; 3 = grain swollen, collar incomplete and narrow; 4 = grain swollen, collar complete and wide; 5 = grain split or segmented, collar complete and wide; 6 = grain dispersed, merging with collar; and 7 = grain completely dispersed and intermingled. Check samples with scores of 2 to 7 were run with each analysis. Webb used disposable plastic trays for this test.

Bhattacharya used the scoring scheme and modified test conditions of Bhattacharya and Sowbhagya (1972, 1980) and Bhattacharya (1979b,c) and also determined alkali degradation pattern type (Bhattacharya and Sowbhagya 1972, 1980). A 9-point score card was used and 6 grains in 20 ml 1.4% KOH were used (Juliano et al 1982). The degradation

patterns reported were type A characterized by progressive cracking and corrosion, type B by progressive grilling and cottony transformation, type C by opening and splitting with gradual dense cottony transformation of the grain with increasing KOH level, type B_1 by grain being neither cracked nor corroded, but merely showing some hairy growth and gradual step-by-step swelling and gelatinization, and type D (exclusively given by waxy rice) by a more or less exaggerated C-type reaction, except that the collar was negligible and transparent from the beginning (Bhattacharya 1979b).

Siddiq reported the use of 16 hours incubation time instead of 23 hours for distinguishing between low- and intermediate-GT samples in 1.7% KOH. This method had an advantage over the use of a lower KOH concentration for 23 hours for lower-GT samples because 2 sets of values were obtained from 1 run by reading after 16 hours to differentiate low- and intermediate-GT rices, in addition to the 23-hour standard 1.7% KOH alkali test values.

Breckenridge and Pillaiyar used the alkali test employing 1.0-1.1% KOH for 4 hours to estimate the degree of parboiling of milled rice (Zakiuddin Ali and Bhattacharya 1972, Bhattacharya 1979a, Mohanloss and Pillaiyar 1980b). Raw grains remained unattacked whereas the extent of degradation of parboiled rice was proportional to the severity of parboiling. The method, however, cannot distinguish between pressure-parboiled and ordinary-parboiled rices.

Gel consistency

Seventeen respondents reported using the gel consistency test (Table 10). They represented regions in which high-amylose rices were common. The method of Cagampang et al (1973) using 100 mg rice flour in 2 ml 0.2 N KOH was used. Flour prepared with a Wig-L-Bug Amalgamator (10 grains for 40 seconds) was placed in 13 mm outside diam x 100 mm culture tubes and wetted with 0.2 ml 95% ethanol containing 0.025% thymol blue. Two ml 0.2 N KOH was added, with sufficient mixing with a Vortex Genie mixer with speed set at 6. The tubes were covered with glass marbles and heated in a vigorously boiling water bath for 8 minutes, making sure the tube contents reached two-thirds the height of the tube. The tubes were then removed from the bath for 5 minutes, cooled in an ice-water bath for 20 minutes, and laid flat on the laboratory table over a ruled graphing paper for 30 minutes or 1 hour. Total length of the blue-colored gel from the bottom of the tube to the gel front was measured in millimeters as an index of cold-paste viscosity and classified as hard gel (26-40 mm), medium gel (41-60 mm), and soft gel (61-100 mm). A Udy mill with 0.25-mm sieve is now used at IRRI instead of the Wig-L-Bug Amalgamator with savings in time.

Siddiq adapted the method to single-grain genetic analysis of segregating populations using 10 mg of 100-mesh (0.15 mm) flour in 0.2 ml 0.2 N KOH in 7 mm diam x 75 mm rimless test tubes (Zaman 1981).

Protein content

Protein was measured by nine respondents by the Kjeldahl method (Juliano and Pascual 1980) (Table 10). Ammonia in the Kjeldahl digest was either determined colorimetrically, as indophenol blue after reaction with hypochlorite and alkaline phenol, using automated AutoAnalyzer modules, or distilled and titrated. Diên also determined nonprotein nitrogen from aqueous extract soluble in 20% trichloroacetic acid. Protein nitrogen was calculated by difference from Kjeldahl and nonprotein nitrogen contents. The factor 5.95 was used to convert Kjeldahl nitrogen to crude protein. Diên also determined lysine content based on the reaction of the free epsilon-amino group of lysine in rice proteins with ninhydrin.

Other tests

Diên determined total starch by the classical method of Bertrand and crude fat (total lipids) by Soxhlet extraction with dry diethyl ether for 16-20 hours. Webb measured surface lipids of milled rice by Soxhlet extraction of 12 g head milled rice with petroleum ether (boiling point 30-60°C) for 30 minutes (Hogan and Deobald 1961).

Fossati measured the surface area per gram of raw milled rice (Bhattacharya and Sowbhagya 1971):

$$\text{Surface area } (cm^2/g) = \frac{3}{4}\pi\sqrt{\frac{B^2 + T^2}{2}} \cdot L \cdot N$$

assuming the grain to be a conoellipsoid with its length as L/2 and the two axes as B and T, where L = length, B = breadth, T = thickness in centimeters (mean of 20 grains), and N = number of grains per gram calculated from duplicate 100-grain weight determinations. This parameter has been claimed by Bhattacharya and Sowbhagya (1971) to correlate with the minimum cooking time of raw rice.

DISCUSSION

This survey has provided useful information for all collaborators to consider in work with cooking methods, texture, and aroma.

Cooking methods

Cooking time. Minimum cooking time was determined mainly by respondents who cook rice in excess boiling water (Table 1) to obtain comparable degrees of cooking among rice samples differing in starch GT and grain thickness (Juliano et al 1981b).

Bhattacharya and Sowbhagya (1971) showed that the rate of water uptake (cooking time) by 20 diverse rices in boiling water was primarily related to the surface area (size and shape) of the milled grain and unrelated to other grain properties. Juliano et al (1969), however, found cooking time for milled rice, among isogenic pairs of similar

grain dimensions but differing in GT, to directly correlate with final GT. Calculation of the correlation of grain properties with cooking time of the 10 rices used in the cooperative test on instrument methods for cooked-rice texture (Juliano et al 1981b) showed better correlation of mean cooking time with final GT (r = 0.75*) than with surface area per gram of rice (r = -0.49ns). When 2 coarse (thick) rices with L-W ratio < 2.5 were deleted (n = 8), the r with final GT became 0.93** and that with surface area per gram became -0.62ns. Evidently, although grain size and shape affected cooking time, it was a less important factor than starch final GT. This observation supports the conclusions of the kinetic studies of cooking rice by Suzuki et al (1976) and Cheigh et al (1978) that below 110°C, the cooking rate was limited by the reaction rate of rice components with water. Only above this temperature was the reaction rate limited by the rate of diffusion of water through the cooked layer toward the interface of uncooked core where the reaction occurred.

Volume expansion and water absorption tests. Preliminary screening tests for an arbitrary cooking time are complicated also by varietal differences in cooking time (rate of cooking). Contact with water during washing and presoaking is known to reduce cooking time because the absorbed water facilitates heat transfer and gelatinization (Desikachar and Subrahmanyan 1961, Santos et al 1980). Differences in the boiling procedure, for example, whether the grain is immediately in contact with boiling water or with cold water in a container immersed into a boiling water bath, would definitely also affect water absorption and volume expansion at similar heating periods. If the time when the cooking water in the tube reaches boiling water temperature is considered, some degree of precooking will have been involved.

In view of these factors, cooking with the amount of water that the rice will absorb has the advantage of having a standing period after the heater is shut off which tends to complete the cooking of the rice grain (Table 5). Differences in the tightness of the lid and number of samples per cooker also may lead to differences in degree of cooking. The use of excess water in the outer pot (~ 200 ml) and using the cooker as a steamer for 20 minutes boiling provided more reproducible water absorption values (Perez and Juliano 1979). The rice cooker heater provided the same temperature at the bottom of the beaker containing the rice, whether or not the beaker touches the outer pan bottom based on recent observations at IRRI. Rice-water samples originally were placed in the cooker once the outer-pot water boils. They are now placed in the cooker before turning the cooker on and the 20-minute cooking commences when boiling starts. Rice cookers without an outer-pot thermostat may use the inner pot as the outer boiler with samples placed in beakers with measured amounts of water.

In the oven method at 176°C (Batcher et al 1956, 1957, 1963a,b), actual temperature of the rice remained close to 100°C while there was still free water. Steam loss is higher than in the cooker method at 0.35 g/g rice as against 0.13 g/g in the cooker with excess water in the outer pot (Perez and Juliano 1979). The major disadvantage of the cooker and oven methods is that the bottom portion of the cooked rice tends to be overcooked or moist and the top layer is drier. Sample for texture determination has to be taken from the middle portion.

In the excess-water method, Bhattacharya and Sowbhagya (1971) observed that rices cooked to minimum cooking time in excess water have similar water contents of about 73% or a water-rice ratio of 2.5. Other workers verified that with a cooking time of minimum time plus 2 minutes, mean water content of rice was 73.5% but the 10 samples were between 69 and 76% in mean water content (Juliano et al 1981b). Bhattacharya et al (1978) achieved 73% water content by steaming rice in a covered shallow dish with 2.5 times water for 45 minutes but he stirred the sample 0, 5, 15, and 60 minutes after cooking to prevent grain-to-grain adhesion. By using the rice cooker and a water-rice ratio of 2.65 to allow for steam loss, better reproducibility of water content of cooked rice (74.7 to 75.3%) was obtained with minimal operator time (IRRI 1982).

In the excess-water method, water absorption ratios based on the weight of cooked rice and that of raw rice without correction for solids loss on cooking water are approximations only. No loss of solids occurs in the rice cooker method. Actual determination of water content of cooked rice or of solids in cooking water is used to correct for this loss in dry matter of rice during cooking. The correction for volume expansion is more difficult and probably not necessary because the solids loss probably does not decrease the volume of raw rice appreciably.

Bhattacharya and Sowbhagya (1971) reported that water uptake differences shown at 20 minutes of boiling are removed when minimum cooking time was adopted. Thus, volume expansion and water absorption determinations done for an arbitrary time without standing time may measure only the relative cooking rate of the samples, which are mainly affected by starch GT, and to a lesser extent, by grain thickness. Thus, water uptake at 77°C is useful in identifying high-GT rices such as Century Patna 231, because only low- and intermediate-GT rices showed appreciable water absorption above their GT at 77°C (Halick and Kelly 1959). The only important function of volume expansion and absorption seems to be to check the reproducibility of the cooking process before texture evaluation.

Grain elongation. The same problems (discussed above) apply to the grain elongation test. Environmental factors, particularly ambient temperature during ripening, affect starch GT as indexed by the alkali spreading value (Nikuni et al 1969. Resurreccion et al 1977). Basmati rice grown in the Punjab usually has an alkali spreading value of 6-7 and a boiling time of 10 minutes is adequate for presoaked grain (Baloch, 1980, unpubl.

data at IRRI; Azeez and Shafi 1966), but other respondents use at least 15 minutes or the minimum cooking time, which is usually more than 15 minutes (Juliano et al 1981) (Table 3). Because most elongating rices are low- to intermediate-amylose types, they are prone to overcooking, resulting in splitting and curling of grains (Baloch 1980). An IRRI crop of Basmati had an alkali spreading value of 3-5 and a cooking time of 15 minutes seemed adequate (Thant 1970).

To reduce the difference in cooking rate of rices brought about by differences in starch GT or alkali spreading value, cooking to optimum cooking time was used by four of the respondents (Table 3). However, rice cooked to 73-75% water as done in the excess-water method is much softer in texture than rice cooked to optimum texture, as discussed in the next section. Suspending the rice in a wire basket instead of putting it directly into the boiling bath may give a more even cooking of the grains because they do not come in direct contact with the higher-temperature heat source.

Japonica rices, although coarse-grained, elongate considerably on cooking, as observed for Bulgarian (Milev 1964), Japanese (Ishimura et al 1979), and U. S. and Australian rices (Juliano et al 1981b). A detailed study of volume expansion during cooking of Japanese rices, which have low GT or alkali spreading value of 6-7, revealed greatest expansion in length, followed by width, and then thickness (Ishimura et al 1979).

Water-rice ratio for optimum texture

Bhattacharya and Sowbhagya (1971) claimed that rice should be cooked to 73-75% water based on minimum cooking time either in excess water or by a shallow-dish method (Bhattacharya et al 1978). The survey, however, indicated that 19 respondents cooked rice in the water that the rice will absorb; 2 cooked rice in an oven at 176°C.

A recent study of the effect of water-rice ratio on hardness of cooked rice in the rice cooker method (using the same 10 rices used in the instrument methods for cooked rice) demonstrated the primary role of water-rice ratio in determining cooked-rice hardness (IRRI 1982). The water-rice ratio for acceptable soft texture (less than 10 kg Instron hardness) increased with increasing amylose content from about 0.9-1.1 for waxy rice, 1.2-1.4 for low-amylose rice, 1.5-1.6 for intermediate-amylose rice, and 1.7-2.0 for high-amylose rice. In the IRRI modified rice cooker method, water-rice ratios of 1.3 for waxy rice, 1.7 for low-amylose rice, 1.9 for intermediate-amylose rice, and 2.1 for high- amylose rice are used (Juliano and Pascual 1980). Even with this adjusted water-rice ratio based on amylose content, amylose content still correlated with cooked-rice Instron hardness (r = 0.59**, n = 266) and stickiness (r = -0.82**, n = 268). Hardness values ranged from 3.0 to 10.1 kg. Because of differences in water-rice ratio used, volume expansion and water absorption correlated positively with amylose content.

A fixed water-rice ratio of 1.6 for taste panel evaluation of boiled rice was originally used at IRRI (Juliano et al 1965). Because of the practice of housewives to adjust water level to obtain soft enough cooked-rice texture, subsequent sensory tests used 360-380 ml water/200 g rice with 40 ml in the outer cooker pot (del Mundo 1979). Using representative rices of the 4 amylose types from the instrument methods for cooked-rice texture (Juliano et al 1981b), the total range of hardness values was 3 kg at the water-rice ratio of 2.65 (corresponding to 75% water) but much larger at 5 kg at ratio 2.1, 6 kg at ratio 2.0 and 1.9, 7 kg at ratio 1.8, and 8 kg at ratio 1.7 (IRRI 1982). Thus, for a screening technique, a constant water-rice ratio of 1.7 to 2.1 would be most sensitive for samples covering all the amylose types. For programs with a narrower range of amylose types, the water-rice ratio may be adjusted correspondingly.

An examination of Table 5 reveals that waxy rices are cooked at a water-rice ratio of 0.8-1.3, low-amylose rices at 1.2-1.7 (except the 0.6 g method of Iwasaki), and intermediate- and high-amylose rices at 1.7-2.5. Higher ratios (more than 2.1) were employed by Bhattacharya and Pillaiyar. Thus, respondents actually adjusted the water-rice ratio to obtain optimum texture with the rice cooker type method. Despite the water-rice ratio lower than 2.65 needed for 75% water in the cooker method, acceptable texture is achieved, probably due to the several minutes of standing of the covered cooker after the heat is turned off.

Similar observations are applicable to the Amylograph and gel consistency tests. Halick and Kelly (1959) used a 10% (wet basis) paste for the Amylograph viscosity curve similar to those used for other cereal starches. This paste level was particularly suited to high-amylose rices, but 12% levels were better suited to intermediate- and low-amylose types (Perez and Juliano 1979). Waxy rices, however, did not improve in Amylograph differentiation with the increase in paste level (Merca and Juliano 1981). With gel consistency also, a higher paste level of 120 mg/2 ml 0.2 N KOH instead of 100 mg gave better differentiation among low-amylose rices (Perez and Juliano 1979). With waxy rices, neutral gel consistency of 200 mg/2 ml 0.15 N potassium acetate gave better differentiation than the regular gel consistency test of 100 mg/2 ml 0.2 N KOH (Perez 1979).

Consistent observations and trends were obtained between relative optimum water-rice ratios required for cooking to optimum texture among rice types and ratio optimum for Amylography and gel consistency above. Bhattacharya and Sowbhagya (1979, 1981), however, proposed Amylograph comparison based on constant peak viscosity rather than constant paste concentration, and advocated that cooked rice should be assessed at the same water level of 73% (Bhattacharya and Sowbhagya 1971).

Texture methods

Considerable variation was observed in both the sensory methods (Table 7) and the instrument methods for evaluating hardness, stickiness, and

other properties of cooked rice, in addition to the effects of cooking variables on cooked-rice texture. As a standard cooking method, the excess-water method has the advantage of similar water content but suffers from reduced sensitivity (IRRI 1982). Nonetheless, the cooperative testing of instrument methods for cooked-rice texture, using this method, revealed that most instrument methods were more sensitive than a taste panel in differentiating among cooked rices (Juliano et al 1981b).

The need to standardize the scoring system for sensory evaluation of cooked rice exists. A similar need is evident for instrument methods because even with the same instrument, such as in Instron or Texturometer, respondents use their own unique methods (Tables 8 and 9). Analysis of individual or discrete (3) grains has been developed for texture determination using the Texturometer (Suzuki 1979b, Okabe 1979), Tensipresser (Tsuji 1980, 1981), Viscoelastograph (Laignelet and Feillet 1979), and Instron food tester texture profile or double-bite technique (Blakeney 1979). The use of similar parameters and plunger materials should make the values obtained with these instruments better related.

Aroma

Aroma screening in breeding programs is hampered by the ready saturation of the human nose. Unfortunately, characterization of the aroma principles of rice has not been made except for Kaorimai rice in Japan (Yajima et al 1979). Yajima and his colleagues showed by gas chromatography-mass spectrometry that the difference in olfactory characteristics between Kaorimai and Koshihikari (nonscented) rice was due to the difference in balance or proportions of a few components, but the characteristic flavor compounds were not identified. The Western Regional Research Center Food Quality Laboratory group recently entered a cooperative arrangement with IRRI for the characterization of the chemical principles in aromatic rices and the feasibility of monitoring them by gas chromatography in breeding programs.

Indirect and other methods

Cooperative tests have shown the reproducibility of the colorimetric method of amylose-iodine complex for amylose assay on milled rice (Juliano 1971, Juliano et al 1981a). Water-soluble amylose in boiling water correlates with amylose content of milled rice and explains why starch iodine blue value at 97°C for whole milled Japanese rices with low amylose content correlated with cooked-rice texture (Kurasawa et al 1962). Juliano et al (1968), however, demonstrated extreme varietal differences in hot-water-soluble amylose among high-amylose rice flours and recommended this screening method only for low- and intermediate-amylose rices. Bhattacharya et al (1978) confirmed these results and the fact that the high-amylose rice with high water-insoluble amylose had different Amylograph curves from those with low water-insoluble amylose. Detailed studies indicated that the differences in starch solubility among high-amylose rices were more dramatic for amylopectin than for amylose (Juliano 1979b). Because of differences in hot-water-soluble amylose of only a few percentage points, the gel consistency test of Cagampang et al (1973) better identifies the rices with low water-soluble amylose to be those with hard gel consistency. They are also characterized by high Amylograph setback and consistency values (Perez and Juliano 1979, Juliano and Pascual 1980).

Actual starch determination by Diên (Table 10) allows calculation of amylose:amylopectin. Since starch plus protein usually constitute 98.5% of dry matter of milled rice (Juliano et al 1964a), starch content may be calculated from protein content of milled rice.

Alkali spreading value was shown recently (in an international cooperative test) to be highly reproducible and the scoring systems of Little et al (1958) and Bhattacharya and Sowbhagya (1972) were both satisfactory (Juliano et al 1982). Unfortunately, the respondents found the alkali degradation patterns A, B, B_1, C, and D difficult to recognize even in the presence of detailed description and photographs. The alkali spreading value may also be used for identifying rices with hard gel consistency (low water-soluble amylose) as most of them have values of 6-7 (Juliano 1979a). The optimum KOH concentration depends on consistency (Cagampang et al 1973), high alkali viscogram peak viscosity (Suzuki 1979a), and with low water-soluble amylose (high water-insoluble amylose) in boiling water (Juliano 1979a,b). Optimum differentiation among high-amylose milled rices occurs in the range of 85-100 mg/2 ml 0.2 N KOH (IRRI 1982).

Protein screening provides an index of the nutritional value of the milled rice and is indirectly an indicator of cooking quality. High-protein rices take a longer time to cook than average-protein rices of the same varieties and as such require a higher water-rice ratio to achieve the same water content of cooked rice and allow for greater steam loss (Juliano et al 1965). The analysis of nonprotein nitrogen allows the calculation of true protein content of milled rice, but most of the nonprotein nitrogen of milled rice is free amino acids and seldom exceeded more than 0.1-0.2% of total Kjeldahl nitrogen based on ninhydrin reaction (IRRI, 1974, unpubl. data).

Surface and total lipids measure degree of milling of the milled rice and thus measure keeping quality of the rice. The tests verify if the rices have comparable degrees of milling, and thus whiteness and appearance.

The two other properties (Table 10) are surface area per gram of rice and equilibrium water content of rice at 25-30°C. Surface area per gram of rice has limited value in view of the greater effect of starch final GT or alkali spreading value

on cooking time as discussed in the earlier section on Cooking time. Equilibrium water content of steeped raw rice at room temperature indirectly measures amylose content because of the inverse relationship between the two properties (Antonio and Juliano 1973, Indudhara Swamy et al 1971). However, chalky grains such as white core and white belly also contribute to higher water content of steeped grain by providing space for free water. Recently, Bhattacharya et al (1979) observed differences in equilibrium water content even among Indian high-amylose rices with translucent grains. These differences were confirmed to be mainly due to the negative correlation between starch final GT and equilibrium water content of high-amylose rices (IRRI 1980).

A major problem involves the measurement of severity of parboiling in view of the pressure parboiling of rough rice. The starch is fully gelatinized but degree of retrogradation of the starch also has to be measured. Bhattacharya (1979a) reviewed the methods for parboiled rice, which included equilibrium water content of rice at room temperature, water uptake at 60 and 96°C, and alkali test in 1.0-1.1% KOH for 1 hour. The suitable method seems to be puffed volume because pressure-parboiled Indian rices are preferred for the preparation of puffed rice. Earlier studies indicated that puffed volume of milled rice is directly related to degree of parboiling of the rice grain (Antonio and Juliano 1973).

RECOMMENDATIONS FOR COOPERATIVE TESTING

Cooperative testing should concentrate on direct cooking methods because indirect methods have been evaluated recently (Juliano 1971; Juliano et al 1980, 1981a,b, 1982). Because boiling and steaming of rice by the various methods are done at boiling water temperature, the major variable among the methods is the water content of the cooked rice (Table 2). To verify the authenticity of this observation, a possible cooperative study would be the comparison of the hardness of rice cooked to 73-75% water in excess water (minimum cooking time + 2 minutes) and that of rice cooked by the rice cooker method to true water-rice ratio of 2.5 corrected for steam loss, preferably with the water added to the rice before heating. The use of a steaming time of 20 minutes with excess water in the outer pot also insures a steam-saturated atmosphere in the vessel during cooking.

Another possible area of cooperative testing is to compare the use of single grain or discrete grains and bulk cooked rice for cooked-rice texture using instrument methods such as the Texturometer, Tensipresser, Viscoelastograph, and Instron texture profile system. Considerable variation in cooked-rice hardness has been observed for individual grains, for example, in the Instron food tester (Juliano et al 1981b). A similar wide range of values is observed for the cracking hardness of individual raw brown-rice grains (IRRI 1982).

A third possible method for cooperative testing is grain elongation during cooking. Presoaking for 15 minutes plus 10 minutes boiling in a wire basket (not touching the bottom of the cooking vessel) should give better results than the indirect method using the cold water used for soaking during the boiling step because the lag time required for the soaking water to boil is affected by many variables. In the wire basket method, the grains are immediately subjected to boiling water. Water uptake of the rice during cooking should also be determined.

Amylography would render itself to cooperative testing as a fourth possibility just to determine the actual differences in results to be expected among Visco/Amylographs or Viscographs in rice. Flours prepared by the same mill should be used. Preferably 10% paste should be used for high-amylose rice and waxy rice and 12% paste for low-amylose and intermediate-amylose rices (Perez and Juliano 1979). Moisture content of the flour should be determined to insure the same paste concentration. Final GT determination may be run and copies of the Amylograms should be provided for comparison purposes.

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