Influence of Varietal Difference on Properties of Parboiled Rice

K. R. UNNIKRISHNAN and K. R. BHATTACHARYA[1]

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ABSTRACT

Thirteen rice varieties with a wide range of quality attributes (high-amylose to waxy) were parboiled under mild and severe conditions. Hydration, amylose solubility, gel mobility, pasting behavior, slurry viscosity, and texture of the cooked rice samples changed in the order raw rice to mild to severely parboiled rice. However, the initial gradation of properties among the different varieties remained largely unchanged after parboiling. Thus, although rice became harder and less sticky after parboiling, a sticky variety remained relatively sticky and a nonsticky variety relatively nonsticky. Rice of quality types I and II (high total and insoluble amylose) were the most suitable for canning, as revealed by the canning-stability test. The texture of cooked rice, whether raw or parboiled, was highly correlated to the water-insoluble amylose content. Lipid-amylose complexation did not seem to explain the hardening of rice after parboiling.

Parboiling is essentially precooking of rice within the husk (Bhattacharya and Ali 1985). It is an important industry, for about half the rice produced in South Asia is consumed after parboiling. It is possible to prepare parboiled rice of diverse quality by adopting different systems of parboiling and also by varying the degree of heat treatment in each (Bhattacharya 1985).

Studies by several workers suggest that the initial quality of the rice to be parboiled influences the quality of the product (Webb et al 1968; Webb 1969; Raghavendra Rao and Juliano 1970; Arai et al 1975; Feillet and Alary 1975a,b; Vitti et al 1975; Alary et al 1977; Lequerica and Tortosa 1977). If this is valid for all types of rice, yet another way of exploiting the potential of the parboiling process to produce rice of different attributes would be to use different quality types of rice.

Bhattacharya et al (1982) classified rice into eight quality types based primarily on their total and water-insoluble amylose contents. Representative samples of these different quality types were parboiled under mild and severe conditions, and various attributes of the samples were determined. The main aim was to study how the initial rice quality influenced the quality of the parboiled product. However, the design of experiments additionally provided the opportunity to verify the accuracy of the earlier determined pattern of properties among different raw rice types (Bhattacharya et al 1978, 1982), as well as the pattern of changes in rice properties that occur upon parboiling (Bhattacharya and Ali 1985).

MATERIALS AND METHODS

Paddy was obtained from the V. C. Farm, Mandya, of the University of Agricultural Sciences. Samples were air-dried to 12–13% moisture (wet basis, wb), fumigated, and stored in closed containers for about five months at room temperature and then refrigerated (4–6° C) until these studies. During the experiments, processed samples were returned to the cold room whenever not in use. Samples selected were two varieties from each quality type (I through VIII) according to the classification of Bhattacharya et al (1982), except that no sample of type VI and only one sample of type V were available.

Samples were parboiled by the basic method of Bhattacharya and Indudhara Swamy (1967). Paddy was soaked in warm water (the temperature of water after mixing in paddy was adjusted to roughly 5° C below the gelatinization temperature of each sample) and left overnight. The water was drained off and the soaked paddy was steamed at either 0 or 1 kg/cm^2 gauge pressure for 10 min to prepare mildly or severely parboiled rice, respectively.

[1]Discipline of Grain Science and Technology, Central Food Technological Research Institute, Mysore, 570 013, India.

All samples were air-dried and milled to about 8% degree of milling using McGill laboratory equipment. Broken grains were separated using a sizing device and then discarded. A portion of the rice was ground first in a Buhler laboratory grinder (type MLI 204) and then in a Raymond hammer mill to pass through a 60-mesh screen. This flour was used for the various analyses, including viscography. For the gel-consistency test, 100–200 mg of the above flour was further ground in a Wig-L-Bug amalgamator for 30–60 sec; the amount of flour and the time of grinding were adjusted to give a uniform 100-mesh powder for each sample. All samples were placed in a room adjusted to 27° C and 65% rh for moisture equalization.

To study the role of lipids on the properties of parboiled rice, a sample of milled raw rice was divided into two portions, and one portion was defatted before they were parboiled. Defatting was done by Soxhlet extraction first with 85% aqueous methanol and then with a methanol-chloroform (1:1) mixture for several days each. Both the defatted and undefatted portions were then soaked overnight in distilled water at room temperature, drained, steamed at atmospheric pressure for 10 min, and dried.

Analytical Methods

Amylose content of raw milled rice was determined by the method of Sowbhagya and Bhattacharya (1979), and its water-insoluble amylose was calculated by subtracting water-soluble amylose (see below). The gelatinization temperature (GT) of the raw milled rices were calculated from their alkali scores (Bhattacharya et al 1982). Equilibrium moisture content attained by rice when soaked in water at room temperature (EMC-S) was determined both immediately after steaming (immediate EMC-S) and after air-drying and milling (final EMC-S) by methods described earlier (Ali and Bhattacharya 1976). Water uptake by rice when cooked for 1 hr at 96° C (W_{96}) and at a lower temperature (W_{LT}) were determined as described by Ali and Bhattacharya (1972). Water-soluble amylose content of rice flour by extraction at 96° C for 20 min (sA_{96}) and at a low temperature for 1 hr (sA_{LT}) were determined as described by Bhattacharya et al (1972) and Ali and Bhattacharya (1972) but with rice flour defatted by Soxhlet extraction with methanol.

Earlier work from this laboratory (Bhattacharya and Ali 1985) showed that the water uptake of whole-grain rice at 60° C when expressed as a fraction of that at 96° C (W_{60}/W_{96}), and the amount of amylose dissolved from rice flour in water at 50° C expressed as a fraction of that dissolved at 96° C (sA_{50}/sA_{96}) provide good indications of the degree of parboiling. These values usually lie around 5 and 2%, respectively, in raw rice and go up to approximately 50 and 15%, respectively, for severely parboiled rice. In using these tests in the present study, the temperatures selected for the low-temperature hydration had to be adjusted to the GT of the varieties for valid intervarietal comparison. Samples showing a GT of 68° C or more were soaked at 60° C for the lower-temperature water-uptake test and at 50° C for the soluble-amylose test, whereas for those samples with a GT of less than 68° C, the corresponding temperatures chosen were 55 and 45° C, respectively. The parameters were then expressed as W_{LT}/W_{96} and sA_{LT}/sA_{96}.

The apparent viscosity of a 20% (dry basis, db) aqueous slurry of rice flour at 27° C was determined on a concentric cylinder viscometer (Rheotest II) using cylinder S_3 by the method of Unnikrishnan and Bhattacharya (1983), and Brabender viscograms of the rice flours were studied by the multiconcentration method of viscography described by Bhattacharya and Sowbhagya (1979). Gel consistency was determined by dispersing 100 mg (wb) of 100-mesh flour in 2 ml of 0.2 *N* KOH in a 13-mm diameter test tube and noting the distance the gel travelled when the tube was laid horizontally for 1 hr, as described by Cagampang et al (1973) and Perez (1979). However, a longer tube (150 mm) was used, and, to avoid the confusion of a longer gel travel being expressed as lesser gel consistency and vice versa, the value was expressed as gel mobility (K. R. Unnikrishnan and K. R. Bhattacharya, *unpublished*).

Canning stability test for suitability for parboil-canning processing was performed as described by Webb and Adair (1970) with some modifications. Briefly, an Erlenmeyer flask containing 5 g of milled rice and 100 ml of distilled water was heated in a boiling water bath for 20 min, cooled under the tap, and then steamed for 1 hr at 1 kg/cm^2 gauge pressure in an autoclave. The flask was again cooled, and the rice was drained and then washed over a standard 1.7-mm wire sieve (Endecotts, London). The cooked rice retained over the sieve was surface dried with filter paper, dried in the oven at 105° C for 24 hr, and weighed. The loss in dry solids was calculated.

All analyses were done in duplicate except for EMC-S and Brabender viscograms, which were determined only once for each sample.

Texture of Cooked Rice

For estimating the texture of cooked rice, rice was cooked with 2.5 times its weight of water (Deshpande and Bhattacharya 1982). For the sensory test, 20 g of milled rice and 50 ml of distilled water were placed in a 250-ml beaker, covered with a petri dish, and open steamed in an autoclave for 45 min, 50 min, and 60 min for raw, mild, and severely parboiled rice, respectively. For instrumental texture measurement, to ensure uniform and exact absorption of water by all grains, 2 g of rice was taken in 1–2 grain layers along with 5 ml of water in a pair of 5.2-cm flat petri dishes and placed inside a loosely covered steel dish. Several such dishes were then placed in a cooking stand (described before) and cooked by open steaming for 45, 50, and 60 min in an autoclave (Deshpande and Bhattacharya 1982).

Sensory tests were made using fingers alone rather than by mouth (Sowbhagya et al 1987). All samples were code numbered, and several samples arranged randomly were presented at one time to a panel of six judges who scored them sequentially. Each sample was tested on two different occasions, and the mean of all the scores for a sample was calculated. Samples were scored for tenderness, moistness, and stickiness, in which the highest score corresponded to the highest quality (Table I).

Instrumental measurement of texture was done using the Chopin-INRA viscoelastograph with some modification of the method of Laignelet and Feillet (1979). Briefly, several cooked grains were pressed between two parallel plates under a fixed load for 35 sec and then allowed to recover, after removing the load, for 20 sec. The measurement was replicated five times for each sample with fresh grains. The load used was 500 g, which was verified in preliminary trials to give the best differentiation among the samples. Three cooked grains were initially used for the test with each sample, as prescribed. However, these results showed some abnormal varietal pattern. Examination showed that varieties with small grains gave readings that were too low, and those with big grains were too high, suggesting that perhaps the weight rather than the number of grains to be taken for a test ought to be reasonably constant. The average grain weight (uncooked raw milled rice) of each variety was therefore determined using a Numigral grain counter (Tecator, Sweden), and the number of cooked grains of each variety taken for the test was adjusted so that the total weight of the uncooked grains was about 50–60 mg. The average grain weights of the samples in the order listed in Table II were 17.8, 21.9, 13.2, 14.1, 11.0, 17.8, 9.0, 15.4, 18.1, 20.0, 18.6, 17.5, and 19.1 mg, respectively. Firmness (F) and elastic recovery (ER) were calculated from the readings as

$$F = (e_1/e) \times 100\ (\%)$$

$$ER = [(e_2 - e_1)/(e - e_1)] \times 100\ (\%)$$

TABLE I
Score Card for Sensory Evaluation of Texture of Cooked Rice

Score	Stickiness	Tenderness	Moistness
1	Not sticky, well separated grains	Hard	Very dry
3	Not sticky, partially separated grains	Firm	Rather dry
5	Rather sticky	Moderate	Slightly moist
7	Very sticky	Soft	Moist
9	Like paste	Mashy	Very moist

TABLE II
Experimental Rice Varieties and Their Physicochemical Properties

Variety		Amylose (%, db)		GT[b]	EMC-S[c]	W_{96}[d]	W_{LT}/W_{96}[d]	sA_{LT}/sA_{96}[e]	Gel Mobility
No.[a]	Name	Total	Insoluble	(°C)	(%, wb)	(g/g)	(%)	(%)	(mm)
11	T(N)1	28.1	17.4	65	29.8	3.72	6.8	2.5	30
12	Jaya	28.2	17.3	65	29.5	3.85	6.7	2.5	32
21	GEB 24	27.2	13.5	69	27.9	4.01	6.4	2.7	34
22	Co 32	27.5	14.1	69	28.0	4.10	6.5	2.5	31
31	Adt 8	27.9	10.8	68	28.0	3.73	6.5	2.7	48
32	S 317	28.5	10.2	70	26.9	3.70	6.2	2.5	92
41	Br 9	25.8	9.0	72	29.3	4.31	6.2	2.6	61
42	N 10 B	24.5	9.5	71	28.4	4.19	6.0	2.7	32
51	Intan	25.6	8.2	69	29.2	3.96	6.9	2.6	62
71	K 84	23.3	9.0	66	30.3	3.76	7.2	2.0	50
72	Changlei	19.2	6.4	65	30.5	4.18	6.8	2.0	54
81	Asm 44	4.8	3.9	65	34.8	3.93	8.5	···	72
82	Purple puttu	5.2	4.0	64	36.0	3.36	10.5	···	82

[a] The first digit of the code number identifies the quality type of the rice; thus, no. 21 belongs to quality type II, no. 72 to type VII, and so on. The second digit stands for the serial number within the type.
[b] GT = Gelatinization temperature.
[c] EMC-S = Equilibrium moisture content of rice soaked in water at room temperature.
[d] W_{96} = Water uptake of rice cooked 1 hr at 96° C; W_{LT}/W_{96} = ratio of water uptake of rice cooked at a lower temperature (55 or 60° C) to W_{96}.
[e] sA_{LT}/sA_{96} = Ratio of water-soluble amylose content of rice flour extracted at low temperature (45 or 50° C) to that extracted at 96° C.

TABLE III
Change in Physicochemical Properties of Rice after Parboiling[a]

Variety No.[b]	EMC-S[c] Immediate		EMC-S[c] Final		EMC-S[c] Final/Immediate (%)		W_{96}[d] (g/g)		W_{LT}/W_{96}[d] (%)		sA_{96}[e] (%, db)		sA_{LT}/sA_{96}[e] (%)		Gel Mobility (mm)	
	M/R	S/R	M/R	S/R	M	S	M/R	S/R	M/R	S/R	M/R	S/R	M/R	S/R	M/R	S/R
11	2.39	4.51	2.04	3.18	85.2	70.6	0.93	0.69	3.1	5.6	0.89	0.68	1.92	5.20	1.51	2.03
12	2.89	4.88	2.30	3.46	79.6	70.8	0.91	0.68	3.1	5.6	0.90	0.72	1.88	4.96	1.57	2.00
21	1.80	4.29	1.48	2.54	82.3	59.3	0.92	0.70	3.0	5.8	0.89	0.71	1.85	4.74	1.39	1.86
22	1.93	4.67	1.56	2.74	80.6	58.7	0.90	0.69	3.2	5.7	0.89	0.75	1.92	4.96	1.32	1.81
31	1.92	4.07	1.55	2.16	80.6	53.2	0.91	0.72	3.0	5.6	0.89	0.70	1.85	4.67	1.35	1.62
32	2.08	4.47	1.66	2.44	79.5	54.6	0.90	0.72	3.1	5.8	0.90	0.73	1.84	4.68	1.30	1.60
41	2.14	4.22	1.63	2.27	76.1	53.7	0.93	0.72	3.0	5.9	0.88	0.71	1.85	4.54	1.32	1.57
42	2.41	4.80	1.85	2.59	76.6	53.9	0.91	0.71	3.2	6.0	0.90	0.69	1.70	4.78	1.41	1.75
51	2.37	4.97	1.79	2.50	75.7	50.4	0.92	0.70	2.9	5.7	0.88	0.69	1.77	4.54	1.39	1.76
71	3.34	5.80	2.26	2.77	67.8	47.7	0.90	0.72	3.1	5.7	0.87	0.69	1.70	4.65	1.63	1.84
72	3.42	6.62	2.37	3.08	69.4	46.6	0.91	0.72	3.3	5.9	0.86	0.66	1.60	4.60	1.61	1.95
81	2.98	8.89	2.06	6.88	69.2	77.4	0.92	0.86	3.3	6.4	···	···	···	···	1.20	1.48
82	3.54	11.38	2.47	8.32	69.8	73.1	0.86	0.82	3.8	6.7	···	···	···	···	1.18	1.40

[a] R = raw (unprocessed), M = mildly parboiled, and S = severely parboiled rice.
[b] The first digit of the code number identifies the quality type of the rice; the second digit stands for the serial number within the type (Table II).
[c] To calculate the ratios, EMC-S values were used on a dry basis.
[d] W_{96} = Water uptake of rice cooked 1 hr at 96° C; W_{LT}/W_{96} = ratio of water uptake of rice cooked at a lower temperature (55 or 60° C) to W_{96}.
[e] sA_{96} = Water-soluble amylose extracted at 96° C for 20 min; sA_{LT}/sA_{96} = ratio of water-soluble amylose content of rice flour extracted at lower temperature (45 or 50° C) to sA_{96}.

where e = thickness of grains (mm) before compression,
e_1 = thickness of grains (mm) after compression, and
e_2 = thickness of grains (mm) after recovery.

RESULTS AND DISCUSSION

Hydration and Related Properties

The different varieties of rice and their properties (as raw rice) are shown in Table II. The samples are listed according to their quality types, based primarily on their amylose contents (Bhattacharya et al 1982) and are assigned code numbers to indicate the quality types of the samples, as explained in a footnote.

The EMC-S values of the varieties were characteristic of their quality types (Bhattacharya et al 1982). The values of W_{LT}/W_{96} and of sA_{LT}/sA_{96} were quite constant (barring the two waxy samples, nos. 81 and 82) as predicted (Ali and Bhattacharya 1972). The gel mobility values showed an increasing trend from type I to type VIII (Perez 1979), but with some scatter. The water uptake (W_{96}) values did not show any type specificity. This is to be expected, for the water uptake of rice is related primarily to its size, shape (surface area), and other physical factors, and not to its intrinsic quality (Bhattacharya and Sowbhagya 1971).

All the above indexes except amylose content changed after parboiling (Table III). The water uptake and amylose solubility at 96° C decreased, while those at the lower temperature (55 and 60° C, 45 and 50° C, respectively) increased. The EMC-S values also increased. All these changes are as observed earlier with one or two varieties (Bhattacharya and Ali 1985). The gel mobility also increased after parboiling, as noted separately (K. R. Unnikrishnan and K. R. Bhattacharya, *unpublished*).

However, despite large differences in initial attributes among the quality types (Table II), the factor by which each attribute changed after parboiling was relatively constant among the different samples (Table III). In other words, differences in attributes existing in native rice were largely carried over even after mild or severe parboiling. Waxy rices (nos. 81 and 82), especially the severely parboiled samples, differed slightly from this pattern, the reasons for which are not clear. After severe parboiling, the waxy rice became somewhat deformed, and part of the endosperm oozed out of the husk. It is not known whether this deformation has anything to do with the difference in properties. As seen from the W_{LT}/W_{96} values in Table II, waxy rice differed from nonwaxy rice even in the raw stage. The ratio of final to immediate EMC-S (Table III) fell gradually from type I to type VIII rice (except waxy severely parboiled) and is discussed later.

TABLE IV
Brabender Viscographic Indexes of Raw and Parboiled Rice

Variety No.[a]	Breakdown[b] (BU) Raw	MPB	SPB	Relative Breakdown[b,c] (%) Raw	MPB	SPB	P max (BD = 0)[d] Raw	MPB	SPB
11	0	0	0	0	0	0	1,200	1,450	···
12	0	0	0	0	0	0	1,100	1,500	···
21	100	50	0	13	5	0	700	850	···
22	100	0	0	13	0	0	650	1,100	···
31	250	200	100	29	20	13	150	450	800
32	350	250	100	50	31	14	170	450	750
41	···	100	50	···	12	5	···	350	700
42	300	150	100	48	20	14	180	300	650
51	350	100	50	54	12	5	220	300	1,000
71	420	150	100	131	21	14	160	250	700
72	450	100	20	113	20	3	150	360	850
81	350	200	480	175	100	300	220	380	460
82	450	···	450	265	···	225	210	250	400

[a] The first digit of the code number identifies the quality type of the rice; the second digit stands for the serial number within the type (Table II).
[b] At peak viscosity of 1,000 BU. MPB = Mildly parboiled rice; SPB = severely parboiled rice.
[c] Breakdown/ (breakdown + setback), by the method of Bhattacharya and Sowbhagya (1979).
[d] Maximum peak viscosity in BU for which there is no breakdown.

Brabender Viscograms

As shown in Table IV, the raw rice samples showed a characteristic pattern of breakdown and relative breakdown, when read at a constant peak viscosity of 1,000 BU, or of the maximum value of peak viscosity for which the breakdown was zero, as discussed earlier (Bhattacharya and Sowbhagya 1979). After parboiling, these values changed as found earlier with one variety (Ali and Bhattacharya 1980). But the pattern of changes was similar in all the samples, and the intervarietal pattern remained largely unchanged.

Slurry Viscosity

The viscosities of 20% (db) aqueous slurries of flours of one sample from each type are shown in Figure 1. In raw rice, the viscosities showed a characteristic pattern among the different samples, which seems to be related to their EMC-S and amylose contents (Table II). As observed in our earlier work with one sample (Unnikrishnan and Bhattacharya 1983), the viscosities

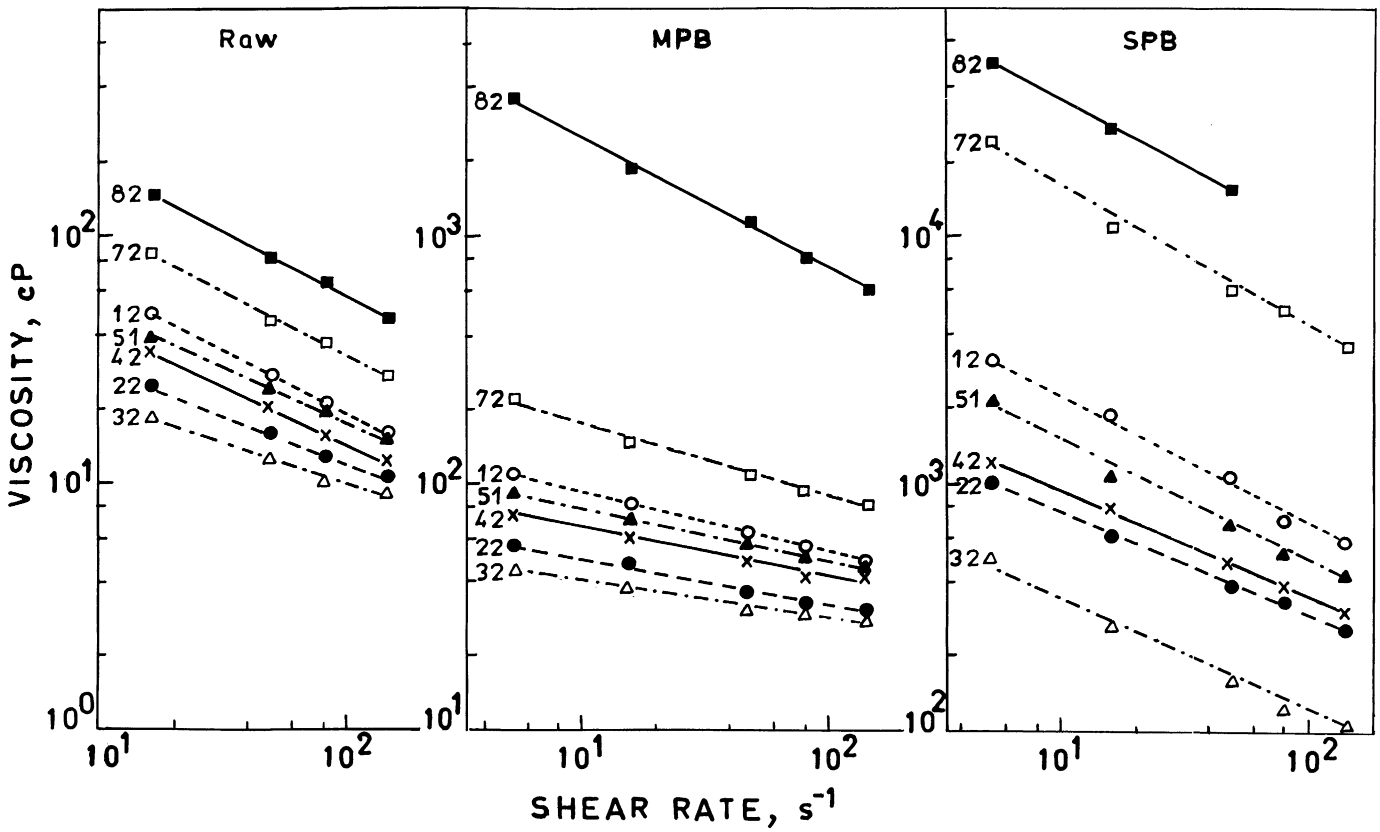

Fig. 1. Viscosity of aqueous slurries of raw, mild (**MPB**), and severely (**SPB**) parboiled rice flour at 27° C. Numbers identify the samples (see Table II). Slurry concentration: 20% (db) for all, except sample 82 (15%).

TABLE V
Sensory Scores of Cooked Raw and Parboiled Rice[a]

Variety No.[b]	Stickiness			Tenderness			Moistness		
	Raw	MPB	SPB	Raw	MPB	SPB	Raw	MPB	SPB
11	1.82	1.09	1.00	2.63	2.00	1.68	2.68	2.41	2.09
12	1.64	1.18	1.00	2.72	2.27	1.77	2.91	2.18	1.86
21	2.45	1.59	1.04	3.00	2.73	2.04	2.95	3.18	2.68
22	3.14	1.59	1.23	3.18	2.91	2.28	3.50	2.86	3.27
31	3.50	1.73	1.41	3.18	2.77	2.45	3.73	3.36	2.86
32	3.27	2.27	1.64	4.14	3.22	2.77	4.23	3.95	3.28
41	3.95	3.04	1.73	4.64	3.82	3.36	4.80	4.50	3.54
42	3.59	2.64	1.73	4.18	3.73	3.18	4.41	4.45	3.72
51	4.36	3.41	2.23	4.45	4.13	3.68	4.63	4.64	3.86
71	5.27	4.64	3.64	5.54	5.04	4.64	6.18	5.45	5.18
72	5.16	4.68	3.82	6.00	5.36	4.91	6.41	5.86	5.27
81	8.00	7.77	8.14	7.82	7.45	8.18	8.00	8.00	8.18
82	8.18	8.00	8.64	8.18	8.00	8.50	8.59	8.68	8.64

[a]MPB = Mildly parboiled; SPB = severely parboiled.
[b]The first digit of the code number identifies the quality type of the rice; the second digit stands for the serial number within the type (Table II).

TABLE VI
Instrumental Measures of Texture of Cooked Raw and Parboiled Rice[a]

Variety No.[b]	Firmness (%)			Elastic Recovery (%)		
	Raw	MPB	SPB	Raw	MPB	SPB
11	54.2	60.1	65.0	49.1	62.9	73.8
12	62.0	65.3	70.0	55.4	72.6	77.7
21	49.4	55.4	60.2	44.2	57.1	69.2
22	45.5	52.6	59.4	38.3	54.3	65.4
31	38.3	45.8	54.9	23.1	44.4	57.2
32	36.6	44.2	54.2	20.2	41.6	54.9
41	29.1	39.2	50.4	15.8	31.1	48.5
42	27.7	42.5	52.7	15.4	32.7	54.0
51	24.0	36.5	47.1	11.6	21.6	43.8
71	22.2	28.3	37.2	7.2	14.3	27.0
72	20.3	24.6	35.6	6.4	8.3	17.9
81	14.1	14.8	11.9	1.4	1.6	1.4
82	14.0	15.2	12.0	0.9	1.5	0.9

[a]MPB = Mildly parboiled; SPB = severely parboiled.
[b]The first digit of the code number identifies the quality type of the rice; the second digit stands for the serial number within the type (Table II).

increased upon parboiling from raw rice to mild to severely parboiled rice. However, the nature of the curves and the intervarietal gradation remained largely unchanged among the three categories.

Texture of Cooked Rice

The sensory and instrumental values of the texture of cooked rice are shown in Tables V and VI, respectively. There is a distinct decrease in stickiness, tenderness, and moistness and an increase in firmness and elasticity from raw rice to mild to severely parboiled rice. This confirms the popular observation that cooked parboiled rice is harder and less sticky than cooked raw rice. This pattern of change upon parboiling appeared on the whole similar and uniform in all the varieties (with the exception of waxy rice, which showed exceptions in other properties as well). As a result, both the sensory and instrumental results showed a distinct gradation from type I to type VIII rice, not only in raw rice but also in the parboiled samples. Thus, the mean values of the instrumental textural indexes (firmness, elastic recovery) of the eight rice types in Table VI showed a statistically significant ($P < 0.05$) type-to-type gradation as tested by a modified Duncan's new multiple range test (Harter 1960). Even the sensory texture scores, although numerically very close (Table V), showed a fairly distinct type-to-type gradation in raw as well as parboiled rice (Table VII). If these gradations in raw rice prove the soundness of the quality classification of rice (Bhattacharya et al 1982), those for parboiled rice show again that initial differences in quality attributes of rice were largely carried over even after parboiling.

An interesting consequence of the vertical and horizontal gradations in textural attributes of the samples in Tables V and VI is that the mean numerical values of the textural indexes by quality type were more or less identical when one moved diagonally downward from left to right in these tables. In other words, speaking generally, the overall texture of raw rice of any one quality type is more or less the same as that of mild parboiled rice of the next type and of severely parboiled rice of the type after that, and so on. This textural equivalence opens up two possibilities. First, it might be possible to substitute raw rice for mild or severely parboiled rice and vice versa for a given consumer demand if the variety or processing conditions or both are appropriately selected. In particular, consumers of firm raw rice might accept low- or intermediate-amylose parboiled rice with their nutritional advantages. Second, to produce parboiled rice of a given texture, the processor can adjust either the processing condition or the variety, or both, thus increasing the flexibility of his operation.

The three sensory and two instrumental attributes of texture were very closely correlated with each other (positively within each set and inversely between the two sets). The absolute value of correlation coefficient between any two of the parameters (stickiness, tenderness, moistness, firmness, elastic recovery) was highly significant in each case ($P < 0.001$), the lowest value of r being 0.850 and the highest 0.996 (n = 13). These data show the sensitivity of the sensory texture test even with the fingers as well as the usefulness of the Chopin-INRA viscoelastograph as a texture-measuring instrument for rice. Hardness and stickiness of cooked rice were strongly inversely correlated, as observed earlier (Manohar Kumar et al 1976; Bhattacharya et al 1978, 1982; Perez and Juliano 1979; Juliano et al 1981). Thus the r values for correlations between sensory stickiness and viscoelastograph firmness were −0.901, −0.947, and −0.969 for raw, mild, and severely parboiled rices, respectively (n = 13).

Relation of Texture to Insoluble and Total Amylose

As shown earlier, the insoluble amylose content of raw rice plays a profound role in the quality of rice, including its texture after cooking (Bhattacharya et al 1978, 1982; Deshpande and Bhattacharya 1982). The present study supported this conclusion. Figure 2 shows that the relationship was true not only for raw rice but also for parboiled rice (for firmness; other textural parameters gave very similar curves and are therefore not shown); all the data for the three sets of samples fell in a single curve. The solubility of amylose in water at 96° C decreased after parboiling (Table III); as a result, the insoluble amylose content (total minus soluble amylose) correspondingly increased. It is not known whether the harder texture of cooked parboiled rice is caused by this increased insoluble amylose or whether the relation is coincidental. Yet the correlation is striking and confirms the importance of insoluble amylose as a quality indicator of rice.

The texture of cooked rice showed a distinct relationship to the amylose content also (Fig. 3), except that there were three separate curves here—for the total amylose, unlike insoluble amylose, remained unchanged after parboiling. The steep upward turn of the curves occurs because the samples of types III, II, and I possessed an almost identical high amylose content but an increasing amount of insoluble amylose (Table II).

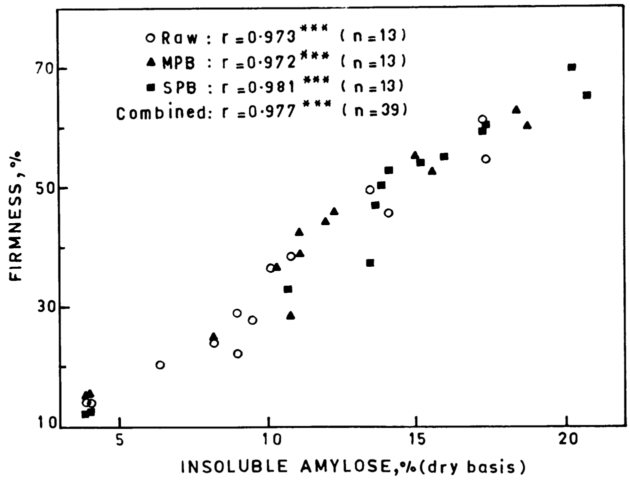

Fig. 2. Relation between insoluble amylose content of raw and parboiled rice and cooked-rice firmness (viscoelastograph).

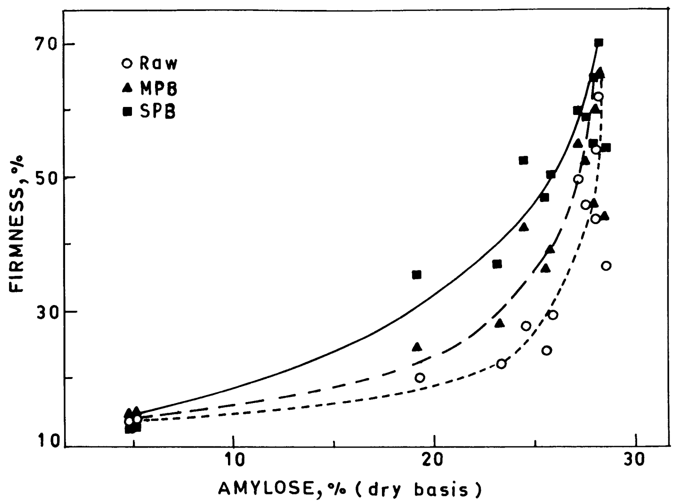

Fig. 3. Relation between amylose content of raw and parboiled rice and cooked-rice firmness (viscoelastograph).

TABLE VII
Statistical Significance of Type-to-Type Gradation in the Sensory Attributes of Texture of Cooked Raw and Parboiled Rice[a,b]

Rice Type	Stickiness			Tenderness			Moistness		
	Raw	MPB	SPB	Raw	MPB	SPB	Raw	MPB	SPB
I	a	a	a	a	a	a	a	a	a
II	b	ab	ab	a	b	bc	ab	ab	ab
III	c	b	bc	b	c	ab	bc	bc	bc
IV	cd	c	cd	b	c	cd	c	cd	cd
V	d	c	d	b	c	d	c	d	d
VII	e	d	e	c	d	e	d	e	e
VIII	f	e	f	d	e	f	e	f	f

[a]Significance of differences among means of scores by type in Table V analyzed by Duncan's new multiple range test. Different letters within a column show statistically significant difference ($P < 0.05$).
[b]MPB = Mildly parboiled; SPB = severely parboiled.

TABLE VIII
Loss of Solids (% dry basis) After Canning Stability Test of Raw and Parboiled Rice[a]

Variety No.[b]	Raw	MPB	SPB	MPB/Raw (%)	SPB/Raw (%)
11	22.3	16.3	10.6	73.1	47.5
12	20.2	14.3	10.1	70.8	50.0
21	22.6	17.1	11.6	75.7	51.3
22	26.2	19.6	14.0	74.8	53.4
31	32.6	24.8	18.5	76.1	56.7
32	30.9	23.0	16.5	74.4	53.4
41	36.4	28.4	23.4	78.0	64.3
42	35.1	28.2	22.7	80.3	64.7
51	34.6	28.8	25.9	83.2	74.8
71	38.5	34.5	33.0	89.6	85.7
72	42.3	36.9	36.1	87.2	85.3
81	55.0	44.8	46.6	81.5	84.7
82	51.9	45.3	49.9	87.3	96.1

[a]MPB = Mildly parboiled; SPB = severely parboiled.
[b]The first digit of the code number identifies the quality type of the rice; the second digit stands for the serial number within the type (Table II).

TABLE IX
Equilibrium Moisture Content Attained After Soaking in Water (EMC-S) of Parboiled Undefatted and Defatted Rice

	Immediate EMC-S (%, db)		Final EMC-S (%, db)		Final/Immediate EMC-S (%)	
Variety	Undefatted	Defatted	Undefatted	Defatted	Undefatted	Defatted
GEB 24	135.3	171.0	84.8	99.2	62.7	58.0
N 10 B	153.8	175.5	78.6	91.6	51.1	52.2

Canning Stability Test

The loss of rice solids after parboil-canning processing is shown in Table VIII. Varieties showing a solid loss of up to about 16–17% under standard conditions are considered suitable for parboil-canning processing (Webb and Adair 1970). According to this criterion, type III rice after severe parboiling (i.e., steaming under 1 kg/cm^2 gauge pressure) and type II rice after mild parboiling (i.e., open steamed) can be considered suitable for the process. More importantly, type I and type II rices after severe parboiling gave far less solids loss and should be far more suitable for parboil-canning processing than American varieties now being processed. This result is one example of how one can achieve a desired end-product quality by exploiting the difference in quality of rice to be parboiled.

The solids loss after the parboil-canning process not only increased from severely to mildly parboiled to raw rice but also systematically from type I to type VII rice, showing again that the initial varietal differences were maintained after parboiling. However, in this case, the relative reduction in solids loss was highest in type I rice and gradually decreased up to type VIII rice. In other words, the effect of parboiling seemed to slightly decrease as the amylose content decreased. This result is slightly at variance with the earlier data.

Nature of Starch Reassociation in Parboiled Rice

As discussed by Bhattacharya and Ali (1985), the nature of starch reassociation after parboiling remains to be clarified. Ali and Bhattacharya (1976) suggested that it could be starch retrogradation, whereas Charbonniere (1975) and Priestley (1976a,b, 1977) thought of it as lipid-amylose complexation. To examine this aspect, the EMC-S values of samples were determined both immediately after parboiling and after final drying and milling; the ratio of final to immediate EMC-S gives an index of the reassociation (Bhattacharya and Ali 1985). Interestingly, this ratio was less than 1.0 (indicating a fall in EMC-S after drying) both in waxy rice, which had little or no amylose, and in the nonwaxy samples (Table III), showing similar starch reassociation in either. Further, both defatted and undefatted samples of milled raw rice, when parboiled by soaking and steaming, gave nearly identical ratios of final-to-immediate EMC-S (Table IX), showing the unimportance of lipid. These two findings cast doubt on the hypothesis that the peculiar properties of parboiled rice are a result of lipid-amylose complexation.

The values of the ratio of final to the immediate EMC-S progressively fell somewhat from type I to type VIII rice (except in the case of waxy, severely parboiled rice; Table III). Apparently, starch reassociation, i.e., the effect of parboiling, increased somewhat from type I to type VIII rice. This finding is in contrast to those where the effect appeared to be more or less constant among the different varieties (Tables III–VI), as well as to the values of solids loss in Table VIII where the effect appeared to increase in the reverse direction. The reasons for these minor differences are not known.

CONCLUSIONS

The above results show that parboiling, carried out under a definite set of processing conditions, affects the various physicochemical and textural parameters of rice by a relatively constant amount, irrespective of the variety being processed. In other words, the differences in various quality parameters that exist among different native rice varieties are largely maintained even after parboiling, but all varieties are modified in a definite manner and to a definite extent.

Two significant practical conclusions emerge from the above conclusion. First, it provides the processor one more tool to produce parboiled rice of any desired quality. For example, instead of using processing conditions that are too severe or too mild, he can select rice from quality types I and II or from types V, VI, and VII for producing parboiled rice of firm or soft texture, respectively. Second, at least some raw-rice consumers—especially those in India, Burma, and Thailand, who are used to high-amylose (types II and III) raw rice—would perhaps accept parboiled rice if it were prepared from rice of quality types V, VI, or VII. In as much as parboiling has profound technological as well as nutritional advantages (Bhattacharya 1985), this conclusion may be of far-reaching significance.

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LITERATURE CITED

ALARY, R., LAIGNELET, B., and FEILLET, P. 1977. Effect of amylose content on some characteristics of parboiled rice. J. Agric. Food Chem. 25:261.

ALI, S. Z., and BHATTACHARYA, K. R. 1972. Hydration and amylose-solubility behaviour of parboiled rice. Lebensm. Wiss. Technol. 5:207.

ALI, S. Z., and BHATTACHARYA, K. R. 1976. Starch retrogradation and starch damage in parboiled rice and flaked rice. Staerke 28:233.

ALI, S. Z., and BHATTACHARYA, K. R. 1980. Pasting behaviour of parboiled rice. J. Texture Stud. 11:239.

ARAI, K., RAGHAVENDRA RAO, S. N., and DESIKACHAR, H. S. R. 1975. Studies on the effect of parboiling on japonica and indica rice. Jap. J. Trop. Agric. 19:7.

BHATTACHARYA, K. R. 1985. Parboiling of rice. Pages 289-348 in: Rice Chemistry and Technology, 2nd ed. B. O. Juliano, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

BHATTACHARYA, K. R., and ALI, S. Z. 1985. Changes during parboiling and properties of parboiled rice. Pages 105-167 in: Adv. Cereal Sci. Technol. Vol. 7. Am. Assoc. Cereal Chem.: St. Paul, MN.

BHATTACHARYA, K. R., and INDUDHARA SWAMY, Y. M. 1967. Conditions of drying parboiled paddy for optimum milling quality. Cereal Chem. 44:592.

BHATTACHARYA, K. R., and SOWBHAGYA, C. M. 1971. Water uptake by rice during cooking. Cereal Sci. Today 16:420.

BHATTACHARYA, K. R., and SOWBHAGYA, C. M. 1979. Pasting behavior of rice: A new method of viscography. J. Food Sci. 44:797.

BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M. 1972. Interrelationship between certain physicochemical properties of rice. J. Food Sci. 37:733.

BHATTACHARYA, K. R., SOWBHAGYA, C. M., and INDUDHARA SWAMY, Y. M. 1978. Importance of insoluble amylose as a determinant of rice quality. J. Sci. Food Agric. 29:359.

BHATTACHARYA, K. R., SOWBHAGYA, C. M. and INDUDHARA SWAMY, Y. M. 1982. Quality profiles of rice: A tentative scheme for classification. J. Food Sci. 47:564.

CAGAMPANG, G. B., PEREZ, C. M., and JULIANO, B. O. 1973. A gel consistency test for eating quality of rice. J. Sci. Food Agric. 24:1589.

CHARBONNIERE, R. 1975. Structure physique de l'amidon du riz natif, etuve, precuit, appertise, retrograde (Physical structure of native, parboiled, precooked, canned, and retrograded rice starch). Bull. Inf. Rizicul. France 160:14.

DESHPANDE, S. S., and BHATTACHARYA, K. R. 1982. The texture of cooked rice. J. Texture Stud. 13:31.

FEILLET, P., and ALARY, R. 1975a. Influence des caracteristiques varietales, de l'etuvage et de l'usinage sur l'aptitude des riz a l'appertisation (Influence of varietal characteristics, of parboiling, and of milling on the suitability of rice for canning). Bull. Inf. Rizicul. France 158:15.

FEILLET, P., and ALARY, R. 1975b. Etuvage du riz. Influence des conditions de traitments et des facteurs varietaut sur les caracteristiques des produits finis (Parboiling of rice. Effect of processing conditions and varietal differences on the quality of the finished product). Ann. Technol. Agric. 24:11.

HARTER, H. L. 1960. Critical values of Duncan's new multiple range test. Biometrics 16:671.

JULIANO, B. O., PEREZ, C. M., BARBER, S., BLAKENEY, A. B., IWASAKI, T., SHIBUYA, N., KENEASTER, K. K., CHUNG, S., LAIGNELET, B., LAUNAY, B., DEL MUNDO, A. M., SUZUKI, H., SHIKI, J., TSUJI, S., TOKOYAMA, J., TATSUMI, K., and WEBB, B. D. 1981. International cooperative comparison of instrument methods for cooked rice texture. J. Texture Stud. 12:17.

LAIGNELET, B., and FEILLET, P. 1979. Use of the viscoelastograph for measuring the texture of cooked rice. Pages 355-361 in: Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst.: Los Baños, Laguna, Philippines.

LEQUERICA, J. L., and TORTOSA, E. 1977. Sancochado de arroces cultivados en Espana. 1. Comportamiento e el proceso (Parboiling of Spanish rice varieties. I. Behavior during the process). Revista Agroquim. Technol. Alimentos 17:42. (Abstr.) Food Sci. Technol. 9:12M1387, 1977.

MANOHAR KUMAR, B., UPADHYAY, J. K., and BHATTACHARYA, K. R. 1976. Objective tests for the stickiness of cooked rice. J. Texture Stud. 7:271.

PEREZ, C. M. 1979. Gel consistency and viscosity of rice. Pages 293-302 in: Chemical Aspects of Rice Grain Quality. Int. Rice Res. Inst.: Los Baños, Laguna, Philippines.

PEREZ, C. M., and JULIANO, B. O. 1979. Indicators of eating quality for non-waxy rice. Food Chem. 4:185.

PRIESTLEY, R. J. 1976a. Studies on parboiled rice. 1. Comparison of the characteristics of raw and parboiled rice. Food Chem. 1:5.

PRIESTLEY, R. J. 1976b. Studies on parboiled rice. 2. Quantitative study of the effects of steaming on various properties of parboiled rice. Food Chem. 1:139.

PRIESTLEY, R. J. 1977. Studies on parboiled rice. 3. Characteristics of parboiled rice on recooking. Food Chem. 2:43.

RAGHAVENDRA RAO, S. N., and JULIANO, B. O. 1970. Effect of parboiling on some physicochemical properties of rice. J. Agric. Food Chem. 18:289.

SOWBHAGYA, C. M., and BHATTACHARYA, K. R. 1979. Simplified determination of amylose in milled rice. Staerke 31:159.

SOWBHAGYA, C. M., RAMESH, B. S., and BHATTACHARYA, K. R. 1987. Relation of cooked-rice texture to other physicochemical characteristics of rice. J. Cereal Sci. 5:287-299.

UNNIKRISHNAN, K. R., and BHATTACHARYA, K. R. 1983. Cold-slurry viscosity of processed rice flour. J. Texture Stud. 14:21.

VITTI, P., LEITAO, R. F. F., and DIZZINATTO, A. 1975. Parboiling of rice varieties (in Portuguese). Coletanca Inst. Tecnol. Alimentos 6:103. (Abstr.) Food Sci. Technol. 8:5M618, 1976.

WEBB, B. D. 1969. Rice quality investigation 1968–1969. Rice J. 72(7):10.

WEBB, B. D., and ADAIR, C. R. 1970. Laboratory parboiling apparatus and methods of evaluating parboil-canning stability of rice. Cereal Chem. 47:708.

WEBB, B. D., BOLLICH, C. N., ADAIR, C. R., and JOHNSTON, T. H. 1968. Characteristics of rice varieties in the U.S. Department of Agriculture collection. Crop Sci. 8:361.

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