Effect of Parboiling on Some Physicochemical Properties of Rice

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Rough rice of seven varieties and selections ranging from 2 to 27% in brown-rice amylose content were used to study the effect of parboiling on grain properties. The improvement of grain translucency and hardness, a disruption of protein bodies, and the gelatinization of the starch granules accompanied parboiling. The protein fractions were less efficiently extracted from parboiled rice. The aminogram of the residual protein of both raw and parboiled rices differed from that of whole protein. The cooked kernels of nonwaxy parboiled rice were shorter, but thicker girthwise, than those of raw rice. The starch of the parboiled rice was less soluble than that of raw rice in cooking water. The changes in amylograph characteristics on parboiling were influenced by amylose content of the samples.

Varietal differences in the parboiling of rough rice have recently been reported in such properties as optimum water temperature during presoaking (Bhattacharya and Subba Rao, 1966a) and the reduction of the starch–iodine blue color (De *et al.*, 1966) and amylose content (Kamal *et al.*, 1967). Previous studies in our laboratory indicated that the amylose content is the most important varietal factor related to the eating quality of milled rice (Juliano, 1968). Since parboiling is known to affect the texture of the resulting cooked rice, this study was undertaken to determine the effect of parboiling on the grain structure, cooking characteristics, and starch and protein properties of seven varieties and selections of known composition.

MATERIALS AND METHODS

Samples of IR8, Acc. 9800, Palawan, PI 215936, Century Patna 231 × SLO 17, IR35-23-2, and IR253-16-1-2 rough rice were obtained from the experimental farm of the institute. They varied in age (storage time at 20° C. since harvesting) from 0.1 to 11 months at the time of parboiling.

Parboiling. Rough rice (2 to 3 kg.) was soaked in water about 5° C. below the starch gelatinization temperature for 6 to 7 hours, drained, steamed for 14 minutes in an autoclave at 100° C. and 0 p.s.i.g. pressure, and air-dried in the laboratory. Presoaking below the gelatinization temperature minimized the splitting of grains. Preliminary experiments showed that shorter steaming times resulted in white-core endosperms due to incomplete parboiling (International Rice Research Institute, 1968).

Raw and parboiled samples were dehulled with a McGill sheller and the resulting brown rice was milled in a McGill miller No. 3 to obtain approximately 4% by weight bran removal from all samples. Contaminant nonwaxy kernels of the waxy selection IR253 (0.6 wt. %) were sorted out by hand and removed. The head rice yield was calculated as a percentage of the total amount of milled rice.

Physical Tests. The mean length and width of 20 kernels of rough, brown, and milled rices were determined. The hardness of brown rice was estimated from 10 kernels using a Kiya-type hardness tester (Vidal and Juliano, 1967). Another hardness test consisted of disintegrating 10 kernels of brown rice in a Wig-L-Bug amalgamator for 40 seconds and determining the percentage by weight that passed through an 80-mesh sieve. Brown rice 100-kernel weight was determined in duplicate.

The alkali test on whole milled rice followed the procedure of Little *et al.* (1958). The loss of weight of milled rice flour after 4 days in 2.2*N* HCl at 35° C. was determined following the procedure of Reyes *et al.* (1965). The cooking time in minutes of the milled rice was determined by the method of Ranghino (1966). Cooking tests were made for 10 minutes on the milled rice sample according to the method of Batcher *et al.* (1956) after presoaking for 2 hours. The water uptake ratio, length and width of cooked grains, and the starch–iodine blue color and solids in cooking water were determined. Preliminary experiments showed that presoaking minimized the difference in cooking time between raw and parboiled samples.

The gelatinization and pasting characteristics of 11 wt.% aqueous suspension of brown rice 40-mesh flour were determined by the procedure of Halick and Kelly (1959) using a Brabender Visco/amylograph with a 700-cm. gram sensitivity cartridge and a cooling cover. Its amylograph curve was comparable to that of a 10% slurry of milled rice. The gelatinization temperature was calculated by subtracting 3° C. from the temperature of the initial viscosity increase (Juliano *et al.*, 1964). Two samples of IR8 and CP 231 × SLO 17 were analyzed.

Sections of raw and parboiled rices were prepared and stained according to del Rosario *et al.* (1968). Both polarizing and phase contrast microscopes were employed. X-ray diffractograms of IR8 brown rice were obtained with a Shimadzu GX-II unit using Cu Kα radiation (Ni filter) as previously reported (Juliano *et al.*, 1969).

Composition. Samples were ground in a Waring Blendor and passed through a 40-mesh sieve. The brown rice flour was analyzed for moisture and crude protein (N × 5.95) (American Association of Cereal Chemists, Inc., 1962), and milled rice flour for moisture, amylose (Williams *et al.*, 1958), and iodine binding capacity (Colburn and Schoch, 1964).

A serial extraction of protein fractions was done on defatted brown rice flour according to Cagampang *et al.* (1966) and the starting and residual samples analyzed for total amino acids with a Beckman Model 120C amino acid analyzer (Beckman Instruments, Inc., 1966). Tryptophan was measured by the method of Spies and Chambers (1949). The intrinsic viscosity of the IR253 milled rices was determined in 1*N* KOH at 30° C. in Ubbelohde dilution viscometers according to Greenwood (1964).

Storage. Parboiled and raw rough rice samples were

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Table I. Range and Mean of Some Properties of Seven Samples of Raw and Parboiled Rice

Property	Raw		Parboiled	
	Range	Mean	Range	Mean
A. Brown rice				
100-kernel wt., g.	1.40– 2.73	2.09	1.43– 2.73	2.11
Length, mm.	5.55– 7.28	6.50	5.54– 7.38	6.38
Width, mm.	2.15– 2.81	2.53	2.08– 2.80	2.47
Hardness (Kiya tester)				
Breaking, kg.	4.6 – 6.4	5.4	6.3 –12.1	9.6
Crushing, kg.	7.8 – 9.9	8.9	14.4 –16.3	15.4
Moisture, % wet basis	10.3 –13.2	11.67	10.8 –12.5	11.63
Protein, % dry basis	7.57–12.8	9.99	7.45–12.7	9.86
Albumin, % dry basis	0.63– 1.40	1.00	0.44– 0.77	0.58
Globulin, % dry basis	0.82– 1.74	1.18	0.26– 0.52	0.41
Prolamin, % dry basis	0.20– 0.40	0.29	0.15– 0.19	0.16
Glutelin, % dry basis	3.98– 6.70	4.95	1.80– 4.33	2.83
Extraction efficiency, %	67.2 –80.0	74.1	24.1 –52.0	41.8
B. Milled rice				
Head rice, % of milled rice	42.4 –92.6	75.3	99.4 –100	99.8
% passing through 80-mesh screen on milling	82.8 –94.8	89.0	28.2 –89.8	48.8
Amylose, % dry basis	2.0 –27.2	17.0	2.0 –27.4	16.4
IBC, % dry basis	0.81– 5.88	3.71	1.02– 6.12	3.75
Four-day linterization loss, wt. %	54.0 –70.4	60.7	72.5 –83.2	77.5
Alkali test values				
Spreading	2.2 – 7.0	4.2	3.3 – 6.0	4.7
Clearing	1.2 – 6.0	3.7	3.0 – 5.7	4.4
Cooking test (presoaked grain)				
Water-uptake ratio	2.52– 3.53	3.09	2.63– 3.12	2.88
Solids in cooking water, %	7.4 –15.8	9.9	4.0 – 7.1	5.5
Blue value of cooking water, abs. 600 mμ	0.14– 0.42	0.31	0.04– 0.31	0.19
Length of cooked grain, mm.	8.8 –12.7	10.6	7.9 –11.0	9.3
Width of cooked grain, mm.	2.3 – 3.2	2.8	2.7 – 3.6	3.2
Length of raw grain, mm.	5.42– 6.88	6.20	5.29– 6.88	6.08
Width of raw grain, mm.	2.04– 2.81	2.48	2.06– 2.72	2.44

stored for 8 months in a sealed bin at an ambient temperature and bimonthly samples were drawn, dehulled, milled, and tested for amylograph and cooking time values. IBC values were determined on the 8-month samples.

RESULTS

While many physical properties of the rice kernel were altered by the parboiling treatment (Table I), the 100-kernel weight of the rice did not change. The treated kernels were shorter or narrower for only two varieties. Three varieties, including the waxy IR253 selection, had essentially the same dimensions for both raw and parboiled samples. Quadrat-i-Khuda *et al.* (1962) and Kurien *et al.* (1964) reported that parboiling and subsequent drying cause a decrease in the length and an increase in the width of rough and brown rice.

Parboiling also made the kernel more translucent, including that of the opaque waxy selection IR253. For almost all samples, the harder texture of the endosperm following parboiling was reflected in the improved head rice yields, crushing and breaking hardness values, and the smaller fraction passing through an 80-mesh screen after disintegration in a Wig-L-Bug amalgamator. The only exception was the 11-month old CP 231 × SLO 17 which did not show a significant drop in the fraction passing through the 80-mesh screen. Similar results have been reported by Indian workers (Bhattacharya and Subba Rao, 1966a; Raghavendra Rao *et al.*, 1967). All the treated samples acquired a light tan color.

The parboiled milled rices were slightly more readily digested in the alkali test. They were difficult to evaluate because of their more translucent kernels. Three varieties gave higher alkali spreading values and two gave lower values following parboiling. Five samples showed higher clearing values and two had lower values as a result of parboiling. The powder of all samples was also more readily corroded with 2.2*N* HCl after parboiling. X-ray diffraction analysis indicated that the steaming process destroyed the *A* pattern of starch, whereas soaking alone enhanced the pattern (Figure 1). A microscopic examination of the powder under polarized light showed that the parboiled rice starch granules were no longer birefringent.

Histological examination of raw and parboiled IR8 endosperms showed that parboiling changed the orderly polyhedral structure of the compound starch granules into a coherent mass (Figure 2). The protein bodies (del Rosario *et al.*, 1968) were no longer distinct. The completely translucent parboiled grains showed complete gelatinization of the starch granules throughout the endosperm.

The intrinsic viscosity of raw and parboiled IR253 milled rice was 112 and 117 ml. per gram, respectively, which indicates no appreciable decrease in the molecular size of the starch and protein as a result of parboiling. Autoclaving for 2 hours at 125° C. has been previously demonstrated as decreasing the intrinsic viscosity of amylopectin (Briones *et al.*, 1968).

The cooking time of the parboiled and raw samples was similar (15 to 20 minutes) except for the low-amylose samples, IR35 and IR253, whose parboiled samples cooked at least 1.5 minutes faster than the raw kernels. The cooking time for parboiled rice was difficult to determine by the Ranghino test because of its relatively translucent center. Storage for 8 months did not change these values.

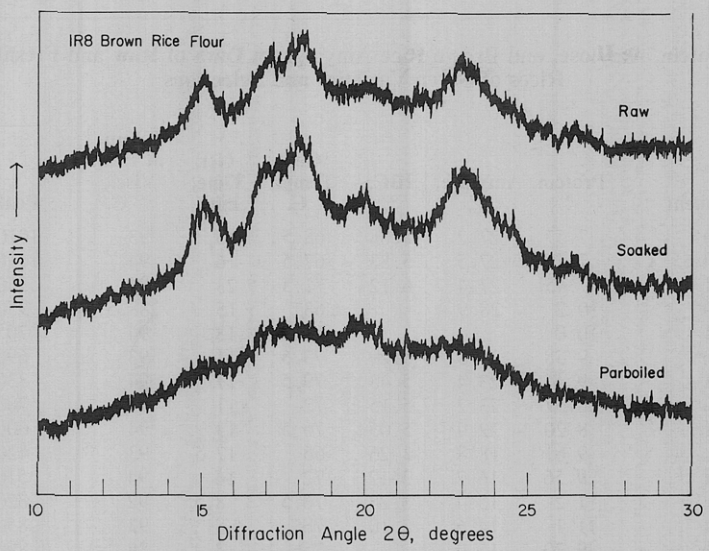

Figure 1. X-ray diffractogram of IR8 brown rice flours

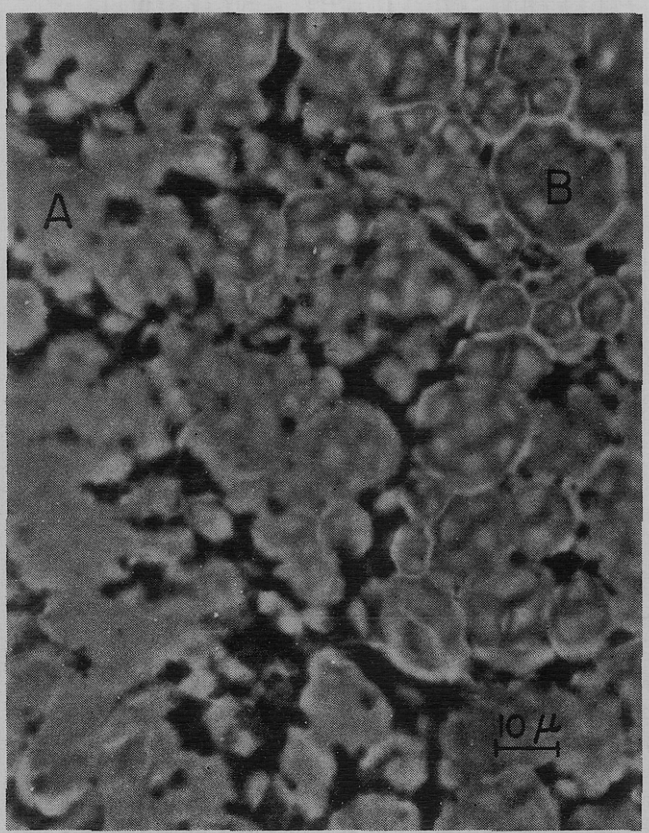

Figure 2. Photomicrograph of an incompletely parboiled rice endosperm stained with hematoxylin showing a gelatinized outer layer (*A*) and an ungelatinized inner portion (*B*) in phase contrast illumination

In cooking tests on presoaked milled rice, the raw samples of three varieties absorbed more water during 10 minutes of cooking than the parboiled rices, while the reverse was true for IR253. In addition, the cooking water of all the raw samples had more dissolved solids and a more intense starch–iodine blue color than that of the parboiled samples. The cooked, parboiled kernels were shorter but wider than the cooked, nonparboiled kernels. Kurien *et al.* (1964) reported similar results for samples cooked to a comparable degree of softness.

Parboiling resulted in interesting changes in the amylograph curve of rice pastes. The temperature of initial viscosity increase was generally higher in the treated samples except for the low-amylose samples IR35 and IR253 (Table II). Although this temperature corresponds to the gelatinization temperature in the raw rices, the latter term cannot be used on the retrograded gelatinized starch of the parboiled samples.

Gelatinization time was taken as the number of minutes required to reach peak viscosity from the first perceptible increase in viscosity. This period was longer for the parboiled samples except for PI 215936 and CP 231 × SLO 17 of intermediate amylose content. In the low-amylose samples IR253, IR35, and CP 231 × SLO 17, peak viscosity occurred at temperatures below 94° C. as was observed in all the raw samples. The treated higher amylose samples had their peak viscosity within the 20 minutes cooking at 94° C. In the case of IR8 and Acc. 9800, distinct peak was not observed and the peak viscosity was almost identical to the final viscosity on cooking at 94° C. Hence, the longer gelatinization time for the parboiled low-amylose samples IR35 and IR253 was due largely to their earlier viscosity increase, and for the high-amylose samples, to the delayed occurrence of their peak viscosity. In general, the temperature of peak viscosity was higher in the parboiled than in the raw samples.

The four amylograph viscosity values were generally less variable in the treated than in the raw samples and reflect reduction in differences of physical structure in the former. A marked decrease in peak viscosity was noted in the higher amylose samples IR8, Acc. 9800, and Palawan. In the PI 215936 samples which had intermediate amylose content, the peak viscosity of the parboiled sample was higher than that of the raw sample. The drop in viscosity on cooking at 94° C., relative to peak viscosity, was generally lower in the treated samples. Final viscosity values on cooling to 50° C. were higher in the parboiled samples except in the high-amylose samples IR8 and Acc. 9800. The viscosity values of the waxy selection IR253 were the least affected by parboiling among the samples. Soaking the IR8 raw rice for 6 hours at 60° C. (below its gelatinization temperature) had little effect on its amylogram. This soaking process also did not decrease the degree of crystallinity of the starch (Figure 1). The parboiled samples usually had an initial viscosity 5 to 20 B.U. above the base line.

The IR8 and CP 231 × SLO 17 samples used in the study were much older than the other five samples so that their raw samples were already aged and had relatively higher amyl-

Table II. Protein, Amylose, and Brown Rice Amylogram Data of Raw and Freshly Parboiled Rices of Seven Varieties and Selections

Variety/Selection	Treatment	Protein, %	Amylose, %	IBC, %	Gel. Temp., ° C.	Gel. Time, min.	Temp. at Peak Visc., ° C.	Viscosity, B.U.[a] Peak	Initial at 94° C.	After 20 min. at 94° C.	Cooled to 50° C.
IR8	Raw (5.5)[c]	7.57	27.2	5.88	68.5	15	93	1010	1000	800	1570
	Soaked at 65° C.	7.78	27.5	5.83	67.5	16	94	1110	1110	980	1650
	Parboiled	7.45	27.4	6.12	71.5	23	94	350	120	350	530
IR8[b]	Raw (0.5)[c]	10.2	28.9		63	15	88.5	950	885	790	1395
	Parboiled	10.0			82.5	18	94	705	400	695	1200
Acc. 9800	Raw (0.1)[c]	9.58	24.9	5.29	73.5	11	93	690	560	385	630
	Parboiled	9.44	23.4	5.43	79.5	17	94	330	225	325	605
Palawan	Raw (1.5)[c]	8.57	23.2	5.15	72	11	91	780	520	385	645
	Parboiled	8.20	22.9	5.05	76.5	13	94	600	540	535	960
PI 215936	Raw (1)[c]	9.61	18.8	3.26	66	17.5	93	420	410	230	380
	Parboiled	9.56	16.7	3.12	72	16	94	510	460	495	720
CP 231 × SLO 17	Raw (11)[c]	11.2	15.4	3.23	76.5	8.5	92	820	600	420	640
	Parboiled	11.1	14.6	3.10	78	8	93	850	700	525	765
CP 231 × SLO 17[b]	Raw (0.5)[c]	9.20	15.0		75	7	88	890	510	455	580
	Parboiled	9.06			75	10	94	940	935	680	950
IR35-23-2	Raw (1)[c]	12.8	7.5	2.40	75.5	8	90	950	520	435	630
	Parboiled	12.7	7.7	2.44	57	20	91	690	615	570	790
IR253-16-1-2	Raw (1)[c]	10.6	2.0	0.81	64	5.5	75.5	415	305	290	355
	Parboiled	10.6	2.0	1.02	32	33	84	410	375	340	415

[a] 11% paste. B.U. = Brabender units. [b] Additional samples. [c] Age of samples in months.

Table III. Amylose and Brown Rice Amylogram Data of Five Raw and Parboiled Rices after Storage for Eight Months

Variety/Selection	Treatment	Amylose, %	IBC, %	Gel. Temp., ° C.	Gel. Time, min.	Temp. at Peak Visc., ° C.	Viscosity, B.U.[a] Peak	Initial at 94° C.	After 20 min. at 94° C.	Cooled to 50° C.
Acc. 9800	Raw (8.1)[b]	21.4	4.09	82	5.5	93.5	960	820	620	790
	Parboiled	20.5	4.30	87	6.5	94	480	300	480	815
Palawan	Raw (9.5)[b]	20.5	4.22	73.5	10	92	955	860	580	660
	Parboiled	20.0	4.17	84	7	94	670	520	640	995
PI 215936	Raw (9)[b]		2.23	75	9	93	640	640	450	515
	Parboiled		3.06	79.5	20	94	460	240	450	720
IR35-23-2	Raw (9)[b]		2.38	76.5	7	90	1065	700	525	735
	Parboiled		2.03	85	11.5	94	550	420	560	725
IR253-16-1-2	Raw (9)[b]	3.3	0.39	66	4.5	75	660	550	520	490
	Parboiled	3.0	0.47	40.5	27	81	400	365	340	400

[a] 11% paste. B.U. = Brabender units. [b] Age of samples in months.

ograph values than freshly harvested rice. Freshly harvested samples of these two varieties were parboiled and the effect of parboiling on their amylograph characteristics was determined. The changes in the amylograph characteristics of these new samples after parboiling were in the same direction as those of the aged samples.

Most of the amylograph characteristics showed changes after storage of the samples for 8 months (Table III). The temperature of initial viscosity increase was higher after storage for all samples. The greatest change, from 57° to 85° C., was in the treated IR35 sample. This temperature of initial viscosity increase exceeded the gelatinization temperature of the aged raw IR35 sample. However, in the waxy sample, it was still lower in the parboiled sample even after 8 months of storage.

Gelatinization time in the stored rice samples was much longer in the three treated low-amylose samples than in the nonparboiled ones. Only the parboiled waxy IR253 sample had a peak viscosity of below 94°C. The longer gelatinization time of parboiled IR253 as compared to the raw sample was due to the lower temperature of viscosity increase and the higher temperature at peak viscosity. Peak viscosity in IR35, PI 215936, and Palawan occurred during the cooking phase at 94° C. The longer gelatinization time of parboiled IR35 and PI 215936 was due to the delayed peak viscosity, in spite of their higher temperature of initial viscosity increase relative to the raw samples. In treated Acc. 9800 and Palawan, the differences in gelatinization time from the raw rices were less because the peak occurred early during the cooking phase despite their higher temperature of initial viscosity increase.

All the raw samples showed increases in the four amylogram viscosity values during storage. Among the parboiled samples, the peak viscosity increased on storage in Acc. 9800 and Palawan, decreased in PI 215936 and IR35, and did not change in IR253. In fact, the viscosity values of the freshly parboiled and the stored IR253 samples were essentially the same.

The protein content dropped slightly during parboiling (Table I) probably because of leaching out of nonprotein nitrogen and albumin. Only Palawan showed a significant decrease in protein. However, the extractability of all the protein fractions decreased by an average of 45% following parboiling, with globulin being most affected on a percentage

decrease basis, and glutelin on a weight basis. The only exception was the similarity of the prolamin level of raw and parboiled Acc. 9800. Raw and parboiled brown rice showed differences in the amino acid pattern between whole and residual protein after serial protein extraction (Table IV). The residual protein had lower levels of arginine and lysine and higher levels of alanine, glutamic acid, leucine, methionine, serine, and threonine. The absence of cystine may have been due to alkaline decomposition during glutelin extraction (Concon, 1966). The aminogram of IR8 brown rice protein was similar to that of earlier analyses (Palmiano *et al.*, 1968).

The amylose content determined potentiometrically (iodine binding capacity, IBC) did not change in any variety after parboiling (Table II). Parboiled PI 215936 and CP 231 × SLO 17 rice had lower colorimetric amylose levels than the raw samples. Storage, however, caused a drop in the IBC of the starch in most raw and parboiled samples (Table II). When starch was extracted from the aged samples with 50% $HClO_4$ and its amylose content determined colorimetrically (McCready *et al.*, 1950), the amylose content was the same as in the starting materials. Slightly lower values were obtained by the method of Williams *et al.* (1958).

Table IV. Mean Aminogram of Raw and Parboiled Brown Rice of Seven Samples before and after Serial Extraction of Proteins, Grams per 16.8 Gram N[a]

	Raw		Parboiled	
Amino Acid	Whole	Residue	Whole	Residue
Alanine	5.49	6.97	5.67	7.22
Arginine	9.04	4.10	8.27	5.78
Aspartic acid	8.74	9.67	9.57	10.1
Cystine	1.25	...	1.32	...
Glutamic acid	20.6	25.9	19.0	24.0
Glycine	4.96	4.72	4.62	5.47
Histidine	2.44	2.18	2.35	2.26
Isoleucine	4.66	5.95	4.24	4.66
Leucine	9.96	12.0	8.56	9.96
Lysine	3.51	1.86	3.54	2.12
Methionine	2.54	4.21	2.20	3.38
Phenylalanine	6.80	7.10	5.23	6.80
Proline	6.24	6.07	4.74	6.50
Serine	5.57	6.22	5.70	7.30
Threonine	3.49	4.49	3.72	4.73
Tryptophan	1.70	n.d.	1.55	n.d.
Tyrosine	4.73	4.35	4.02	4.73
Valine	6.00	6.97	5.85	7.32
Ammonia	2.08	2.66	2.32	1.76

[a] Recalculated to 95% nitrogen recovery.

DISCUSSION

Protein and amylose assays and the 100-kernel weight indicated very little change in the gross composition of the grain as a result of parboiling. However, the gelatinized starch and the disrupted protein bodies seemed to have expanded and occupied all the air spaces in the endosperm. The expansion would explain the improved translucency of parboiled rice. Both the opaque white belly of IR8, caused by the loose arrangement of starch granules (del Rosario *et al.*, 1968), and the opaque waxy endosperm of IR253 disappeared. Mahadevappa and Desikachar (1968) also reported the destruction of oil globules in the aleurone layer by parboiling.

The increased hardness of the endosperm probably reflects the greater adhesion/cohesion between starch granules and protein bodies in parboiled rice. The increased adhesion/cohesion can also help explain the reduced extractability of the protein fractions and the reduced starch solubility in the cooking water. Rice starch–protein interaction has recently been demonstrated by Takeuchi *et al.* (1967). The poorer staining for protein in sections of parboiled rice was previously interpreted as a movement of protein to the aleurone layer during parboiling (De and Rahman, 1965). It might be equally well explained by the masking of protein by the gelatinized starch. It is improbable that rice endosperm protein, which is 90% high molecular weight water-insoluble glutelin (Cagampang *et al.*, 1966), would readily diffuse outward through the cell walls of the endosperm during the short steaming period of parboiling.

Some similarities were noted in the grain properties changes occurring during parboiling and storage or aging. Both resulted in the reduced solubility of milled rice starch during cooking. Similar results have been demonstrated following a heat treatment with either hot water (Kurien *et al.*, 1964; Bhattacharya and Subba Rao, 1966b) or hot air (Bhattacharya *et al.*, 1964; Normand *et al.*, 1964). A reduction in the extractability of protein fractions (Narayana Rao *et al.*, 1954; Primo *et al.*, 1968) and the IBC of starch (Primo *et al.*, 1962) has also been reported as resulting from the storage of milled rice. Although the IBC was not changed by parboiling, the subsequent storage of raw and parboiled samples for 8 months resulted in the reduction of the IBC of most samples when $CaCl_2$ was used as the solvent. Defatting the rice with refluxing ethanol before analysis did not improve the IBC values. When measured by colorimetry using 50% $HClO_4$ or 1*N* NaOH as a solvent, the amylose content of the aged samples was equal to that before aging. The differences in amylose content as indicated by the two solvents may be accounted for by the reduced solubility of starch in $CaCl_2$. Since very little change in the gross composition of the grain occurred during storage, these reduced starch and protein solubilities during storage must be a result of their increased association. No change in IBC was noted in a previous 2-year storage study on rough and milled IR8 rice and its starch (IRRI, 1968). Colorimetric amylose content was also reported to remain constant during rice storage by Hogan (1963).

The changes in the amylograph characteristics of the rice samples on parboiling may be partly ascribed to their differences in amylose content. The degree and the rate of retrogradation of gelatinized starch are related to the amylose content of the starch (Juliano *et al.*, 1964). Only the low-amylose parboiled samples IR253 and IR35 readily swelled and dispersed at lower temperatures during pasting than the corresponding raw samples. During the 8-month storage, the "gelatinization" temperature of IR35 exceeded that of the raw sample, reflecting its slower retrogradation during storage in contrast to the other higher amylose nonwaxy samples. The parboiled waxy sample IR253 still had a lower gelatinization temperature than its raw counterpart, since it should have the slowest rate of retrogradation among the treated samples.

The drop in amylograph peak viscosity resulting from parboiling has been ascribed by Kamal *et al.* (1967) to a higher amylase activity in parboiled rice. Conditions during the steaming phase of parboiling were severe enough to inactivate any amylases present. Ferrel and Pence (1964) previously reported that viscosity drops with increased cooking of the rice grain. Because this drop in peak viscosity was not observed in all the samples we examined, the greater extent of retrogradation in the higher amylose parboiled samples may help explain their low and delayed peak viscosity, reflecting

greater resistance to breakdown. However, the absence of a general relationship between amylose content and peak viscosity drop in these samples must have been due to the fact that parboiled starch has not been completely cooked and that the residual physical structure of the starch granule has also affected its pasting properties (Hofstee, 1962).

The observed resistance of high-amylose varieties such as IR8 to disintegration after gelatinization may be related to the observed *in situ* retrogradation of amylose in high amylose samples in the starch–iodine blue test (Juliano *et al.*, 1968). Hagberg (1967) claimed that some high-amylose rice varieties become extremely firm on parboiling. The starch–iodine blue test may be used to detect such high-amylose varieties.

De *et al.* (1966) reported that of 17 varieties of Pakistani rice, parboiling caused a decrease in 11 varieties of the intensity of starch–iodine blue value at 600 mμ with a decrease in the λ_{max} by 10 to 30 mμ, whereas the other six varieties showed greater blue values without any shift in λ_{max}. They attributed these results to enzymic interconversion of the two starch fractions. The same results might be readily explained by varietal differences in degree of amylose retrogradation during parboiling. The reduced iodine blue staining of the starch in sections of these parboiled rice, particularly IR8, may also be similarly explained. Quadrat-i-Khuda *et al.* (1962) also reported varietal differences in the color change from blue to violet or pink of starch–iodine staining following parboiling.

Aside from the loss of viability of the rice, parboiling affected the physical more than the chemical properties of the grain.

Various aspects of parboiling and aging require further study to resolve conflicting results and to determine the cause or causes of the observed reduction in solubility of starch and protein. For example, Ferrel and Pence (1964) reported that the fat fraction of brown rice has little effect on its amylograph curve. In contrast, Yasumatsu *et al.* (1964) demonstrated that the increase in the amylograph peak viscosity of milled rice during storage is, to a large extent, due to its fatty acid fraction.

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