Studies on the Physicochemical Properties of Rice

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Studies of nonglutinous *indica* and *japonica* rice revealed significant correlations between varieties and chemical composition of rough, brown, and polished rice. *Indica* rice varied more in physicochemical properties than *japonica* rice. In polished rice, significant negative correlations were found between the protein content and content of lysine, methionine, and threonine. Also, there were positive correlations between protein content and content of tyrosine, arginine, and leucine. Various cooking quality tests were determined on the polished rice samples, and their interrelations and correlations with chemical composition were studied. The relationships between physicochemical properties and cooking quality of rice are reviewed.

RICE (*Oryza sativa* L.) is the most important food in Asia, but from the standpoint of quality, it is the least studied among the cereal grains of commerce. Although some correlations have been reported on the relationship between amylose (*6, 17, 55, 69*) or protein (*27, 53*) and certain cooking quality characteristics, the data lack determinations of protein and amylose contents and quality characteristics in the same samples. Both the starch and nonstarch constituents of the polished rice influence cooking characteristics (*36*). The history and age of the rice samples studied complicate correlation studies since these factors are known to affect cooking quality (*12, 23*). Most of the studies have dealt with objective measurements of physical characteristics as indices of cooking quality (*4, 9, 37, 50, 56*).

It was deemed important to determine initially the existing chemical and physical characteristics of samples of both *japonica* and *indica* rice with the same history, and thus establish a basis for further quality studies.

Experimental

Materials. The 16 varieties of rice studied were grown on the Institute's irrigated farm in seed multiplication plots during both seasons of the crop year 1961–62. These consisted of 12 *indica* varieties—Radin Kling, Chinsurah 35, Kolamba 42, Taichung 1, Bir-me-fen, Toro, Gulfrose, Century Patna 231, Rexoro, Texas Patna, Peta, and Milfor 6(2); and four *japonica* varieties—Taichung 65, Chia-nan 8, Kaohsiung 53, and Kaohsiung 68. Century Patna 231 and Kaohsiung 68 are *indica* × *japonica* hybrids.

Two-hundred seedlings of each variety were transplanted, one plant per hill with 25 cm. between hills, in rows 25 to 30 cm. apart. Fertilizer 30–9–0 (30–20–0) was applied at the rate of 100 kg. per hectare. The first crop was grown during the dry season from November 1961 to April 1962, whereas the second or wet season crop was grown from May to November 1962. The mean maximum daily temperature recorded during these two periods was 28.8° and 31.4° C., respectively.

Methods. The clean, dried rough rice samples were milled by a standard method (*62*). The second crop was cleaned further, however, with a South Dakota Seed Blower. The moisture content of the samples was less than 14% prior to milling, as checked by a Steinlite Model 500 RC Electronic Moisture Tester. All samples were dehulled with the McGill Sample Sheller, and the resulting brown rice was polished in the McGill Miller No. 3 for the larger samples, and in the McGill Rice Miller for the smaller samples. The polished rice samples were cleaned in the Bates Laboratory Aspirator.

The first-crop samples of rough, brown, and polished rice were subjected to detailed proximate analyses. The second crop was less extensively analyzed. Samples of rough, brown, and polished rice for chemical analyses were ground in a Wiley standard laboratory mill with a 16-mesh sieve and stored at 0° C. in stoppered bottles. These ground samples were analyzed, in duplicate, by standard methods (*2*). Moisture was determined by the loss of weight after 5 hours at 98°–100° C. in a vacuum oven. Crude fat was estimated with a Goldfisch extractor using petroleum ether. Macro-Kjeldahl nitrogen was determined using a mercuric oxide–potassium sulfate catalyst, and the nitrogen values were converted to protein values with the factor of 5.95, as recommended by Jones (*25*). Crude fiber and ash also were determined. The carbohydrate, or nitrogen-free extract (NFE), content was calculated by difference. The data were recalculated on the dry basis. The 100-grain weight of brown rice and the mean length and width of 10 kernels of rough rice were estimated.

Amylose was estimated on the defatted rice powder by the iodine-colorimetric method of McCready and Hassid (*40*), as modified by Williams and coworkers (*75*), using amylose from Nutritional Biochemicals Corp. as a standard. A Bausch and Lomb Spectronic 20 spectrophotometer was used for the absorbance reading at 590 mμ. Pentosans content of polished rice was estimated by the standard method (*2*) of destructive acid distillation and gravimetric estimation of the phloroglucide of furfural. Starch was calculated by subtracting pentosans content from NFE content.

For the estimation of pentosans composition, about 10 mg. of rice powder (at least 0.1 mg. of pentosans) was hydrolyzed in a sealed tube with 10 ml. of 2% H_2SO_4 for 5 hours at 120° C. (*61*). This procedure gave complete hydrolysis of a 98:2 mixture of rice starch (Matheson Coleman & Bell) and xylan (Nutritional Biochemicals Corp.). The hydrolyzate was neutralized with saturated barium hydroxide and its pH adjusted to 6.8 with barium carbonate. The supernatant liquid was separated by centrifugation and, together with washings, concentrated under reduced pressure at a temperature below 55° C. Aliquots of these samples and of a standard solution of glucose, arabinose, and xylose (98:1:1) were spotted on Whatman No. 1 filter paper, developed with the solvent ethyl acetate–pyridine–water (8:2:1) (*24*) for at least 24 hours, and air-dried. The chromatograms were

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sprayed with alkaline silver nitrate (*70*), and the concentrations of the xylose and arabinose spots were estimated with a Photovolt densitometer (5-mm. aperture and no filter), after the method of McFarren, Brand, and Rutkowski (*47*). The results were expressed as the arabinose-to-xylose ratio.

The amino acid composition of the polished rice samples was estimated by using ion exchange elution chromatography (*45*, *63*) with a Beckman Model 120B Amino Acid Analyzer. Samples containing approximately 3.5 mg. of protein were weighed accurately with a microbalance and were hydrolyzed in an evacuated sealed tube at 110° C. for 22 hours with 1 ml. of a 1:1 by volume mixture of reagent-grade concentrated HCl and distilled water. The samples then were chilled, and the black precipitate (humin) was removed by centrifugation. The HCl was removed by evaporation under reduced pressure of the sample to dryness. The dried samples were dissolved in 5.0 ml. of the pH 2.2 buffer, and light-tan colored hydrolyzates were stored at 4° C. until analyzed. The Beckman standard mixture of 1.0 μmole each of 18 amino acids was used in calibrating both the 150-cm. and the 15-cm., 0.9-cm. diameter columns. The average reproducibility of recovery obtained for the 18 amino acids was 100 ± 3%. Data were expressed as percentage of amino acid in rice proteins on the basis of 16.8% nitrogen content. The methionine values reported include those for methionine sulfoxides. Satisfactory amino acid composition data were obtained for two reagent-grade proteins.

Quality tests run on the polished rice samples were gelatinization temperature, alkali test, starch–iodine-blue test, and amylography. The gelatinization temperature was estimated by observing under polarized light the birefringence end point temperature (BEPT) of samples of a dilute (0.5%) aqueous suspension of rice starch granules, as its temperature was increased slowly at the rate of 0.5° C. per minute. Polished rice was triturated with distilled water, and the resulting suspension was placed in a water bath initially at 50° C. Samples were withdrawn after every degree of rise in temperature and examined under a polarizing microscope at high magnification (500×). The temperature range at which individual starch granules lose anisotropy was recorded as the gelatinization temperature.

The alkali test was performed in triplicate on the polished whole-grain samples, as described by Little and coworkers (*37*), with Century Patna 231 as a standard. Each replicate test sample of six grains was soaked for 23 hours in 10 ml. of 1.5% KOH for the first crop and in the same volume of 1.7% alkali for the second crop. The optimum concentration of alkali was confirmed to be 1.7%.

The starch–iodine-blue test at 77° C. for the dry season samples followed the procedure of Halick and Keneaster (*20*). An Eberbach water bath-shaker with a flat cover was employed. The results were expressed as per cent transmittance, measured with a Bausch and Lomb Spectronic 20 colorimeter at 600 mμ.

The gelatinization and pasting viscosity of the polished rice was estimated by the procedure of Halick and Kelly (*19*) on samples ground in the Wiley mill with the 0.5-mm. sieve. The C. W. Brabender Visco-Amylograph, with the 700-cm. gm. sensitivity cartridge and with cooling cover, was employed.

Table I. Dimensions and Chemical Composition of Rough Rice[a]

Variety	Origin	Kernel Dimensions, Mm. Length	Width	Crude Protein,[b] %	Crude Fiber, %	Crude Fat, %	Ash, %	NFE, %
Indica								
Radin Kling	Malaya	8.0	2.9	6.72	10.66	1.78	6.93	73.91
Chinsurah 35	India	7.2	2.4	7.83	10.39	2.00	8.74	71.04
Kolamba 42	India	7.2	2.4	11.24	11.72	2.57	7.70	66.77
Taichung 1	Taiwan	7.8	3.5	9.39	10.35	1.81	6.77	71.68
Bir-me-fen	Taiwan	8.2	3.1	9.11	12.17	2.14	6.73	69.85
Gulfrose	U.S.A.	8.2	3.2	10.77	10.54	2.19	6.92	69.58
Century Patna 231	U.S.A.	9.3	2.5	11.38	10.15	2.31	8.22	67.94
Toro	U.S.A.	9.2	2.7	10.57	10.75	2.15	8.38	68.15
Rexoro	U.S.A.	8.8	2.4	11.25	8.62	2.22	7.27	70.64
Texas Patna	U.S.A.	9.0	2.3	10.65	9.35	2.61	7.54	69.85
Peta	Philippines	9.0	2.8	6.07	10.93	1.79	6.63	74.58
Milfor 6(2)	Philippines	9.5	3.1	7.71	10.05	2.10	7.39	72.75
Japonica								
Taichung 65	Taiwan	7.4	3.6	8.60	8.96	2.10	6.40	73.94
Chia-nan 8	Taiwan	7.1	3.5	7.85	9.60	2.33	6.44	73.78
Kaohsiung 53	Taiwan	7.0	3.4	8.30	9.61	1.98	6.44	73.67
Kaohsiung 68	Taiwan	7.2	3.7	8.84	9.51	2.03	6.45	73.17
Mean				9.14	10.21	2.13	7.18	71.33
Analysis of variance								
Std. error				0.04	0.16	0.03		
Significant mean diff.				0.12	0.48	0.09		
F-value				1270[c]	35.8[c]	60[c]		

[a] First crop, composition expressed on moisture-free (dry) basis. [b] N × 5.95. [c] Highly significant.

Results and Discussion

In general, the *indica* varieties varied more in physical properties and chemical composition than did the *japonica* varieties for rough, brown, and polished rice.

Rough Rice. The chemical composition of rough rice varied significantly among varieties (Table I). The U.S. varieties showed much higher protein contents than did the varieties from Asia, except for Kolamba 42, but had lower yields. The carbohydrate content was highly significant, but negatively correlated with the protein content, the correlation coefficient being −0.85. These compositional data for rough rice closely agree with those reported by McCall and coworkers (*38*), except that the protein contents are higher. These high protein contents also are evident in the corresponding brown and polished rice samples discussed below.

Brown Rice. The chemical composition of brown rice of the first crop also varied significantly among varieties (Table II). A wide variation in percentage of crude protein was noted. The Asian varieties were generally of lower protein contents than the U.S. samples. Exceptions were Kolamba 42 in the first crop and Taichung 1 and Bir-me-fen in the second crop, which had as high protein contents as the U.S varieties. The protein contents obtained for the U.S. varieties were higher than the 7.38 to 10.82% range reported by Sturgis, Miears, and Walker (*66*) for 29 U.S. varieties and selections. Lindner and coworkers (*35*) found crude protein ranging from 6.00 to 13.61% for 40 varieties of rice in Hungary. A highly significant correlation coefficient of −0.99 was obtained between crude protein and NFE contents. The wide range of protein and crude fat contents for the samples was verified by the chemical analysis of the second crop (Table II). The kernels of the second crop, although generally lighter in weight than those of the first crop, were, in general, higher in protein and fat. Dehulling of rough rice drastically reduced the ash and crude-fiber contents of rice.

The amino acid analysis of brown rice samples of both crops of Texas Patna, Peta, and Kaohsiung 68 showed that the principal acids were glutamic and aspartic (Table III). Peta contained

Table II. Chemical Composition[a] and One-Hundred Grain Weights of Brown Rice

	First Crop						Second Crop		
Variety	100-Grain weight, grams	Crude protein,[b] %	Crude fiber, %	Crude fat, %	Ash, %	NFE, %	100-Grain weight, grams	Crude protein,[b] %	Crude fat, %
Indica									
Radin Kling	1.62	8.66	1.00	2.47	1.71	86.16	1.71	11.70	3.08
Chinsurah 35	1.47	9.49	1.00	2.69	1.71	85.11	1.35	9.20	3.08
Kolamba 42	1.13	13.38	2.57	2.76	1.92	79.37	1.65	10.98	2.72
Taichung 1	2.08	11.85	1.46	2.52	1.78	82.39	1.75	14.23	2.58
Bir-me-fen	1.67	10.92	1.12	2.54	1.80	83.62	1.54	13.65	2.38
Gulfrose	2.10	13.03	1.20	2.68	2.08	81.01	1.79	14.49	2.76
Century Patna 231	1.69	13.42	1.11	3.03	2.13	80.31	1.50	14.77	3.18
Toro	1.65	12.94	1.30	2.72	1.97	81.07	1.41	15.35	3.40
Rexoro	1.66	13.46	1.25	2.81	2.08	80.40	1.59	13.28	3.72
Texas Patna	1.66	13.06	1.10	3.13	2.07	80.64	1.49	13.59	3.91
Peta	2.31	7.32	0.83	2.37	1.53	87.95	2.25	9.52	2.54
Milfor 6(2)	2.48	9.45	1.08	2.71	1.71	85.05	2.51	11.07	3.22
Japonica									
Taichung 65	2.38	10.03	1.10	2.66	1.90	84.31	1.95	11.96	2.92
Chia-nan 8	1.98	9.28	1.17	3.05	1.80	84.70	1.76	11.84	2.95
Kaohsiung 53	1.95	9.67	1.18	2.76	1.76	84.63	1.85	12.20	3.26
Kaohsiung 68	2.12	10.39	1.14	2.58	1.83	84.06	1.86	12.52	3.40
Mean	1.87	11.02	1.23	2.72	1.86	83.17	1.75	12.52	3.07
Analysis of variance									
Std. error		0.14	0.04	0.03				0.16	0.07
Significant mean diff.		0.42	0.12	0.09				0.46	0.22
F-value		200.5[c]	75[c]	45[c]				1114[c]	31[c]

[a] Dry basis. [b] N × 5.95. [c] Highly significant.

Table III. Amino Acid Composition (%) of Brown Rice[a] (Three Varieties)

	First Crop			Second Crop				Reported Values	
Amino Acid	Texas Patna	Peta	Kaohsiung 68	Texas Patna	Peta	Kaohsiung 68	Mean	Kik (28)	Adda (1)
Alanine	5.94	6.24	6.07	5.63	5.36	6.70	5.99		
Arginine	8.23	7.40	7.70	7.63	6.49	8.98	7.74	9.02	8.9
Aspartic acid	10.07	9.56	10.11	11.18	8.40	13.24	10.43	4.82	5.2
Cystine	1.25	1.27	0.96	1.08	1.12	1.14	1.14	1.71	0.9
Glutamic acid	20.80	20.61	21.07	19.72	18.21	21.77	20.36	11.69	13.5
Glycine	4.84	5.06	4.98	4.74	4.35	5.80	4.96	6.41	
Histidine	2.12	2.30	2.30	2.32	2.11	2.74	2.32	3.13	
Isoleucine[b]	3.90	3.86	3.80	3.86	3.60	4.33	3.89	4.84	12.4[c]
Leucine[b]	8.37	7.97	10.05	7.92	6.90	6.89	8.02	7.98	
Lysine[b]	3.39	4.14	3.50	3.32	3.40	4.31	3.68	3.74	3.4
Methionine[b]	2.13	2.99	2.03	2.34	2.26	2.95	2.45	3.27	
Phenylalanine[b]	4.94	4.96	5.42	4.99	4.36	6.28	5.16	4.43	4.3
Proline	4.73	4.90	4.85	4.55	4.28	5.44	4.79	5.27	
Serine	4.24	5.11	5.39	5.07	5.45	6.13	5.23	4.56	3.9
Threonine[b]	3.67	4.01	4.77	3.58	4.16	4.40	4.10	3.85	2.8
Tyrosine	3.75	2.40	3.78	3.79	2.64	3.64	3.33	4.13	3.9
Valine[b]	5.63	5.86	5.87	5.42	5.06	6.18	5.67	7.13	7.08
Ammonia	1.91	2.34	2.42	2.29	2.10	2.77	2.30		
Total	99.91	100.98	105.07	99.43	90.25	113.69	101.56		
Recovery, % of total N	88.8	91.4	94.1	89.5	81.4	105.3	91.7		
Crude protein, %	13.06	7.32	10.39	13.59	9.52	12.52			

[a] Calculated to 16.8% of N. [b] Nutritionally essential to man (*57*). [c] Content of isoleucine and leucine.

the lowest tyrosine content of the three varieties. The analyses obtained were much higher in glutamic and aspartic acid contents than those reported by Kik (*28*) through microbiological assays and by Adda and Rivoire (*1*) by paper chromatography.

Polished Rice. The contents of crude protein, crude fiber, and ash varied greatly among varieties (Table IV). This variation was not observed in crude fat content. The crude protein contents of about one half of the varieties are higher than the range of 5 to 10% protein reported for polished rice (*38*). A highly significant correlation coefficient of −0.99 was obtained between the crude protein and NFE contents. This correlation was previously reported by McCall and coworkers (*39*) for eight U.S. rice varieties. The protein content of the second crop was higher. Polished rice on the average had more than 8% lower protein content than brown rice, and this content was essentially a linear function of the protein content of brown rice. Crude protein and ash contents were highly significantly, positively correlated.

The compositions of starch, pentosans, and crude protein of polished rice were estimated in the first crop without prior isolation of these constituents. The amylose content of polished rice varied significantly among the varieties. Expressed as percentage of total starch, the mean amylose content was 27.1%, ranging from 15.9 for Toro to 36.6 for Bir-me-fen. The *indica* varieties had a wider range of amylose values than did the *japonica* samples. The values of 15.9 to 28.0% for the U.S. varieties compare with those reported by Williams and coworkers (*75*) and by Beachell and Stansel (*6*). The starch of all the Asian *indica* samples contained more than 30% amylose. This contrasts with the 17.5% maximum amylose content reported for Indian-rice starch by Rao, Murthy, and Subrahmanya (*55*) as determined by iodine-potentiometric titration (*5*).

Table IV. Chemical Composition (%) of Polished Rice[a]

Variety	First Crop: Crude protein[b]	Crude fiber	Crude fat	Ash	NFE	Amylose	Pentosans	A/X[c]	Second Crop: Crude protein[b]	Amylose	Pentosans A/X[c]
Indica											
Radin Kling	7.39	0.14	0.55	0.54	91.38	28.3	1.11		9.10	23.0	
Chinsurah 35	8.49	0.40	0.50	0.50	90.11	29.2	1.82		8.82	28.5	
Kolamba 42	10.68	0.45	0.39	0.68	87.80	30.6	1.50		8.84	27.0	
Taichung 1	10.19	0.36	0.38	0.52	88.55	31.3	1.03		12.45	27.7	
Bir-me-fen	9.74	0.29	0.31	0.53	89.13	32.2	1.20		11.61	27.7	
Gulfrose	12.09	0.61	0.48	0.67	86.15	17.5	1.52		11.94	14.6	
Century Patna 231	12.22	0.40	0.40	0.74	86.24	16.0	1.15	1.5	13.02	13.5	
Toro	11.40	0.33	0.46	0.61	87.20	13.7	1.26	0.91	13.30	13.4	1.1
Rexoro	12.55	0.29	0.40	0.59	86.17	21.2	1.30		11.08	25.1	
Texas Patna	12.12	0.34	0.44	0.61	86.49	23.8	1.56	1.0	11.07	24.8	0.85
Peta	6.50	0.21	0.30	0.40	92.59	32.8	1.43	0.67	7.53	30.2	0.68
Milfor 6(2)	8.31	0.37	0.41	0.45	90.46	26.8	0.92		10.36	25.1	
Japonica											
Taichung 65	8.92	0.24	0.54	0.62	89.68	18.5	0.92	1.6	9.70	16.7	1.5
Chia-nan 8	7.87	0.31	0.48	0.53	90.81	19.5	1.38		8.51	17.3	
Kaohsiung 53	8.47	0.45	0.47	0.50	90.11	18.8	1.64		10.28	16.2	
Kaohsiung 68	9.09	0.26	0.45	0.47	89.73	19.3	1.92	1.6	10.28	16.7	1.9
Mean	9.75	0.34	0.44	0.56	88.91	23.7	1.35	1.2	10.49	21.7	1.2
Analysis of variance											
Std. error	0.45	0.02		0.02		0.75	0.16				
Significant mean diff.	1.35	0.06		0.06		2.24	0.484				
F-value	17.76[d]	20[d]	2.25	20[d]		62.55[d]	2.67[e]				

[a] Dry basis. [b] N × 5.95. The high nitrogen contents were checked by another laboratory. Comparable Kjeldahl nitrogen analysis of polished rice of 4 U.S. varieties grown at Beaumont, Texas, were obtained at the Institute and the Rice Quality Laboratory at Beaumont (*73*). [c] Arabinose-to-xylose ratio. Mean of first crop excludes that of Century Patna 231. [d] Highly significant. [e] Significant.

Table V. Amino Acid Composition (%) of Polished Rice[a]

Amino Acid	*Indica*: Peta	Taichung 1	Rexoro	Mean (12 var.)	*Japonica*: Taichung 65	Mean (4 var.)	Over-all Mean (16 var.)	r^b	Reported Values, Reference No.: (8)	(31)	(29)	(11) (Peta var.)
Alanine	6.22	6.48	6.12	6.32	6.36	6.17	6.28	−0.09		5.92		
Arginine	8.44	9.26	9.20	8.93	9.08	8.95	8.94	+0.61[d]	8.3	8.38	10.31	9.80
Aspartic acid	10.84	10.90	10.46	10.97	10.44	10.60	10.88	−0.27		10.28	4.82	
Cystine	1.45	1.20	1.10	1.15	1.15	1.00	1.12	−0.09	1.2		1.48	0.80
Glutamic acid	23.96	22.95	21.07	23.15	23.72	23.29	23.19	+0.05		17.39	11.31	
Glycine	5.69	5.24	4.94	5.12	5.24	5.02	5.10	−0.37		5.25	7.32	
Histidine	2.73	2.59	2.55	2.60	2.58	2.54	2.58	+0.05	2.6	2.40	3.15	3.70
Isoleucine[c]	4.77	4.89	4.77	4.78	3.62	4.42	4.69	+0.08	4.9	5.56	5.15	6.80
Leucine[c]	9.68	9.55	9.43	9.56	9.31	9.22	9.47	+0.55[d]	8.8	9.56	9.48	7.67
Lysine[c]	4.86	4.35	3.80	4.03	3.92	3.91	4.00	−0.64[e]	3.6	5.17	3.66	4.85
Methionine[c]	2.78	2.12	1.42	2.03	1.99	1.85	1.98	−0.72[e]	1.9	2.00	3.82	4.77
Phenylalanine[c]	5.84	6.24	6.00	6.07	5.90	6.02	6.06	+0.34	4.9	5.16	4.82	5.15
Proline	5.47	5.61	5.16	5.30	4.89	5.48	5.34	−0.43		5.05	4.65	
Serine	5.78	5.68	5.41	5.67	5.79	5.88	5.72	−0.18		5.06	4.99	
Threonine[c]	4.52	3.90	3.82	4.01	3.95	3.93	3.99	−0.65[e]	3.8	4.38	5.15	3.88
Tyrosine	2.94	3.87	4.08	3.72	3.42	3.44	3.65	+0.89[e]	6.1	6.39	5.32	1.42
Valine[c]	6.56	6.59	6.09	6.20	6.13	6.06	6.16	+0.02	6.6	6.90	7.65	6.71
Ammonia	2.44	2.59	2.92	2.47	2.65	2.62	2.50	+0.38				
Total	114.97	114.01	108.34	112.08	110.14	110.40	111.65					
Recovery, % of Total n	103.0	103.4	100.0	100.8	100.6	100.5	100.8					
Crude Protein, % dry basis	6.50	10.19	12.55		8.92							

[a] First crop; values calculated to 16.8% of N. [b] Correlation coefficient between protein content and individual amino acid values. [c] Nutritionally essential to man (*57*). [d] Significant. [e] Highly significant.

Williams (*75*) reported a high positive correlation between this titration method and her colorimetric method. The values of 21 to 22% amylose in starch obtained in the *japonica* varieties were similar to those reported by Tani (*69*) for Japanese rice starch.

The amylose contents of polished rice of the second crop were lower than those of the first. This may be attributed, in part, to the reduced starch contents as a result of the higher protein contents of these samples. The relatively higher temperature during heading of the second crop may have been a factor since low temperature is reported to result in an increase in amylose content of the rice kernel (*6, 17, 65, 67*).

The pentosans content of polished rice varied significantly among varieties, averaging 1.35 ± 0.16%. These values compare with the 1 to 2% pentosans reported by McCall and coworkers (*38*). In the five varieties analyzed for pentosans composition, the ratio of arabinose to xylose averaged 1.2 in both seasons. The *japonica* samples had higher values, ranging from 1.5 to 1.9 than did the *indica* samples which ranged from 0.67 to 1.1. The first crop of Century Patna 231 had an arabinose to xylose ratio of 1.5, which approached the values obtained for the *japonica* varieties. Since Kaohsiung 68 also is a hybrid, as is Century Patna 231, these data indicate that *japonica* and *japonica* × *indica* hybrid varieties may be differentiated from *indica* varieties by this analysis of pentosans composition. Bevenue and Williams (*7*) and Matsuo and Nanba (*42*) reported similar arabinose-to-xylose ratios of approximately 1:1 for hemi-

Table VI. Gelatinization Temperatures, Alkali Tests, and Iodine-Blue Values of Polished Rice

Variety	First Crop: Gelatinization Temp. (BEPT), ° C.	First Crop: Alkali Test Spreading	First Crop: Alkali Test Clearing	First Crop: Iodine transmission, %	Second Crop: Gelatinization temp. (BEPT), ° C.	Second Crop: Alkali Test Spreading	Second Crop: Alkali Test Clearing
Indica							
Radin Kling	63–72	2.5	1.5	14.0	65–72	4.6	3.4
Chinsurah 35	62–70	4.0	3.0	23.6	65–72	4.8	2.7
Kolamba 42	60–66	4.7	3.5	27.0	64–72	4.6	2.2
Taichung 1	54–62	7.0	6.0	12.8	55–62	7.0	6.0
Bir-me-fen	65–72	3.7	2.7	6.5	63–72	4.7	3.6
Gulfrose	59–66.5	6.5	5.2	61.8	60–65.5	6.6	5.4
Century Patna 231	68–75	2.2	1.2	83.5	72.5–76.5	2.7	1.7
Toro	58–67	6.7	5.0	62.8	55.5–63	6.4	5.7
Rexoro	64–71	2.3	1.3	41.8	66–72.5	3.7	2.3
Texas Patna	62–71	3.2	2.2	32.0	63.5–71	4.1	2.8
Peta	69–73	3.3	2.3	6.7	61.5–72	4.4	3.4
Milfor 6(2)	59–70	4.8	3.8	20.8	55–66	6.4	5.4
Japonica							
Taichung 65	62–67	6.7	4.8	32.7	59–67	6.6	5.2
Chia-nan 8	50–62	6.0	5.0	29.0	61–65.5	6.7	4.8
Kaohsiung 53	56–66	5.7	4.7	37.0	61–65.5	6.0	5.0
Kaohsiung 68	57–66	6.7	4.7	35.0	60–64	6.6	5.3
Mean	60.5–68.5	4.8	3.6	32.9	61.5–68.5	5.4	4.1
Analysis of variance							
Std. error		0.24	0.22	1.0			
Significant mean diff.		0.67	0.61	3.0			
F-values		50.00[a]	46.67[a]	565.7[a]			

[a] Highly significant.

cellulose B extracted from polished rice, and the same ratio was reported by Preece and Mackenzie (*51*) for the water-soluble hemicelluloses of rice grits.

The amino acid composition of polished rice proteins of the first crop and the correlation coefficients between protein content and the individual acids were determined (Table V). The protein content had significant negative correlations with its lysine, methionine, and threonine contents. The protein content also showed significant positive correlations with its tyrosine, arginine, and leucine contents. These acids, except arginine, are nutritionally essential to man (*57*). Variation in amino acid composition among varieties of rice have been reported (*29*, *33*). The lack of any definite trend between protein contents and the contents of essential amino acids among these varieties agrees with the reported (*33*, *74*) low consistency in the relationship between the contents of protein and essential amino acids of different rice varieties grown at the same location. Environment, particularly nitrogen fertilization, is claimed to be a more important factor than variety (*29*, *33*). The mean N recovery was 100.8%, higher than that for brown rice (Table III). As with brown rice, the principal acids were glutamic and aspartic, but the mean content of glutamic acid of polished-rice proteins was 3% higher. The effect of polishing on the contents of the other amino acids is reflected in the analyses of brown- and polished-rice proteins.

The amino acid composition data compare favorably with those of Block and Weiss (*8*) and of Kimura (*31*), although the present values were higher in glutamic acid. In comparison, the microbiological amino acid assays of Kik (*28*) were lower in glutamic and aspartic acids but of higher glycine, methionine, and cystine contents. The microbiological analysis of Concepcion and Cruz (*11*) and the present data on different samples of the Peta variety were similar only in lysine and valine values. The dissimilar results of the chromatographic and the microbiological methods also were noted by Sasaoka (*59*) for rice glutelins.

Quality Tests. Quality tests were performed on the polished rice of both crops. The *japonica* varieties showed low final gelatinization temperatures ranging from 62° to 67° C. in both crops, whereas the *indica* samples had a wider range of values from 62° to 76.5° C. (Table VI). The same final gelatinization temperatures were obtained using the amylograph method of Halick and coworkers (*18*).

The mean gelatinization temperatures of both crops were practically the same, although the environmental temperature was, on the average, 2.6° C. higher during the second crop season than during the first. U.S. workers (*6*, *65*) noted that a cooler temperature, especially during ripening, resulted in starch with lower gelatinization temperature, higher amylose content, and higher amylograph setback. However, as noted in Table IV, the mean amylose content of polished rice was 8% lower in the second crop.

Gelatinization temperature and amylose content were positively, but not significantly, correlated. However, when the varieties Century Patna 231 and Taichung 1 were disregarded, a highly significant correlation was obtained between amylose content and final gelatinization temperature. The correlation coefficient was +0.63 for the first crop, and +0.87 for the second. This relationship indicates that, in general, the higher amylose starches are more resistant to gelatinization. The independence of gelatinization temperature and amylose content has been reported (*6*, *19*). The final gelatinization temperature of the samples was not significantly correlated with protein content. This supports the observation of Liau (*34*) that raw and purified rice starches have the same gelatinization temperature.

Rice may be classified according to cooking properties on the basis of final gelatinization temperature, rather than on grain length (*6*). This classification has considerable merit since gelatinization temperature has been reported to be highly correlated with other quality tests (*4*, *37*). Rice varieties with starch gelatinization temperatures below 70° C. are classified as low; intermediate, between 70° and 74° C.; and high, 75° C. and higher. On this basis, all the *japonica* varieties and the *indica* varieties Gulfrose, Toro, and Taichung 1 had low gelatinization temperature in both crops. Century Patna 231 had a high gelatinization temperature in both crops, agreeing with observations in the U.S. (*19*). All the other *indica* samples showed intermediate gelatinization temperatures in both crops, except for the low gelatinization temperatures for Kolamba 42 in the first crop, and for Milfor 6(2) in the second crop.

The alkali spreading and clearing values (*37*) were highly significantly correlated with gelatinization temperatures, the correlation coefficients being −0.89 for spreading and −0.85 for clearing in the first crop, and −0.95 and −0.91, respectively, in the second crop. The *japonica* varieties and the *indica* samples of low gelatinization temperatures generally had minimum alkali spreading ratings of 6 and alkali clearing values of 5 (Table VI). Varieties of intermediate gelatinization temperature usually had values ranging from 4 to 5 for alkali spreading and from 3 to 4 for clearing. The samples of Century Patna 231 were always the least soluble whereas those of Taichung 1 were totally disintegrated by the alkali.

The starch–iodine-blue values at 77° C. (*20*) for the first crop averaged 32.9% transmission but were highly variable and ranged from 6.5% for Bir-me-fen to 83.5% for Century Patna 231 (Table VI). When Century Patna 231, the variety with a high gelatinization temperature, was excluded from the series, and with the iodine transmission values converted into absorbance units, a highly significant correlation between this test and the true amylose content of rice starch was revealed. A coefficient of +0.860 was derived, whereas Williams and coworkers (*75*) reported a coefficient of +0.916.

Amylograph viscosity data of the rice powder (Table VII) of the 16 varieties in the first crop and of 10 varieties in the second crop showed similar gelatinization periods. Peak viscosity was reached between 88° and 92° C. in all samples. Negative, although not significant, correlation coefficients were obtained between protein content of polished rice and the peak viscosity ($r = -0.38$) and setback ($r = -0.34$) in the first crop. The high protein contents of the U.S. varieties may explain the much lower values for peak viscosity obtained as compared with those reported for the same varieties by Halick and Kelly (*79*). The relatively lower peak values obtained in the second crop may be attributed in part to its higher protein contents of the varieties. However, the positive, although not significant, influence ($r = +0.48$) of protein content on peak viscosity in this crop contrasts with the negative coefficient observed in the first crop. The U.S. varieties were not represented in the second crop. This stresses the importance of sample selection. Peak viscosity was not related to the contents of pentosans, crude fat, crude fiber, and ash.

Setback value, which is the difference between the final viscosity at 50° C. and the peak viscosity, was highly significantly correlated with amylose content, the correlation coefficients being +0.78 in the first crop and +0.75 in the second. Primo and coworkers (*52*) also reported positive setbacks for 10 Spanish rice varieties. The high amylose content of the *japonica* samples may account for the positive setbacks obtained, in contrast to the negative values reported by Halick and Kelly (*79*) for California *japonica* varieties. The lower setbacks of the second crop may be similarly due to lower amylose contents (Table V).

The correlation coefficients between the various physicochemical characteristics of polished rice are summarized in Table VIII.

Table VII. Gelatinization and Pasting Characteristics of Polished Rice Powder[a]

	First Crop				Second Crop[b]			
	Gel.	Viscosity, B.U.[c]			Gel.	Viscosity, B.U.[c]		
Variety	time, min.	Peak	Cooled to 50° C.	Setback	time, min.	Peak	Cooled to 50° C.	Setback
Indica								
Radin Kling	14	690	1050	+360	13.5	630	1015	+385
Chinsurah 35	14.5	800	1270	+470	15	645	1050	+405
Kolamba 42	18	530	990	+460	14.5	410	585	+175
Taichung 1	19	570	1050	+480	16	560	1090	+530
Bir-me-fen	16	490	600	+110				
Gulfrose	17	560	645	+85				
Century Patna 231	12	660	680	+20				
Toro	17.5	550	590	+40				
Rexoro	14.5	570	740	+170				
Texas Patna	13	605	780	+175				
Peta	16	690	1130	+440	14.5	570	890	+320
Milfor 6(2)	17	625	725	+110	16.5	600	680	+80
Japonica								
Taichung 65	17	520	690	+170	16	450	490	+40
Chia-nan 8	17	635	665	+30	19	550	575	+25
Kaohsiung 53	19	540	675	+135	17.5	535	600	+65
Kaohsiung 68	18.5	565	685	+120	18.5	430	505	+75
Mean	16	600	810	+210	16	540	750	+210

[a] The data were comparable to within 30 B.U. in setback values for identical samples of polished rice to amylograms obtained at the Rice Quality Laboratory, Beaumont, Texas (*73*). Variation in values for peak and final viscosity were greater than 30 B.U. but no distinct trend was evident.
[b] Only 10 varieties had sufficient samples for amylography.
[c] B.U. = Brabender Units.

Table VIII. Summary of Correlation Coefficients of Physicochemical Characteristics of Polished Rice[a]

Characteristics	Crop	Protein	Amylose	Gelatinization Temp.	Amylograph Peak Viscosity
NFE	First	−0.99[b]			
Amylose	First	−0.42	+1.00		
	Second	−0.42	+1.00		
Gelatinization temp.	First	−0.07	+0.17 (+0.63)[b,c]	+1.00	
	Second	−0.21	+0.34 (+0.87)[b,c]	+1.00	
Alkali test					
Spreading	First			−0.89[b]	
	Second			−0.95[b]	
Clearing	First			−0.85[b]	
	Second			−0.91[b]	
Iodine-blue test	First		(+0.86)[b,d]		
Amylograph viscosity					
Peak	First	−0.38	+0.24		+1.00
	Second	(+0.48)[e]	(+0.43)[e]		+1.00
Setback	First	−0.34	+0.78[b]	−0.01	
	Second		(+0.75)[b,e]		
Pentosans	First	−0.00005			+0.25
Crude fat	First	−0.095			+0.18
Crude fiber	First	+0.490			−0.16
Ash	First	+0.772[b]			−0.28

[a] For 16 varieties, unless in parentheses. [b] Highly significant. [c] Excludes Century Patna 231 and Taichung 1. [d] Excludes Century Patna 231. [e] Only 10 varieties; excludes Bir-me-fen, Gulfrose, Toro, Rexoro, Texas Patna, and Century Patna 231.

The Physicochemical Basis of the Cooking Quality of Rice. Rice is unique among the cereals in that it is cooked and consumed as whole grain. The cooking of rice results essentially in the gelatinization and swelling of the starch granules in the rice endosperm, with absorption of water. Although rice starch, when being cooked, may increase as much as 60 times in volume (*36*), the rice kernel swells no more than 4 times, the nonstarch kernel constituents obviously suppressing this swelling.

Aside from the composition of starch and the composition of the nonstarch constituents, the physical structure of the starch granule appears to be important. This is reflected by the fact that gelatinization temperature is not always predictable from relative amylose contents of rice varieties (*6*, *79*). Gelatinization temperature seems to be an index of the ease of cooking of polished rice. Varieties with high gelatinization temperature, such as Century Patna 231, take a longer time to cook than most long-grain varieties of intermediate gelatinization temperature (*79*).

Cereal starches are characterized by

an A-type, x-ray powder diffraction pattern using the classification of Katz (*26*), and have water contents ranging from 10 to 12%. Tuber starches, such as potato starch, have B-type patterns and 16 to 18% water. Hizukuri and coworkers (*22*) demonstrated the effect of temperature upon the crystalline type of starch synthesized by germinating soybean seeds, where a transition series from one similar to the A-type (Ca type) at 28° C. to the B-type below 13.4° C. was induced, depending upon the temperature of germination chosen. By analogy, the effect of low temperature in decreasing the gelatinization temperature of rice starch may be interpreted as a shift in granule architecture from the A- to the B-type, through the intermediate C-types. In fact, Okamura (*47*) and Ueda and Ota (*72*) claim that the x-ray powder pattern of rice starch is the C- rather than the A-type.

The crystallinity of the starch granule most probably is due mainly to the hydrogen bonding of the hydroxyl groups of the amylopectin moiety since glutinous rice also has an x-ray diffraction pattern identical to that of nonglutinous rice (*44*, *46*). This indicates that crystallinity involves short-chain associations.

The nature and amounts of the nonstarch constituents are important as these materials act as a physical barrier to the swelling of the starch granules on cooking. Primo and coworkers (*53*) recently demonstrated that the protein content of the outer layer of cooked polished rice grains differed among varieties and had a highly significant negative correlation to panel scores for cohesiveness. Similarly, a significant positive correlation between the protein content of raw rice and panel preference was observed. High-quality U.S. varieties, such as Rexoro, are relatively high in protein (*66*). Late nitrogen fertilization was shown to result in higher protein content in the rice kernel, principally in the glutelin fraction (*49*). Kester and Pence (*27*) reported a lower water uptake value of California *japonica* rice as a result of higher nitrogen fertilization.

The nature and thickness of the cell walls of the rice endosperm also could be an important consideration. Little and Dawson (*36*) noted that the location of disintegration of rice grains when being cooked was characterized by thin cell walls and protein matrices. The water absorption and swelling of rice during cooking may be a function of the surface area of the kernel aside from other physicochemical considerations. This may explain (*20*) why long-grain varieties are claimed to have a higher degree of water absorption than round, short-grained rice.

The nutritional significance of the cooking properties of rice has been thoroughly reviewed by Kik and Williams (*30*).

The cooking quality of rice is influenced by its storage history. During the storage of rough rice, changes in the culinary properties of the resultant polished rice, such as the progressive decrease in cohesiveness and in the amount of sediment and soluble starch, are observed. The grain moisture contents of 14% or lower in storage would be more consistent with a gel $\rightleftarrows$ crystal or precipitate equilibrium rather than with the sol $\rightleftarrows$ gel change advanced by Rao (*54*). The type of crystal x-ray pattern of rice starch does not change in prolonged storage (*47*). A progressive decrease in β-amylase susceptibility of gelatinized samples was noted by Hogan (*23*) in rough rice stored at both ambient and cold storage conditions, whereas the trend in α-amylase hydrolysis was not consistent. In contrast, increased α- and β-amylase susceptibilities were observed in ungelatinized rice. These changes in storage were accompanied by progressive increases in amylograph peak and setback viscosities and a decrease in water uptake values.

The biochemical or enzymic activity of the seed during the storage of rough rice needs to be studied further. Free fatty acids formed during storage can form an addition product with starch (*16*). This product has a lower solubility than starch in hot water. Sreenivasan (*64*) postulated that the lowering in amylase activity during storage decreases the cohesiveness of cooked rice. The role of amylases during the cooking of rice needs to be further clarified, since addition of bacterial amylase at the time of boiling to *indica* polished rice was reported (*68*) to increase its cohesiveness in cooking, whereas Desikachar and Subrahmanyan (*14*) claimed that added α-amylase had no effect on the cohesiveness of cooked rice.

Physical changes of the nonstarch constituents also may occur during storage. Denaturation of the protein matrix and changes in viability may be important factors. Desikachar and Subrahmanyan (*13*) noted the relative fragility of the cell walls of newly harvested Indian rice, as evidenced by their tendency to burst earlier during cooking than those of 1-year old rice.

The susceptibility of freshly cooked rice to amylase hydrolysis may provide an index of the changes in starch association as a result of cooking and subsequent cooling (*58*). This method should provide information on the extent to which the amylogram of the rice powder (*19*) simulates the changes occurring during the actual cooking process. Setback estimates amylose content, setback viscosity being a measure of the retrogradation of amylose (*43*) during the cooling of the starch paste. Since *indica* rice has a higher peak viscosity than *japonica* rice (*15*), whereas the opposite order was found (*69*) for the purified *japonica* and *indica* rice starches, the amylogram of polished rice powder definitely is not analogous to that of purified starch.

Starch composition is an important factor in determining the quality of cooked rice. The starch fractions, amylose and amylopectin, are presumably evenly distributed in the granule as noted by Badenhuizen (*3*) in corn starch. Cooked waxy and *japonica* rices are characteristically moist and sticky, whereas *indica* rice is dry and flaky. Amylopectin is more hygroscopic than amylose (*76*) and glutinous or waxy rice starch, which is essentially all amylopectin, is reported to be completely converted to a turbid paste at 65° C. (*44*). The higher amylopectin content of a low-amylose variety may thus explain why its cooked grain is more cohesive than high-amylose rice. Kurasawa and coworkers (*32*) noted that cooked rice of varieties with 27.8 and 32.5% amylose were less cohesive than those with 18.0 and 22.3%. Amylose is less soluble in hot water than amylopectin (*76*), and this may explain why *indica* rice is less prone to disintegration when overcooked than *japonica* rice. The disintegration of Toro and Century Patna 231, when overcooked, is consistent with their low amylose contents as compared with the other long-grain U.S. varieties.

The aging properties of cold, cooked rice are related to the composition of the starch. *Indica* rice starch has a higher cold paste viscoelasticity than *japonica* rice starch (*10*, *69*). Films of amylose are elastic and strong, whereas those of amylopectin are weak, nonelastic, and brittle (*76*). In the cooked rice kernel, however, the retrograded amylose would be expected to have a three-dimensional network, and the hardness of cold cooked rice of some *indica* varieties may be related to their high amylose contents.

This starch retrogradation of cooked rice is accompanied by an increased crystallinity of the starch into a B-type x-ray pattern at room temperature (*46*, *48*, *58*), but into an A-type pattern on dehydration at 80° to 100° C. (*46*, *58*). Presumably the amylopectin moiety is involved, since rice amylose retrogrades rapidly in water (*71*) and must be essentially retrograded in freshly cooked rice. Ozaki (*48*) noted that the rate of retrogradation proceeded rapidly during the first 4 days and depended mainly upon the moisture content of the cooked rice and the temperature. These data were consistent with the temperature-concentration effect observed by Hizukuri (*21*) in the crystallization of amylodextrins.

This hardening of cooked rice is analogous to the staling of bread crumb in storage, for which amylopectin association has been advanced as the cause (*60*). The hardened crumb is readily softened by heating above 50° C. This probably involves the destruction of amylopectin hydrogen bonding since amylopectin is more water-soluble than amylose (*76*). Prior to being eaten, cold cooked rice often is heated to soften it, especially by consumers of *japonica* rice. Further studies are needed to elucidate this hardening phenomenon of cooked rice.

The existing knowledge on the nature of rice cooking still is incomplete, and the exact physicochemical role of the constituents of the rice grain, as influenced by variety, composition, and environment, is still in the speculative stage. Further studies are required on the biochemical and physicochemical changes which occur during the ripening and storage of rice. Preferably, samples for study should include extremes in starch composition, nonglutinous (nonwaxy), and glutinous (waxy) rices of both *japonica* and *indica* subspecies.

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