Rice Grain Hardness and Its Relationship to Some Milling, Cooking, and Processing Characteristics[1]

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ABSTRACT

Hardness was determined on milled, brown, and rough rice forms of 28 long-, medium-, and short-grain rice varieties varying widely in milling, cooking, and processing characteristics. Hardness was determined by five indirect methods: time to grind (BMHT), particle size index (PSI), near-infrared reflectance (NIR), resistance to grinding (RES), and crushing force (KIYA). Each hardness test showed a relatively wide range in values among one or more of the milled, brown, and rough rice forms. BMHT, NIR, and KIYA hardness methods differentiated between all three rice forms, whereas PSI and RES distinguished only one form of rice. Correlations among hardness indices and the three rice forms and among rice forms for each hardness test were significant but of a relatively low order of magnitude. Correlations between hardness and rice grain quality parameters (milling yield, amylose, alkali spreading value, gelatinization temperature, protein, and grain size and shape) showed some associations but were generally either low or insignificant.

Rice hardness is important to many facets of the rice industry, and the numerous studies on this subject were recently reviewed in considerable detail (Pomeranz and Webb 1985). Rice grain hardness has been implicated as a factor in such diverse areas as storage changes and aging (Barber 1972, Moritaka and Yasumatsu 1972, Villareal et al 1976, Indudhara Swamy et al 1978), drying and handling (Nagato et al 1964, Kunze and Hall 1965), kernel appearance and translucency (Nagato 1962), resistance to insects (Rout et al 1976, Peng and Hsia 1984), and processing and grain breakage during the milling process (Kunze and Choudhury 1972, Goodman and Rao 1983). Reduced grain breakage during milling is particularly important; all rice markets discriminate greatly against broken milled rice because its value is only from 30 to 50% as great as the value of whole kernel (head) milled rice.

This research was carried out to determine the range and variation of hardness in comparably grown United States rice varieties as measured by five different indirect hardness indices used routinely on wheat and other grains; and secondly, to show the relationship of hardness values to some important rice milling, cooking, and processing characteristics.

MATERIALS AND METHODS

Twenty-eight rice varieties including all the major commercial long-, medium-, and short-grain types produced in the United States were studied. The rices included 15 long-grain, 11 medium-grain, and two short-grain types listed here. U.S. long-grain: Bellemont, BN73, Bond, Labelle, Leah, Lebonnet, Lemont, L201, Newbonnet, Newrex, Skybonnet, and Starbonnet. International long-grain: CICA-6, CICA-8, and IR-36. U.S. medium-grain: Brazos, LA-110, Mars, M-9, M-201, Nato, Nova 76, Pecos, RU 82011199, Saturn, and Vista. U.S. short-grain: Nortai and S-201. All varieties were grown in the 1983 crop year in the Uniform Rice Performance Nursery at Beaumont, TX.

The samples were hand-harvested at 18–22% moisture, cleaned, and dried slowly with warm heated air (30–38°C) for approximately 36 hr to a storage moisture content of 12.5 ± 0.5%. Rough, brown, and milled rice forms of each variety were obtained from the same representative sample. Rough rice required no further processing. Brown rice was prepared by dehulling rough rice in a Satake laboratory rubber roll sheller. Milled rice was prepared in a McGill #2 laboratory mill as described by Adair et al (1973).

Hardness was determined on rough, brown, and milled rice forms (equilibrated to 12.5 ± 0.5% moisture) of each variety by five indirect measures: 1) the time to grind 4 g of rice with the Brabender automatic microhardness tester (BMHT) (Miller et al 1984), 2) particle size index (PSI) (Miller et al 1982), 3) near-infrared (NIR) reflectance at 1,680 nm (Bruinsma and Rubenthaler 1978), 4) resistance to grinding (RES) by the Stenvert hardness tester (Lai et al 1983), and 5) the average force required to crush 40 individual kernels of each rice sample was determined with a KIYA grain hardness tester (Kongseree and Juliano 1972). All hardness measurement values represent the average of duplicate determinations.

Milling yield in terms of percent whole milled kernel (head) rice yield and percent total milled rice yield (includes milled [head] rice plus brokens) was estimated by the procedure outlined by Adair et al (1973). Milled rice amylose content was determined colorimetrically by the modified method of Juliano (1971). Amylographic gelatinization temperatures were measured according to the procedure of Halick et al (1960). Alkali spreading value of milled rice in contact with dilute alkali was subjectively evaluated by the procedure developed by Little et al (1958). Protein was determined by AACC method 46-13 (1961). Rice grain length, width, thickness, and weight were measured as described by Adair et al (1973). Analytical results are the average of duplicate determinations, except for amylographic gelatinization temperature, for which a single analysis was made.

The various measured characteristics were compared for relationships by the coefficient of linear correlation. The significance of differences between means of milled, brown, and rough rice forms for each hardness index were obtained using protected Fishers' Significant Difference (FSD) analysis.

RESULTS AND DISCUSSION

Table I gives the range and mean values of the various hardness tests and grain quality parameters for milled, brown, and rough rice forms. Each of the five hardness measurements showed a rather wide range in values between or among one or more of the milled, brown, and rough rice forms. The data demonstrate the probable variation existing in these measured hardness characteristics among comparably grown United States rice varieties. Hardness values for milled and brown rice forms tended to be more similar in magnitude than rough rice values, primarily because of the

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influence of the outer protective hull of the rough rice grain. The hull has little or no influence on the actual individual hardness of the brown or milled rice grains, and one cannot infer from the data that the rough rice husk is harder than brown or milled kernels. However, the data do show that correlations among and between measurements are influenced by the protective hull.

The range of BMHT hardness values for milled forms of all the rices was very narrow, increasing slightly for brown rice and markedly for the rough rice forms. Mean BMHT values were significantly different between rice forms and increased progressively with milled, brown, and rough rice, respectively. A rather wide range in NIR reflectance hardness values was observed in all rice forms, and mean values decreased significantly from milled to brown to rough. PSI hardness measurements were similar in range with only the mean value for brown rice significantly different. The range for RES hardness values was relatively wide and essentially constant for all rice forms, but the mean value for milled rice differed significantly. KIYA hardness value ranges were somewhat narrow for milled and brown rice and rather wide for rough rice. Mean KIYA hardness measurements were significantly different for all rice forms and increased with milled, brown, and rough rice, respectively.

TABLE I
Mean and Range for Grain Hardness and Some Physical and Chemical Parameters of Quality of Milled, Brown, and Rough Forms of Rice

Characteristic	Rice Form	Range	Mean	FSD[a]
Hardness tests				
Brabender micro hardness tester				
(sec)	Milled	14.5–16.6	15.6 a	
	Brown	20.7–26.7	24.1 b	2.9
	Rough	30.0–50.2	39.8 c	
Near-infrared reflectance				
at 1,680 nm	Milled	408–509	487 c	
	Brown	388–492	465 b	16.2
	Rough	328–403	373 a	
Particle size index (throughs, %)	Milled	15.1–25.2	18.8 b	
	Brown	15.8–21.8	17.2 a	1.4
	Rough	15.9–23.9	18.9 b	
Resistance to grinding by the				
Stenvert hardness tester (sec)	Milled	25.2–41.0	37.4 b	
	Brown	19.8–33.0	28.8 a	3.2
	Rough	19.0–37.4	26.2 a	
KIYA grain hardness tester				
(kg/kernel)	Milled	4.9–7.7	6.5 a	
	Brown	6.2–9.6	8.2 b	0.6
	Rough	10.4–18.7	16.0 c	
Grain quality parameters				
Milling yields				
Whole kernel (head) rice (%)	Rough	41.6–67.1	54.1	
Total milled rice (%)	Rough	61.4–72.2	67.0	
Grain size, shape, and weight				
Length (mm)	Milled	5.2–7.8	6.4	
	Brown	5.3–8.1	6.6	
	Rough	7.2–10.6	8.7	
Width (mm)	Milled	1.9–3.0	2.3	
	Brown	2.0–3.1	2.4	
	Rough	2.3–3.6	2.8	
Thickness (mm)	Milled	1.5–2.0	1.7	
	Brown	1.6–2.1	1.8	
	Rough	1.7–2.2	2.0	
1,000-grain weight (g)	Milled	15.9–22.6	19.2	
	Brown	15.7–21.6	18.8	
	Rough	20.8–29.2	23.9	
Amylose (%)[b]	Milled	14.9–27.1	20.6	
Gelatinization temperature (°C)	Milled	63.8–73.1	69.2	
Alkali spreading value (avg. no.)	Milled	2.5–6.9	4.7	
Protein content (%)[c]	Milled	7.1–11.0	9.2	
	Brown	9.2–14.0	10.5	
	Rough	7.9–13.0	9.5	

[a] Fishers' significant difference between means of milled, brown, and rough forms for each hardness index. $P<0.05$.
[b] Dry basis.
[c] N × 5.95, dry basis.

The commonly used grain quality parameters listed in Table I are those characteristics considered most important in judging the qualities of United States rice (Webb and Stermer 1972). The range and mean values given for whole kernel (head) and total milled rice yields, grain size, and shape (length, width, thickness), grain weight, amylose, gelatinization temperature, alkali spreading value, and protein for rices used in this study are representative of those existing among milled, brown, and rough rice forms of United States rice varieties.

Relation Among Hardness Indices for Different Forms of Rice

The relation among and between the five indices of hardness for each form (milled, brown, rough) of rice are shown in Table II. Milled rice had the largest number of significant correlation coefficients at the $P=0.01$ level. The most significant relationships were between NIR reflectance and RES and between PSI and RES for milled rice.

For brown and rough rice forms, only NIR reflectance and PSI were significantly related ($P=0.01$). BMHT was not significantly related ($P=0.01$) to any other hardness index for any form of rice. The absence of and the generally low orders of magnitude of r values between the five hardness indices for the three forms of rice reflects, in large part, the diversity of characteristics being measured by the different hardness tests.

Relation Among Forms of Rice for Five Hardness Indices

Significant ($P = 0.01$) correlation coefficients between milled, brown, and rough rice forms are shown in Table III. Milled and brown rice were significantly related for all hardness indices except PSI hardness measurements. Significant correlations for brown and rough rice were obtained for all except the RES hardness index. Rough and milled rice forms were not significantly

TABLE II
Correlation Among Five Indices of Hardness for Milled, Brown, and Rough Rice Forms

Rice Form	Correlation[a]	Correlation Coefficient[b]
Milled	NIR vs. RES	0.77**
	NIR vs. PSI	−0.62**
	NIR vs. KIYA	0.55**
	PSI vs. RES	−0.74**
	PSI vs. KIYA	−0.50**
	RES vs. KIYA	−0.56**
Brown	NIR vs. PSI	−0.57**
Rough	NIR vs. PSI	−0.78**

[a] NIR, near-infrared reflectance; PSI, particle size index; RES, resistance to grinding on the Stenvert hardness tester; KIYA, grain hardness tester.
[b] ** Indicates significance at $P=0.01$.

TABLE III
Correlation Between Milled, Brown, and Rough Rice Forms for Five Indices of Hardness

Hardness Index	Correlation	Correlation Coefficient[a]
Brabender micro hardness tester	Milled vs. Brown rice	0.65**
	Brown vs. Rough rice	−0.62**
Near-infrared reflectance	Milled vs. Brown rice	0.53**
	Brown vs. Rough rice	0.54**
Particle size index	Brown vs. Rough rice	0.60**
Resistance to grinding by the Stenvert hardness tester	Milled vs. Brown rice	0.58**
KIYA grain hardness tester	Milled vs. Brown rice	0.81**
	Brown vs. Rough rice	0.61**

[a] ** Indicates significance at $P=0.01$.

correlated for any hardness test measurement at the $P = 0.01$ level but were related for all hardness indices at the $P = 0.05$ level of significance (not shown). Whereas the relationships shown in Table III were significant, the r values were of a relatively low order of magnitude, indicating the complexity of differences in characteristics existing among the various rice forms.

Relation Between Some Rice Quality Parameters and Five Indices of Hardness

Milling quality. Milling quality is based on the yield of whole kernel (head) rice because this is the product of greatest economic value, being twice as valuable as the broken kernels. The value of the annual rice crop in the United States alone would be increased by millions of dollars if no breakage occurred during milling. There has been much speculation that hardness is a factor in milling yields but little definitive information is available to support or contradict this assumption (Kunze and Choudhury 1972). The relationship of whole kernel (head) rice milling yield and total milled (includes brokens) rice yields to hardness test indices are shown in Table IV. Both NIR reflectance and PSI values of the brown and rough rice forms were significantly related ($P = 0.01$) to whole kernel (head) rice yields. Total milled rice yield was significantly correlated ($P = 0.01$) with NIR reflectance and BMHT hardness measurements of the rough rice form. However, the low r values obtained indicate that rice breakage during milling is influenced, as would be expected, by factors or characteristics other than those measured by the five hardness indices studied. Goodman and Rao (1983) also reported whole kernel milled rice yields to show a low correlation to crushing strength hardness ($r = 0.22$) as measured by direct compression of 10 individual milled rice kernels with the Instron universal testing machine. As implied by Barber and de Barber (1979), because of the complexities of factors influencing milling yields, the actual direct test milling procedure (which, in itself, is a breakage test for rice) continues to be the most reliable method for estimating milling yields for rice.

Amylose content. Amylose content is considered one of the most important characteristics to describe rice cooking, eating, and processing quality (Williams et al 1958) as it has been shown to be a factor in cooked rice texture and parboiling. Rice varieties that cook dry and fluffy with the grains separate have relatively high amylose levels, whereas rices with low amylose levels cook moist and sticky with the grains clumping together. Amylose content of milled rice was not significantly correlated to any of the five hardness test measurements (Table IV) confirming previous results obtained by Kongseree and Juliano (1972).

Gelatinization Temperature and Alkali Spreading Value

The alkali spreading value (the disintegration pattern of the milled kernel in 1.7% KOH solution) of rice is an important measure of quality in that it is highly correlated with gelatinization temperature (Simpson et al 1965). Gelatinization temperature is important in both regular milled and parboiled rice, where the rice is usually steeped at or near its gelatinization temperature (Gariboldi 1974). Table IV shows that alkali spreading value and gelatinization temperature are significantly correlated ($P = 0.01$) with both RES and BMHT hardness values, but the r values are of a relatively low order of magnitude.

Protein Content

Although protein is not a factor in rice marketing quality, it is important to nutrition, and its level is monitored routinely in United States rice breeding programs. The relation of protein to hardness in wheat has not been conclusively demonstrated (Pomeranz and Miller 1982), and conflicting results are often obtained with other grains (Pomeranz et al 1984). Correlation coefficients for the five hardness test values to protein in milled, brown, and rough rice forms are shown in Table IV. Both NIR reflectance and PSI values of the brown rice forms were significantly correlated ($P = 0.01$) with protein in milled and in brown rice. Only NIR reflectance values of rough rice forms were significantly ($P = 0.01$) related to protein levels in rough rice. Correlation coefficients were of a relatively low order of magnitude and inconclusive.

Grain Size, Shape, and Weight

Rice in the United States is produced and marketed according to grain size and shape; therefore, length, width, thickness, and weight

TABLE IV
Correlation Between Some Rice Quality Parameters and Five Indices of Hardness

Correlation[a]	Correlation Coefficient[b]
Whole kernel (head) rice milling yield vs.	
Brown rice NIR	0.49**
Rough rice NIR	0.55**
Brown rice PSI	−0.51**
Rough rice PSI	−0.51**
Total milled rice yield vs.	
Rough rice NIR	0.63**
Rough rice BMHT	−0.56**
Amylose content vs.	
...	...
Gelatinization temperature vs.	
Rough rice RES	−0.56**
Alkali spreading value vs.	
Brown rice BMHT	−0.55**
Rough rice BMHT	−0.53**
Rough rice RES	0.58**
Protein in milled rice vs.	
Brown rice NIR	−0.49**
Brown rice PSI	0.55**
Protein in brown rice vs.	
Brown rice NIR	−0.53**
Brown rice PSI	0.49**
Protein in rough rice vs.	
Rough rice NIR	−0.58**
Length of milled rice vs.	
Milled rice KIYA	−0.54**
Rough rice BMHT	0.55**
Rough rice RES	−0.81**
Length of brown rice vs.	
Milled rice KIYA	−0.52**
Rough rice BMHT	0.54**
Rough rice RES	−0.80**
Length of rough rice vs.	
Milled rice KIYA	−0.49**
Rough rice RES	−0.79**
Width of milled rice vs.	
Rough rice BMHT	−0.55**
Rough rice RES	0.51**
Width of brown rice vs.	
Rough rice BMHT	−0.58**
Rough rice RES	0.52**
Width of rough rice vs.	
Milled rice RES	−0.50**
Rough rice RES	0.51**
Rough rice BMHT	−0.53**
Thickness of milled rice vs.	
Milled rice PSI	0.52**
Milled rice RES	−0.58**
Brown rice NIR	−0.60**
Rough rice BMHT	−0.74**
Thickness of brown rice vs.	
Milled rice PSI	0.55**
Milled rice RES	−0.63**
Brown rice NIR	−0.60**
Rough rice BMHT	−0.76**
Thickness of rough rice vs.	
Milled rice PSI	0.55**
Milled rice RES	−0.58**
Rough rice BMHT	−0.67**
Grain weight of milled rice vs.	
...	...
Grain weight of brown rice vs.	
Rough rice BMHT	−0.52**
Grain weight of rough rice vs.	
Rough rice BMHT	−0.52**

[a] BMHT, Brabender micro hardness tester; KIYA, grain hardness tester; NIR, near-infrared reflectance; PSI, particle size index; and RES, resistance to grinding on the Stenvert hardness tester.

of the rice grain are of vital interest to those involved in the many facets of the rice industry. These properties are primary quality factors in breeding, producing, handling, drying, cleaning, marketing, and processing of end-use rice products. The relation of grain length, width, thickness, and weight of milled, brown, and rough rice to the five indices of hardness are given in Table IV. Significant correlations ($P = 0.01$) ranging from 0.49–0.81 were obtained between grain length, width, thickness, and weight, and the measured hardness test values. RES hardness measurements of rough rice gave the highest r values for length of milled, brown, and rough rice. Width of milled, brown, and rough rice was significantly ($P = 0.01$) related to BMHT and RES hardness values, but r values were of a lower order than for length. Grain size and shape, particularly thickness, are known to affect hardness in corn and other grains (Pomeranz et al 1984). In rice, BMHT, NIR reflectance, RES, and PSI measurements were all significantly ($P = 0.01$) related to grain thickness with BMHT hardness values of rough rice giving the highest correlation coefficient for thickness of milled, brown, and rough rice. Rough rice BMHT hardness values were significantly ($P = 0.01$) correlated with kernel weight of brown and rough rice, but none of the hardness indices were significantly related to milled kernel weight.

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