Screening for Stable High Head Rice Yields in Rough Rice

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ABSTRACT

Varietal differences in head rice yields were demonstrated by subjecting rough rice to moisture adsorption stress (soaking in 30°C water) for 1-3 hr, air-drying, and subjecting the brown rice to micromilling with a Kett Pearlest mill. An earlier method consisted of soaking brown rice in water for 5-10 min and determining the percentage of cracked grains. IR60 and IR58 were the IR nonwaxy rices most resistant to grain fissuring. The stress test is preferably done on rough rice and shade-dried to 14% moisture so that only the susceptible varieties crack. Alkali spreading value (starch gelatinization temperature) and apparent amylose content were less important than brown rice translucency in affecting head rice yield of stressed grain from the International Rice Research Institute crops. Rices grown in Palmira, Colombia, and at Beaumont, TX, in the United States differed in stressed head rice yield from those grown at the International Rice Research Institute in the Philippines.

One of the major problems of the rice processing industry is fissured or cracked brown rice brought about by environmental and varietal factors. The resultant excessive cracked grains (brokens) reduce the market value of milled rice. The fissures occur during moisture adsorption in relatively dry rough rice (Kunze 1985, Srinivas and Bhashyam 1985). The rice grain is hygroscopic and responds dynamically and physically to moisture and temperature changes in its environment; however, moisture gradients are more responsible than temperature gradients for producing stress fissures.

Varietal differences in the rate and extent of fissuring of brown rice during moisture adsorption were reported by Kunze and Hall (1965) for four U.S. long-grain rices. Century Patna 231, a low-amylose, high gelatinization temperature (GT) rice was the most fissure resistant. Srinivas and Bhashyam (1985) reported that fissure resistance can be selected within a variety, in spite of small genetic variation in some varieties, if the variety shows a diverse grain reaction to alkali digestion; fissure resistance was associated with low alkali digestion (higher GT). The low-GT, high-amylose variety IR42 was recently "banned" in Malaysia because of poor head rice yield of overripe grain (Anonymous 1984). The same variety was more susceptible to cracking during sun-drying than other IR rices tested (Gayanilo 1990). Delayed harvest of up to two weeks reduces head rice yield in susceptible varieties (Berrio and Cuevas-Perez 1989).

In Australian and U.S. breeding programs, screening for fissure resistance includes comparing head rice yields of rough rice at regular and delayed harvests. Head rice yields of varieties in these countries tend to be higher (56-61% for U.S. long grain [Webb 1985]) than those in the tropics (41-61% [Khush and Juliano 1985]). This technique of delayed harvest would not be very reliable in monsoon Asia because occasional rains during the ripening period correspond to different stages of grain desiccation for rices differing in growth duration (days to maturity), which may result in variable stress on the varieties.

Earlier screening methods studied at the International Rice Research Institute (IRRI) included further drying of already-dried grain (at 12-14% moisture) using either an infrared lamp or an air oven. Drying was followed by moisture adsorption stress and milling in a microfriction mill to observe cracking or decrease in head rice (Ibabao et al 1987). However, reproducibility was variable and was affected by the number of samples being simultaneously dried, probably because all varieties are reported to be susceptible to cracking at moisture contents below 14% (Srinivas et al 1978). This article reports on a study of the use of wetting methods on shade- and oven-dried grain (14% moisture) for crack-resistance screening among IR rices.

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MATERIALS AND METHODS

Samples were obtained from the IR variety demonstration plots (unreplicated, IR5, IR8, IR20, IR22, IR24, IR26, IR28, IR29, IR30, IR32, IR34, IR36, IR38, IR40, IR42, IR43, IR44, IR45, IR46, IR48, IR50, IR52, IR54, IR56, IR58, IR60, IR62, IR64, IR65, and IR66 in 1987, plus IR68, IR70, IR72, and IR74 in 1990) and the 1990 dry season yield trial plots (duplicate, IR50, IR68, IR72, IR74, and 32 promising IR lines) of the Plant Breeding, Genetics, and Biochemistry Division at the IRRI farm. Freshly harvested grain was either shade-dried to 14% moisture in the laboratory or oven-dried at 40°C to 14% moisture content and cooled. Later samples were obtained already oven-dried at 35–40°C and cooled. Ten additional samples were obtained from the International Network for Genetic Evaluation in Rice (INGER) 1988–89 trials at Palmira, Colombia, from the USDA ARS Rice Research Southern Plains Region, Beaumont, TX, and from the Central Food Technological Research Institute (CFTRI), Mysore, India. Seeds of 10 rices from INGER were grown in the IRRI farm in the 1989 dry season. The samples were aged if less than four months after harvest when received and equilibrated at 20–25°C, 60–75% rh to 12–14% moisture (wb). Moisture content was determined by oven-drying the rice flour at 130°C for 1 hr (AACC 1983).

Moisture Stress on Brown Rice

Rough rice was dehulled with a Satake THU-35 dehusker. Duplicate samples of 100 random or selected whole-grain brown rice were soaked in 30°C water for 5, 10, and 15 min. The cracked grains were observed with a fiber optics illuminator (McDonald 1958). Initial percent cracked grains was also estimated before soaking (0 min of soaking, unstressed). Waxy rices IR29 and IR65 were excluded because of the difficulty in observing cracks in the opaque grains.

Moisture Stress on Rough Rice

Duplicate samples of rough rice (8–10 g) were soaked in 30°C water for 0 (unstressed), 1, 2, and 3 hr. They were then air-dried and dehulled in a Satake THU-35 dehusker. Brown rice (5 g) was milled for 1 min in a Kett Pearlest mill. Head rice (>0.75 of whole grain length) was determined by proper sieving or actual manual picking of the brokens. Using a McGill 2 friction mill, 90–100 g of brown rice was milled for 1 min with a 685-g weight 11.5 cm from the fulcrum and then milled for 1 min without the weight. The resulting milled rice was weighed and separated into head rice and brokens using a Satake testing rice grader with 4.75-mm mesh indentation. Total milled rice and head rice yields were calculated as percentage by weight of rough rice.

Physicochemical Analyses

Translucency of brown rice was measured in duplicate with a Riken Sanno rice meter (brown rice model). Milled rice was analyzed for alkali spreading value of duplicate six grains in 10.0 ml of 1.7% KOH at 30°C for 23 hr (Little et al 1958). Milled rice was ground in a Udy cyclone mill with a 60-mesh sieve and analyzed for apparent amylose content (Juliano et al 1981) and gel consistency (Cagampang et al 1973).

The IR rices were sieved into various thickness grades (slotted sieves: 5 [2.5 mm], 4 7/8 [2.1 mm], and 1/15 [1.6 mm]) using a mechanical sieve shaker. The three thicker fractions were separately processed and subjected to determination of percent hull, brown rice density using an air pycnometer, and head rice yield (without stress).

Particle size index (PSI) was determined by grinding brown rice in a Udy cyclone mill with 1.0-mm sieve and calculating the weight percent that passes through a 200-mesh sieve (Williams et al 1988). Brown rice flour was extracted with 60% 2-propanol or 1-propanol as solvent at a solvent-flour ratio of 4:1 (v/w) for 6 hr. Protein in the extract was determined by the Lowry test using bovine serum albumin standard (Abdelrahman and Hoseney 1984).

Data were subjected to linear correlation analysis.

RESULTS AND DISCUSSION

Cracking Tests on Brown Rice

Unstressed IR brown rice from the 1987 dry season had 2–36% cracked grains (Table I). IR58 and IR60 had the least cracked grains and IR44 had the most. Upon 5 min of soaking at 30°C, IR60 had the lowest percent cracked grains, and IR42 had the highest. After 10 min of soaking, IR30, IR40, and IR45 had more than 90% cracked grains (not shown), but IR36, IR58, and IR60 still had less than 40% cracked grains.

Head rice yield of unstressed IR grain correlated significantly with percent cracked grain after soaking brown rice for 5 min or before soaking only (Table I). Translucency of brown rice (selected) also correlated with percent cracked grains after 5 and 10 min of soaking and with unstressed head rice ($r = 0.61$, $P < 0.05$, $n = 28$). IR42 had 40% head rice, IR44 had 23%, IR58 had 70%, and IR60 had 66%. Head rice yield of stressed grains (3-hr soak of rough rice in 30°C water) showed significant correlation with percent cracked grains after soaking for 0, 5, and 10 min. Head rice yield of stressed grain for the four IR rices were 20% (IR42), 17% (IR44), 58% (IR58), and 62% (IR60). The results indicate that precracked grains (brokens), and those cracked during subsequent moisture stress, both contribute to reduction of head rice yield.

When the brokens were removed from the brown rice samples (0% brokens at 0 min) before soaking in water, IR58 still had no cracked grains after 5 min of soaking (Table I). IR42 had the highest percent cracked grains. After 10 min of soaking, only IR36, IR58, and IR60 still had less than 20% cracked grains; IR30 had the highest. After 15 min of soaking, only IR36, IR58, and IR60 had less than 50% cracked grains. As expected, percent cracked grains was lower in selected (whole grain) samples than it was in the random grain samples (Table I). Brown rice translucency no longer correlated with percent cracked grains ($r = -0.31$ to -0.36, $P > 0.05$). Unstressed head rice yield correlated only with percent cracked grains after 5 min of soaking. Stressed head rice yield was not run.

Percent cracked grains in samples shade- and oven-dried to 14% moisture at 40°C was lower in shade-dried brown rice samples during soaking in 30°C water than it was in samples that were oven-dried to 14% moisture at 40°C (Table II). Shade-dried IR29 (waxy) had a lower percent cracked grains (4%) after 15 min of soaking than did the other waxy sample IR65 (35%). However, in oven-dried samples, IR29 had 58% and IR65 had only 46%, although it was difficult to observe fissuring in the opaque waxy grain. Among nonwaxy rices, IR60 gave the best overall resistance for up to 10 min of soaking. IR42 and IR44 cracked faster than IR58 and IR60 during the soaking of brown rice in water from both shade-dried and oven-dried rough rice.

Head rice yield of the Kett Pearlest-milled, shade-dried,

TABLE I
Percent Cracked Grains from Brown Rice After Soaking in Water Using Random and Selected (Whole) Nonwaxy IR Rices, Shade-Dried to 14% Moisture

Sample	Cracked Grains, % After Soaking			
	0 min	5 min	10 min	15 min
Random samples ($n = 27$)				
Range	2–36	2–68	24–96	...
Mean	12	27	68	...
Correlation coefficient[a]				
Brown rice translucency (22–68%)	–0.36	–0.43	–0.39*[b]	...
Unstressed head rice (23–70%)	–0.67**	–0.60**	–0.31	...
Stressed head rice (17–62%)	–0.85**	–0.79**	–0.45*	...
Selected (whole) grains ($n = 28$)				
Range	...	0–52	8–92	48–100
Mean	...	12	50	82
Correlation coefficient[c]				
Unstressed head rice (23–76%)	...	–0.46*	–0.33	–0.26

[a] 1987 dry season crop, excluding IR29, IR65, and IR66.
[b] Probability: * <0.05, ** < 0.01, others ≥ 0.05.
[c] 1987 dry season crop, excluding IR29 and IR65.

unstressed grain was highest for IR58 (Table II) and lowest for IR8 and IR36. Samples with more than 50% head rice included IR29, IR40, IR42, IR58, and IR60. Head rice yield correlated with percent translucency when waxy rices are excluded (Table II). In unstressed, oven-dried samples, head rice yield was lower for IR44 than it was for IR42, IR58, and IR60. Head rice yields were somewhat higher in oven-dried rough rices than in shade-dried (Table II), even though the oven-dried samples were more susceptible to moisture stress. Unstressed head rice yield was again higher in IR58, IR60, and IR42 than it was in IR44.

With 49 elite lines and varieties grown in the 1987 wet season, the percent cracked grains range was 0–52% even before soaking (mean 12%); it increased 0–54% (mean 16%) upon 5 min of soaking and 5–91% (mean 44%) upon 10 min of soaking (not shown). Percent cracked grains correlated with unstressed head rice yield of 6–61% ($r = -0.50$ at 0 min, -0.55 at 5 min, and -0.51 at 10 min, $P < 0.01$) and with apparent amylose content of 16–27% ($r = -0.54$ at 0 min and -0.59 at 5 min, $P < 0.01$; $r = -0.32$ at 10 min, $P < 0.05$). Percent cracked grains was not significantly correlated with brown rice translucency, alkali spreading value, gel consistency, or milled rice protein content.

Soaking Test on Rough Rice

Because of the subjective nature of percent cracked grain determination and its indirect effect on head rice yield, actual milling of samples (5 g of brown rice) in a Kett Pearlest micromill was investigated and compared with that of a McGill 2 friction mill. Soaking time of 1–3 hr had little effect on the head rice of stressed, shade-dried rough rice. Susceptible variety IR42 had 5–10% head rice stressed and 50% head rice unstressed. Resistant variety IR60 had 60–62% head rice stressed, which was slightly lower than the 65% head rice for unstressed grain (not shown). Resistant IRGA 409 had similar head rice yield for unstressed (46 ± 1%) and stressed grain (44–45%). Slightly resistant IR36 had 20–22% head rice stressed and 26% head rice unstressed. Cuevas-Perez and Peske (1990) also found that soaking in water for 3 hr was a better and more reproducible stress than that produced by a nonsaturated moist environment, such as 75 or 95% rh, for stressing rough rice.

The Kett Pearlest micromill required only a small amount of brown rice (5 g); the McGill mill required 100 g. Comparison of the two mills using IR8, IR36, IR42, IR44, IR60, IR74, and Century Patna/SLO 17 rough rice showed good correspondence among samples. Head rice was 20–64% with the McGill mill, but 17–68% with the Kett Pearlest micromill. In both mills, IR74 registered the highest yield, and IR36 registered the lowest (not shown). Similar results were reported by Ibabao et al (1987).

Ten varieties grown in Colombia, including four IR rices, were tested using the 2–3 hr soak stress test and milled with both mills. The mills both showed the crack resistance of IRGA 409 and Anayansi (Table III). Of the four resistant varieties (Anayansi, IRGA 409, Juma 58, and Sinaloa A80), Juma 58 had the lowest head rice yield. Similar milling results were obtained with the two mills. Check (unstressed) samples had 22–69% head rice in the McGill and 42–65% in the Kett. The stressed grain head rice yield was 23–66% in the McGill and 15–59% in the Kett (Table III). Correlation coefficient between head rice yields for the two mills was 0.94 ($P < 0.01$) for stressed grains and 0.84 ($P < 0.01$) for unstressed. Among IR rices, IR22 and IR60 showed better resistance than did IR36 and IR58. IR58 was unusually

TABLE II
Effect of Shade-Drying or Oven-Drying at 40°C to 14% Moisture on Unstressed Head Rice Yield and Percent Cracked Grains After Soaking 28 IR Nonwaxy Brown Rices in Water[a]

	Brown Rice Translucency, %	Unstressed Head Rice Yield, %	Cracked Grains, % After Soaking			
			0 min	5 min	10 min	15 min
Shade-dried to 14% moisture						
Range	17–62	19–61	0–6	0–13	2–74	4–94
Mean	43	40	1	5	40	65
Brown rice % translucency correlation		0.57**[b]	−0.45*	−0.18	−0.23	−0.18
Unstressed head rice yield (%) correlation			−0.39*	−0.27	−0.13	−0.07
Oven-dried at 40°C to 14% moisture						
Range	...	30–63	0–1	0–40	22–96	36–100
Mean	...	47	0	13	63	88
Brown rice % translucency correlation		0.67**	0.00	−0.14	−0.28	−0.16
Unstressed head rice yield (%) correlation			−0.26	−0.16	−0.11	−0.06

[a] 1987 wet season crop, excluding waxy IR29 and IR65.
[b] Probability: * < 0.05, ** < 0.01, others ≥ 0.05.

TABLE III
Translucency, Head Rice Yield Without and With Stress, and Starch Properties of 10 Nonwaxy Rices Grown at Palmira, Colombia

Variety	Brown Rice Translucency (%)	Head Rice Yield, % McGill 2 Mill Unstressed	McGill 2 Mill Stressed	Kett Pearlest Mill Unstressed	Kett Pearlest Mill Stressed	Amylose, %	Alkali Spreading Value	Gel Consistency (mm)
Anayansi	49	68	66	63	59	29.2	6.2	32
CICA 8	66	66	36	65	27	28.1	6.8	31
Inti	74	64	52	62	41	16.4	7.0	83
IR22	66	67	41	65	31	26.1	7.0	27
IR36	60	22	23	42	28	27.5	6.2	30
IR58	47	52	26	43	15	27.9	7.0	26
IR60	60	64	35	56	31	28.2	6.8	34
IRGA 409	74	69	63	64	56	27.6	7.0	28
JUMA 58	72	65	41	60	29	28.4	7.0	29
Sinaloa A80	74	62	55	55	51	30.4	6.0	52
Mean	64	60	44	58	37			
Correlation coefficients ($n = 10$)[a]								
Brown rice % translucency		0.28	0.44	0.48	0.46			
Alkali spreading value		0.38	−0.16	0.29	−0.41			
Gel consistency		0.13	0.31	0.18	0.28			

[a] Probability all ≥ 0.05.

susceptible, in contrast to previous analysis of IRRI-grown seeds.

Location effect was evident on IRRI and Colombia-grown varieties. IR58 was susceptible at Colombia but resistant at IRRI, whereas IRGA 409 was more resistant at Colombia than at IRRI (Table IV). IR60 was less resistant at Colombia than at IRRI. An IRGA 409 sample from Beaumont, TX, had 58% head rice unstressed and only 7% head rice stressed (Table V).

A detailed study of the Colombia and IRRI crops of IRGA 409, IR58, and IR60 showed no significant correlation of percent stressed head rice yield with brown rice translucency, density, length, width, thickness and equilibrium water content after a 20-hr soak in water, or milled rice alkali spreading value. Stressed head rice yield correlated negatively with brown rice 100-grain weight ($r = -0.85$, $P < 0.05$) and grain thickness ($r = -0.89$, $P < 0.05$).

Among 13 U.S. varieties, the soak test showed considerable range in cracking resistance (Table V). Among medium-grain rices, M201 grown in Biggs, CA, was more resistant than Nato and M201 grown in Beaumont, TX. L202 (grown in Texas), Labelle, and Century Patna 231 showed higher head rice yield than other long-grain rices. Stressed head rice yield correlated significantly with moisture content of milled rice but not with protein content, amylose content, alkali spreading value, unstressed head rice yield, and brown rice translucency. Head rice yields were lower than the 56–61% values of Webb (1985).

TABLE IV
Percent Translucency (%T) and Head Rice Yields Without and With Stress[a] of IRGA 409 and Selected IR Nonwaxy Rices Grown at Colombia and IRRI[b]

	Colombia (1988–89)			IRRI (1989 dry season)		
		Head Rice Yield, %			Head Rice Yield, %	
Variety	%T	Unstressed	Stressed	%T	Unstressed	Stressed
IRGA 409[c]	71	55	54	52	51	42
IR58	52	63	11	44	70	58
IR60	62	55	43	60	68	62
IR22	64	63	36	54	57	41
IR36	61	42	23	38	27	29
IR42				42	40	20
IR44				38	23	17

[a]Rough rice soaked for 3 hr at 30°C. Brown rice (5 g) milled 30 sec in a Kett Pearlest mill. All high-amylose rices.
[b]International Rice Research Institute, Los Baños, Laguna, Philippines.
[c]Beaumont, TX, 1988 crop. 58% head rice unstressed and 7% head rice stressed (Table V).

Indian Rice Lines

Seven Halubbulu lines (Srinivas et al 1978), obtained from Palmira, Colombia, and samples of ES-18 and Vani lines (Bhashyam et al 1984), obtained from CFTRI, Mysore, India, were tested for crack resistance by soaking brown or rough rice in water. The results showed 2–28% head rice of stressed Halubbulu lines 93, 100 (red), 103, 104, 108, 110, and 113 grown in Colombia. No significant differences were noted in susceptibility of Vani lines FT12 (resistant) and FT14 (susceptible) or in ES-18 lines FT81 (resistant) and FT97 (susceptible) (not shown). Not enough samples were obtained to run unstressed head rice yield to check whether the samples were subjected to stress before the test. No further study was undertaken on these lines, which reportedly differ in crack resistance in India.

Effect of Moisture Content on Stress Screening Test

In general, soaking shade-dried grain (16% moisture content) for 3 hr had no effect on head rice yield (Table VI). However, head rice (stressed) actually increased in some samples, such as IR58, but decreased in IR8 and IR34 (not shown). Head rice yield of unstressed grain was lowest for IR44 and highest for IR60. Stressed grain head rice yield was lowest for IR44 and highest for IR60. Thus, 16% moisture content was too high for screening rough rice for crack resistance.

Shade-dried (14% moisture) samples generally showed a reduction of head rice yield (Table VI). Head rice yield of unstressed grain was lowest for IR44 and highest for IR58. Stressed grain head rice was lowest for IR44 and highest for IR60. Samples that maintained >50% head rice yield of stressed grain included IR58 and IR60. Head rice yield, particularly that of unstressed grain, correlated positively with brown rice translucency. Waxy rices IR29 and IR65 were excluded from the correlation because of their opaque endosperm (translucency values 18–22%). Unstressed and stressed head rice yields did not correlate ($P > 0.05$) with the apparent amylose content of milled rice (5.6–27.6%) ($r = -0.25$ unstressed, -0.09 stressed); alkali spreading value (3.0–7.0) ($r = 0.09$ unstressed, -0.11 stressed); and gel consistency (26–100 mm) ($r = 0.35$ unstressed, 0.17 stressed) of the nonwaxy IR rices.

Oven-dried samples from the 1987 wet season crop dried at 40°C to 14% moisture showed mean head rice yield values that were similar to those of shade-dried samples at 14% moisture (Table VI). IR58 had the highest head rice yield for both drying methods, although somewhat lower values were obtained with shade-drying. IR60 and IR29, and even IR42, followed closely. Percent translucency of nonwaxy brown rice correlated again with head rice yield of unstressed grain, probably reflecting the fact

TABLE V
Moisture, Protein, Apparent Amylose Contents, and Head Rice Yields of 13 U.S. Rices Differing in Grain Size and Shape, 1988 Crop

Variety	Location[a]	Moisture Content (% wb)	Protein (% wb)	Amylose (% db)	Alkali Spreading Value	Head Rice Yield (%) Unstressed	Head Rice Yield (%) Stressed	Brown Rice Translucency (%)
Medium grain								
Nato	TX	12	7.3	15.0	7.0	63	25	42
M201	TX	12	8.4	13.3	7.0	58	16	37
M201	CA	13	6.4	16.1	7.0	56	41	48
Long grain								
CP231	TX	13	5.7	15.4	2.0	54	40	46
IRGA 409	TX	13	7.8	26.7	7.0	58	7	58
L202	TX	13	8.2	27.2	4.6	44	47	50
L202	CA	13	6.0	28.2	6.5	49	24	54
Labelle	TX	13	9.9	22.7	5.0	57	38	50
Lebonnet	TX	12	7.3	23.0	4.4	47	13	50
Lemont	TX	11	7.2	23.3	4.9	48	2	40
Rexmont	TX	11	6.7	28.8	6.0	55	11	44
Starbonnet	TX	11	6.9	22.3	4.6	47	16	42
Toro 2	TX	12	6.8	16.6	7.0	54	34	62
Mean		12	7.3	21.4	5.6	58	26	48
r (stressed head)		0.85**[b]	0.04	−0.29	−0.20	0.03	1.00**	0.28

[a]TX = Beaumont, TX; CA = Biggs, CA.
[b]Probability: ** < 0.01, others ≥ 0.05.

that the samples were subjected to field moisture stress before harvest and milling. The range for head rice yield of oven-dried rice was narrower than that for shade-dried rough rice (Table VI). For waxy rice IR29, head rice yield was 60% oven-dried and 53% shade-dried. For waxy IR65, head rice yield was 52% oven-dried and 44% shade-dried.

For the 1990 wet season crop subjected to prolonged oven-drying at 35–40°C, the 2-hr water-soaking treatment drastically reduced head rice yield (Table VI). The best data were for IR60 with head rice yields of 68% (unstressed) and 34% (stressed). IR70 had head rice yields of 48% (unstressed) and 24% (stressed). IR58 had head rice yields of 38% (unstressed) and 10% (stressed). Stressed head rice yield of the other IR rices were 17% (IR36 and IR5); 12% (IR74); 11% (IR26, IR56, and IR64); and <10% (25 others). Again, head rice yield correlated significantly only with brown rice translucency (Table VI). Head rice yield correlations were: protein content ($r = -0.20$ unstressed, -0.04 stressed, $P > 0.05$); amylose content ($r = 0.19$ unstressed, 0.17 stressed); alkali spreading value ($r = -0.16$ unstressed, -0.08 stressed); gel consistency ($r = 0.08$ unstressed, -0.10 stressed).

The result of a 2-hr soak treatment in 30°C water, applied to elite lines oven-dried in bulk at 35–40°C to constant weight, was a very low head rice yield for the 1990 dry season harvest (Table VII). The unstressed grain already showed a wide range of head rice yield. The unstressed IR varieties showed 1–6% head rice yield. The highest head rice yields were those of IR51672-37-3 (36%), IR53936-60-3 (24%), and IR51678-93-2 (15%). Milled rice translucency correlated better with head rice yield of unstressed grain than it did with that of stressed grain. Head rice yield of stressed grain also correlated with milled rice protein and gel consistency but not with apparent amylose content and alkali spreading value. Thus, fissuring occurred below the critical moisture content of a variety or at moisture contents below 13% in all varieties. Critical moisture content of IR rices was 12–16% at the IRRI farm (Juliano and Perez 1993). Siebenmorgen and Jindal (1986) also reported that the reduction of head rice on soaking Tebonnet rough rice occurred only below 13% initial moisture content of dried grain. Again, unstressed head rice yield did not correlate significantly with apparent amylose content, protein content, alkali spreading value, and gel consistency. Stressed head rice yield correlated significantly only with protein content ($r = -0.36$, $P < 0.05$) and gel consistency ($r = 0.48$, $P < 0.05$).

These results demonstrate the importance of performing the soaking test on shade-dried samples at about 14% moisture so that only the susceptible varieties will have reduced head rice yield after moisture adsorption stress. Field-drying of IRRI harvests to moisture contents below 14%, using 35–40°C ovens for extended periods, results in overdrying and equilibrium moisture content of about 12%, which is below the critical moisture content of even the resistant varieties. This is due, in part, to the hysteresis loop during drying (Juliano 1964). This explains why the elite lines had very low head rice yields after stress. However, differentiation still occurred, even with relatively dry starting rough rice.

TABLE VI
Effect of Initial Moisture Content of Shade- and Oven-Dried Rough Rice and Brown Rice Translucency on Head Rice Yield of Unstressed and Stressed IR Nonwaxy Rices[a]

Sample	% Head Rice Yield	
	Unstressed	Stressed
1987 dry season, shade-dried to 16% moisture		
Range	18–67	20–68
Mean	42	45
1987 dry season, shade-dried to 14% moisture		
Range	23–70	17–62
Mean	48	39
Brown rice translucency (22–68%) correlation	0.61**[b]	0.47**
1987 wet season, shade dried to 14% moisture		
Range	30–63	. . .
Mean	47	. . .
Brown rice translucency (22–62%) correlation	0.67**	. . .
1987 wet season, oven-dried at 40°C to 14% moisture		
Range	19–61	. . .
Mean	40	. . .
Brown rice translucency (24–61%) correlation	0.57**	. . .
1990 wet season, oven-dried at 35–40°C		
Range	20–68	1–34
Mean	51	8
Brown rice translucency (20–53%) correlation	0.51**	0.37*
Brown rice particle size index (30–40%) correlation	−0.02	−0.04

[a]28 samples, except 32 samples for 1990 wet season crop.
[b]Probability: * < 0.05, ** < 0.01, others ≥ 0.05.

TABLE VII
Applicability of 2-Hr Soaking in Water on Head Rice Yield of 1990 Dry Season Lines and Control Varieties Oven-Dried at 35–40°C

Sample	Head Rice Yield, %	
	Unstressed	Stressed
Very early maturing		
10 lines	20–42	2–10
IR50	43	6
Early maturing		
10 lines	21–49	1–13
IR72	23	1
Medium-early maturing		
5 lines	35–52	3–14
IR68 (control)	45	5
Medium maturing		
7 lines	17–46	5–36
IR74	54	2
All 36 samples		
Range	17–52	1–36
Mean	27	7
Correlation coefficient with percent translucency	0.72**[a]	0.34*

[a]Probability: * < 0.05, ** < 0.01.

Other Factors

Six IR rough rices that were fractionated into three thickness groups showed decrease in percent hull, increase in brown rice density, and higher head rice yield with increase in thickness, particularly between 1.6–2.1 mm and 2.1–2.5 mm (Table VIII). Head rice yield and density were highest in the 2.1–2.5-mm thick fraction. The increased head rice yield with thicker grain was due, in part, to less hull contribution to rough rice weight (increased brown rice weight) and increased brown rice density. The 2.1–2.5-mm thick fraction was the major fraction in all six rices (42–71%), followed by the 1.6–2.1-mm fraction (14–37%), except for the >2.5-mm fraction in IR44 (38%) and IR58 (18%). The two thickest fractions also had higher rough rice density (1.36–1.39) than that of the thinner fraction (1.33–1.38). Wadsworth and Hayes (1991) also reported that the thinner grains had less head rice yield than that of the thicker grain fractions. Lin (1990) reported a significant correlation between head rice yield and grain thickness ($r = 0.42$, $P < 0.01$) in the second crop in Taiwan but not in the first crop of 43 indica rices.

TABLE VIII
Effect of Rough Rice Thickness on Percent Hull, Brown Rice Density, and Head Rice Yield of Six IR Rices[a]

Rough Rice Thickness, mm	Percent Hull	Brown Rice Density	Head Rice Yield, %
1.6–2.1, range	21.8–34.6	1.294–1.376	21–55
Mean	26.2	1.342	40
2.1–2.5, range	19.9–23.3	1.367–1.391	31–66
Mean	21.1	1.378	48
>2.5, range	19.2–22.8	1.363–1.394	28–64
Mean	20.6	1.374	44

[a]IR36, IR42, IR44, IR58, IR60, and IR66.

PSI is the percentage of flour from brown rice that passes through a 200-mesh sieve in 120 min after grinding in a Udy cyclone mill with 1.0-mm sieve (Williams et al 1988). IRGA 409, CICA 8, and four IR varieties, (PSI 31–45%) correlated negatively with head rice yield unstressed (25–61%, $r = -0.76$, $P < 0.05$) and stressed (22–56%, $r = -0.87$, $P > 0.05$), but not with protein content (8.4–9.3%, $r = -0.06$) or protein extracted from brown rice flour by 2-propanol (0.37–0.54%, $r = 0.06$) or 1-propanol (0.34–0.69%, $r = -0.31$). Prolamin content soluble in propanol is probably not simply related to crack resistance of rice grain, unlike that of millet and corn (Abdelrahman and Hoseney 1984).

When applied to the 1990 wet season crop of 34 IR varieties (Table VI), PSI ranged from 30% (IR22) to 40% (IR42). PSI was only 36% for IR60, IR58, and the susceptible IR44 variety. Among traditional varieties, PSI was 42% (Peta) and 34% (Century Patna 231/SLO 17). In view of these results, correlation coefficient of PSI with head rice was not significant (Table VI). Thus, PSI (which measures crushing hardness of cereals such as wheat that are crushed when milled) may not be directly applicable to rice, which undergoes tangential abrasive milling during processing. Webb et al (1986) reported a significant correlation ($r = -0.51$, $P < 0.01$) between brown rice PSI and unstressed head rice yield for 28 U.S. rices.

The above-mentioned studies demonstrated the complex nature of crack resistance in rice grain. Grain quality factors, apparent amylose content, starch gelatinization temperature as indexed by alkali spreading value, and gel consistency are not significantly related to crack resistance. Brown rice translucency was consistently correlated, but the coefficient was more significant in unstressed grain than it was in the stressed grain. Because cracks occur mainly along the cell walls in the dorsiventral axis (Srinivas 1975), it is possible that the cementing substances in the middle lamella are important, as indicated by pentosan content (Bhashyam et al 1984). Sister-line rices that differ mainly in crack resistance would be ideal samples for further studies. The 1–3 hr soaking test on shade-dried rough rice with 13–14% moisture was shown to be a reliable screening method for crack resistance.

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LITERATURE CITED

ABDELRAHMAN, A. A., and HOSENEY, R. C. 1984. Basis for hardness in pearl millet, grain sorghum, and corn. Cereal Chem. 61:232-235.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 44-15, approved October 1975, revised October 1981. The Association: St. Paul, MN.

ANONYMOUS. 1984. Rice variety withdrawn. Int. Agric. Dev. 5(3):5.

BERRIO, L. E., and CUEVAS-PEREZ, F. E. 1989. Cultivar differences in milling yields under delayed harvesting of rice. Crop Sci. 29:1510-1512.

BHASHYAM, M. K., RAJU, G. N., SRINIVAS, T., and NAIDU, B. S. 1984. Physico-chemical studies in relation to cracking properties in rice using isogenic lines. J. Food Sci. Technol. 21:272-277.

CAGAMPANG, G. B., PEREZ, C. M., and JULIANO, B. O. 1973. A gel consistency test for eating quality of rice. J. Sci. Food Agric. 24:1589-1594.

CUEVAS-PEREZ, F., and PESKE, S. T. 1990. Milling performance of rice varieties under different moisture absorption environments. Trop. Sci. 30:147-152.

GAYANILO, V. G. 1990. Paddy sundrying studies. Pages 21-44 in: Advances in Grain Postharvest Technology Generation and Utilization. J. O. Naewbanij, ed. ASEAN Grain Postharvest Programme: Bangkok, Thailand.

IBABAO, M. G. B., PEREZ, C. M., and JULIANO, B. O. 1987. Screening rice varieties for resistance to fissuring for improved milling quality. Pages 389-397 in: Grain Protection in Post-Harvest Systems. B. M. de Mesa, ed. ASEAN Crops Post-Harvest Programme: Taguig, Metro Manila, Philippines.

JULIANO, B. O. 1964. Hygroscopic equilibria of rough rice. Cereal Chem. 41:191-197.

JULIANO, B. O., and PEREZ, C. M. 1993. Critical moisture content below which rough rice will fissure. Cereal Chem. 70:613-615.

JULIANO, B. O., PEREZ, C. M., BLAKENEY, A. B., CASTILLO, D. T., KONGSEREE, N., LAIGNELET, B., LAPIS, E. T., MURTY, V. V. S., PAULE, C. M., and WEBB, B. D. 1981. International cooperative testing on the amylose content of milled rice. Starch/Staerke 33:157-162.

KHUSH, G. S., and JULIANO, B. O. 1985. Breeding for high-yielding rices of excellent cooking and eating qualities. Pages 61-69 in: Rice Grain Quality and Marketing. International Rice Research Institute: Manila, Philippines.

KUNZE, O. R. 1985. Effect of environment and variety on milling qualities of rice. Pages 37-47 in: Rice Grain Quality and Marketing. International Rice Research Institute: Manila, Philippines.

KUNZE, O. R., and HALL, C. W. 1965. Relative humidity changes that cause brown rice to crack. Trans. ASAE 8:396-399, 405.

LIN, T. F. 1990. Effect of grain morphological characteristics and milling quality on the percentage of head rice in indica rice. Bull. Taichung Dist. Agric. Improv. Stn. 27:9-14 (in Chinese).

LITTLE, R. R., HILDER, G. B., and DAWSON, E. H. 1958. Differential effect of dilute alkali on 25 varieties of milled white rice. Cereal Chem. 35:111-126.

McDONALD, D. J. 1958. A rapid method for determining suncracking in rice. J. Aust. Inst. Agric. Sci. :351-353.

SIEBENMORGEN, T. J., and JINDAL, V. K. 1986. Effects of moisture adsorption on the head rice yield of long-grain rough rice. Trans. ASAE 29:1767-1771.

SRINIVAS, T. 1975. Pattern of crack formation in rice grain as influenced by shape and orientation of cells. J. Sci. Food Agric. 26:1479-1482.

SRINIVAS, T., and BHASHYAM, M. K. 1985. Effect of variety and environment on milling quality of rice. Pages 49-59 in: Rice Grain Quality and Marketing. International Rice Research Institute: Manila, Philippines.

SRINIVAS, T., BHASHYAM, M. K., MUNE GOWDA, M. K., and DESIKACHAR, H. S. R. 1978. Factors affecting crack formation in rice varieties during wetting and field stresses. Indian J. Agric. Sci. 48:424-432.

WADSWORTH, J. I., and HAYES, R. E. 1991. Variation in rice associated with kernel thickness. III. Milling performance and quality characteristics. Trop. Sci. 31:27-44.

WEBB, B. D. 1985. Criteria of rice quality in the United States. Pages 403-442 in: Rice: Chemistry and Technology, 2nd ed. B. O. Juliano, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

WEBB, B. D., POMERANZ, Y., AFEWORK, S., LAI, F. S., and BOLLICH, C. N. 1986. Rice grain hardness and its relationship to some milling, cooking, and processing characteristics. Cereal Chem. 63:27-30.

WILLIAMS, P., EL-HARAMEIN, F. J., NAKKOUL, H., and RIHAWI, S. 1988. Crop Quality Evaluation Methods and Guidelines, 2nd ed. International Center for Agricultural Research in the Dry Areas: Aleppo, Syria.

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