Fissures Related to Post-Drying Treatments in Rough Rice[1]

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ABSTRACT

Rapid drying of field rice would be practical if a treatment could be devised that would inhibit the post-drying fissures that develop in the grain. Investigations were conducted on breaking strengths and on percentage of fissured grains that developed in rough rice stored in different environments after being subjected to drying temperatures of 25, 40, and 60° C. Breaking strengths were generally related to the percentage of grains that had fissured in the treated samples. A storage environment of 11% rh, 45° C produced the lowest percentage of fissured grains, whereas a storage environment of 75% rh, 10° C produced the highest percentage. The storage temperature of 10° C consistently produced more fissured grains in the Brazos variety than did the 45° C temperature, but results of the two storage temperatures were variable for the Labelle variety.

Throughout the world, a primary objective of the rice industry is the production of maximum head yield. Research has shown that much breakage in rice occurs because kernels have been previously weakened by fissures (stress cracks) caused by rapid moisture adsorption or desorption.

Kunze and Hall (1967) found that a moisture gradient was more responsible in producing stress cracks than was a temperature gradient. Later, Kunze and Choudhury (1972) developed hypothetical one-dimensional stress analyses to model the moisture adsorption and desorption behavior of a rice kernel. Chen and Kunze (1983) investigated the effect of relative humidity (rh) and temperature exposures on milling yield of rough rice. They found that rh exposures have a significant effect on the head yield of dried rice (9.3 and 11.9% moisture, d.b.). The higher the rh to which the rice was exposed, the lower was the observed head yield.

Ban (1971) investigated the relationship between rice cracking and high rates of drying. He found that: rice dried from 20 to 13.5% moisture could be dried at a maximum rate of 1.5 percentage points of moisture removal per hour with minor cracking effects; cracking did not necessarily occur during drying or immediately thereafter; and rapidly dried rice, when stored under airtight conditions in which neither drying nor moisture adsorption occurred would fissure with time for 48 hr. Kunze (1979) confirmed that rough rice grains were not fissured at the end of drying, and that a time interval after drying was required before the fissures developed. Nishiyama et al (1979) developed the following crack generation equation for rice after drying:

$$\frac{C - C_e}{C_o - C_e} = e^{-(kt)^m}$$

in which C = crack ratio (in percent) at time t (number of cracked grains to total grains in sample), C_o = initial crack ratio (in percent) when storage starts, C_e = final crack ratio (in percent), t = storage time (h), k = parameter (h^{-1}), and m = dimensionless parameter.

Nishiyama et al (1979) suggested that m and k are upward convex with respect to drying time. The value of m was around 1, and the value of k for brown rice was almost 10 times greater than that for rough rice.

Post-drying fissures in rough rice were also studied by Sharma and Kunze (1982), who were interested in when and for how long after drying fissures developed in grains that were stored in sealed vials. Rough rice at field or storage moisture was dried at 60° C for 2 hr or more. Cumulative counts of grains that fissured were made at 12-hr intervals until 144 hr after drying. Most fissures developed within 48 hr, but some additional fissures developed up to 120 hr after drying.

Kato and Yamashita[3] studied the effect of warm storage temperatures on the development of cracks in dried rice. Rough rice, dried at a high rate ranging from 2.5 to 6 percentage points of moisture removal per hour, was stored in a sealed condition at temperatures of 0, 20, 40, 50, and 60°C. The higher storage temperatures helped to reduce the percentage of fissured grains.

The objectives of this research were: to study the effects of post-drying temperature and relative humidity treatments on the fissures that develop in rough rice during storage; and to determine the relationship between the percentage of fissured grains and grain strengths at certain time intervals after drying with grains in different storage environments.

MATERIALS AND METHODS

Two kinds of rough rice—long-grain Labelle and medium-grain Brazos—were harvested at approximately 25% moisture for use in this investigation. A pneumatic device consisting of a blower, a plenum chamber, and a cylindrical flotation chamber (14-cm i.d.), was used to remove immature grains, which constituted

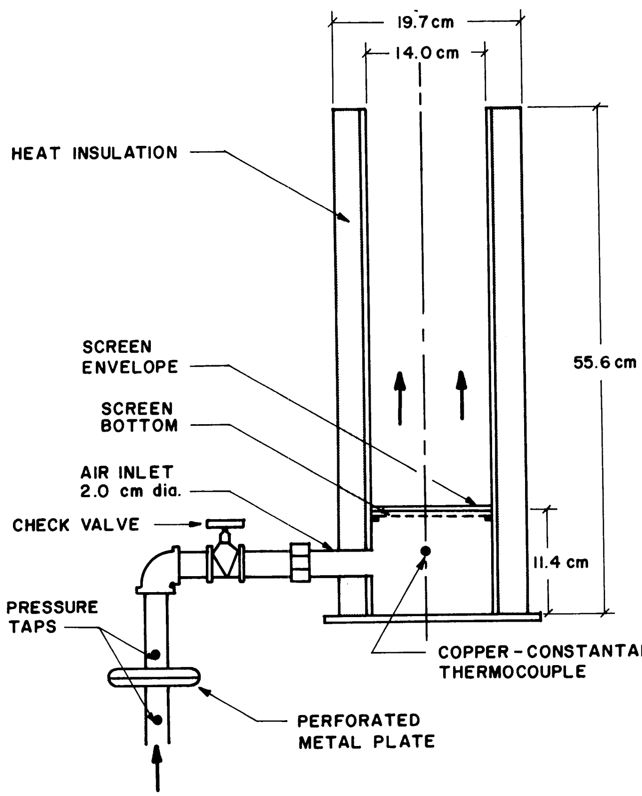

Fig. 1. Dryer in which samples of rough rice were dried from 22 to 12% moisture.

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[3] K. Kato and R. Yamashita. 1979. Study on method of prevention of rice crack—Effect on storage under constant warm temperature after drying. Presented at the 1979 Spring Meeting of the Society of Agricultural Machinery, Japan.

approximately 25% of the initial sample. The remaining sample had approximately 22% moisture and was placed into a sealed container and stored for more than three weeks in an air-conditioned "walk-in" chamber at 10° C (50° F).

A column dryer (14-cm i.d.) (Fig. 1) was used to dry the high-moisture rice to 12% moisture. Three drying temperatures were used—25, 40, and 60° C.

For the bending tests, an Instron universal testing machine was used with a three-point bending test cell (Fig. 2). Each rough rice test grain was positioned across two parallel edges of the test cell base. A rod with an edge across its end was mounted on the crosshead, which was moved downward toward the grain at a speed of 5 mm/min until the rice kernel broke. Values of breaking force were read from an X-Y recorder.

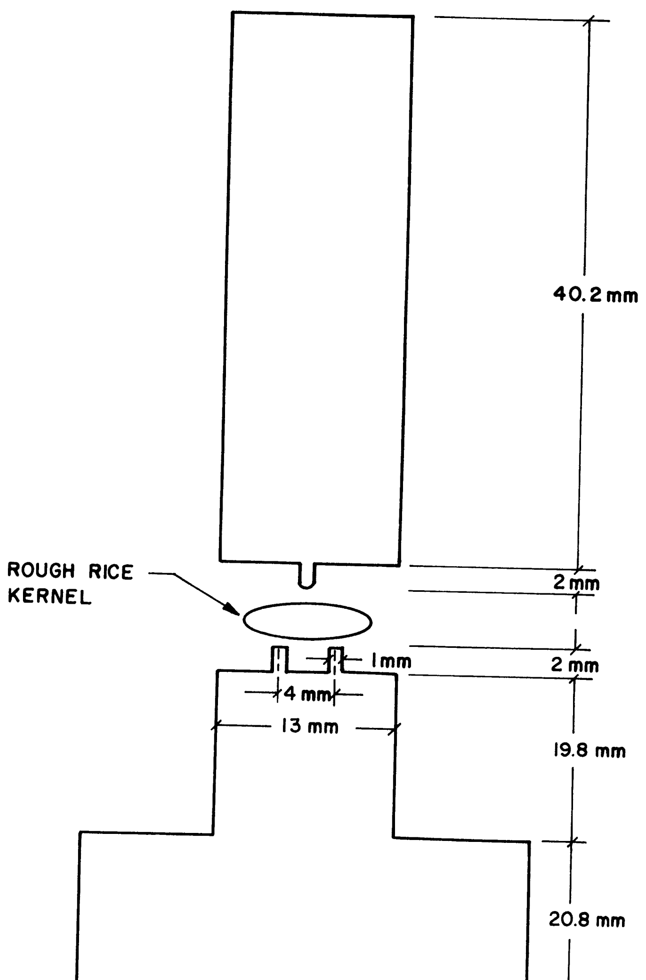

Fig. 2. The three-point bending cell used to break good rice grains after they had been dried and subjected to a certain storage condition for a specified period of time.

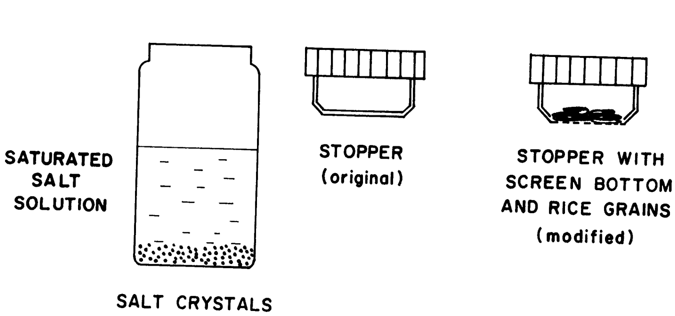

Fig. 3. Side view of the vial and saturated salt solution used to store rice in a controlled environment after drying.

One thousand whole, unfractured grains of rough rice were selected for a given drying condition. Fifty of these grains were used for moisture determination by the oven-dry method. Their theoretical weight at 12% moisture also was determined.

The remaining 950 grains were put into a plastic screen envelope before being placed on the wire mesh bottom of a column dryer (Fig. 1). No other rice was in the dryer. Drying was considered complete when the weight of the rice (950 grains) was equal to the theoretical weight at 12% moisture. Grains were then removed from the envelope and inspected for fissures. True moisture content of 50 of the dried grains was determined by the oven-dry method. Eight subsamples with 100 whole, unfractured grains in each were partitioned from the sample, and the remaining grains were discarded.

Each sample of 100 grains was stored at one of two temperatures (10 and 45° C) and in one of four environments (11, 43, and 75% rh, and in a sealed vial). Each 100-grain sample was divided into four subsamples of 25 grains each. Five vials were used to store one subsample (five grains per vial). Vials containing saturated salt solutions and rice grains (Fig. 3) were stored in two temperature-controlled chambers at 10 and 45° C. Saturated salt solutions of lithium chloride (LiCl), potassium carbonate (K_2CO_3), and sodium chloride (NaCl) were used to provide the relative humidities of 11, 43, and 75%, respectively.

Thirty-two subsamples were required for each drying temperature (two storage temperatures × four relative humidities × four storage times). After 9 hr, the first subsample was removed from the walk-in chamber, and the percentage of fissured grains was determined. Four good unfissured grains were then subjected to bending-strength tests. Similar procedures were used after 24, 48, and 72 hr of storage. The entire procedure was repeated for the other temperature–relative humidity combinations. Two replications were run for each variety, but the bending tests were replicated only once for the 60° C drying treatment. The design of the entire experiment is illustrated in Fig. 4.

RESULTS AND DISCUSSION

The percentage of grains that fissured in the Labelle and Brazos rough rice samples after different treatments (drying temperature, storage temperature, and relative humidity) are given in Tables I and II. Each value is the average of two replications (25 grains per replication).

Drying temperature (drying rate) had a significant effect on the fissuring of rough rice in storage. Grouped samples (200 grains, four subsamples × two replications) of Labelle dried at 25, 40, and 60° C developed an average of 1, 16, and 55% fissured grains, respectively, during the four storage periods in sealed vials at 45° C. For the same conditions, samples of the Brazos variety had 3.0, 6.5, and 50.5% fissured grains (Tables I and II).

Twelve-percent-moisture rice stored in a sealed vial at the 45° C storage temperature would produce an equilibrium rh of about 70% in its limited environment (Wratten and Kendrick 1970). Rice at the same moisture stored in vials at 10° C would produce an equilibrium environment of 57% rh. If the interior vial surfaces

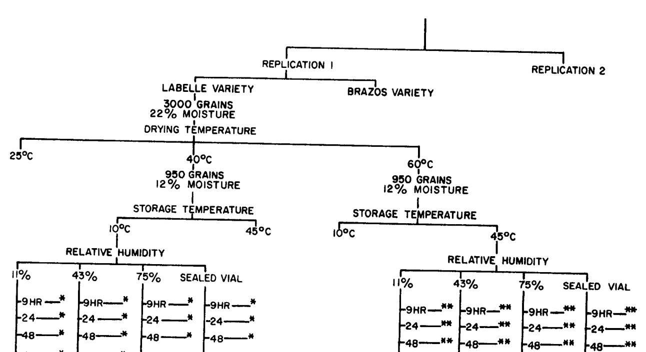

Fig. 4. Design of experiment. —* = grains inspected for fissures. —** = grains inspected for fissures before bending tests.

adsorbed any moisture, then the rh of the limited environment would be less. In this research, rice in the sealed vials responded more nearly like the grains stored in the 43% rh than those stored in the 75% rh.

Labelle generally developed less fissured grains during storage than Brazos. According to Lee and Kunze,[4] long-grain brown rice can withstand a higher maximum stress than medium-grain rice. Moreover, because the Labelle variety is slender, it might fissure less than Brazos because its moisture gradient after drying is smaller.

Effects of storage relative humidity and temperature on the percentage of fissured grains are shown in Figs. 5 and 6 for the Labelle and Brazos samples, respectively. Samples of dried rice (12% moisture) stored at 11% rh developed the smallest percentage of fissured grains, whereas samples stored at 75% developed the highest percentage of fissured grains. Small differences in percentages of fissured grains were observed between samples stored at 43% rh and those stored in sealed vials. Most of the differences were less than 4% for Brazos and 3.5% for Labelle rice. Labelle samples, dried at 60°C before being stored at 11% rh at temperatures of 10 and 45°C, had 11.5 and 36.5 percentage points fewer fissured grains than samples stored in sealed vials at the same temperatures (Table I). For Brazos, the differences were 14.5 and 27.0 percentage points (Table II). Reports by Ban (1971), Kunze (1979), and Nishiyama et al (1979) indicated that grains generally do not fissure during the drying operation, but that fissures may develop after rapid drying. This implies that internal fissures do not develop in the rice grains as long as the moisture flows outward during drying. If moisture continues to flow from the center to the surface of the grains after drying ceases, the moisture buildup on the surface will cause compressive stresses, which in turn cause tensile stresses in the central portions of the grain. When the compressive stresses exceed the internal tensile strength, the grain will fissure. Hence, samples stored in 11% rh developed the fewest fissured grains because the kernel in this environment continued to dry at a slow rate. Because moisture did not buildup on the grain surface, compressive stresses could not develop. The samples

[4] K. W. Lee and O. R. Kunze. 1972. Temperature and moisture effects on mechanical properties of rice. ASAE Paper No. 72-338.

TABLE I
Percentage of Fissured Grains Observed in Labelle Variety[a]

Drying Temperature (°C)	Storage Time (hr)	10°C 11%	10°C 43%	10°C 75%	10°C Control[b]	45°C 11%	45°C 43%	45°C 75%	45°C Control[b]
60	9	16	44	56	30	14	50	80	50
	24	36	52	62	46	18	56	76	64
	48	40	40	62	58	18	60	60	48
	72	40	56	54	44	24	66	68	58
	Mean	33.0	48.0	58.5	44.5	18.5	58.0	71.0	55.0
40	9	0	2	20	20	2	8	12	2
	24	4	8	18	32	0	10	20	24
	48	2	14	18	14	10	12	14	18
	72	4	18	26	12	12	22	12	20
	Mean	2.5	10.5	20.5	19.5	6.0	13.0	14.5	16.0
25	9	0	0	2	0	0	0	4	2
	24	0	0	4	0	0	0	0	2
	48	2	0	8	0	0	0	4	0
	72	0	2	12	2	0	2	6	0
	Mean	0.5	0.5	6.5	0.5	0.0	0.5	3.5	1.0

[a] When rough rice (25 grains per sample) was subjected to indicated drying and storage conditions. Rough rice was dried from 22 to 12% moisture. Each value is the average of two replications.
[b] Sealed vial.

TABLE II
Percentage of Fissured Grains Observed in Brazos Variety[a]

Drying Temperature (°C)	Storage Time (hr)	10°C 11%	10°C 43%	10°C 75%	10°C Control[b]	45°C 11%	45°C 43%	45°C 75%	45°C Control[b]
60	9	44	58	62	50	28	44	70	62
	24	52	72	84	80	26	58	60	50
	48	56	66	80	70	26	56	72	42
	72	52	76	86	62	14	46	62	48
	Mean	51.0	68.0	78.0	65.5	23.5	51.0	66.0	50.5
40	9	16	12	30	6	8	8	32	0
	24	4	14	16	14	0	2	16	10
	48	6	16	26	16	2	8	20	8
	72	2	28	28	14	4	10	14	8
	Mean	7.0	17.5	25.0	12.5	3.5	7.0	20.5	6.5
25	9	0	2	8	4	2	0	6	2
	24	0	6	6	6	2	0	4	4
	48	4	0	2	8	2	8	2	2
	72	4	0	8	6	4	4	4	4
	Mean	2.0	2.0	6.0	6.0	2.5	3.0	4.0	3.0

[a] When rough rice (25 grains per sample) was subjected to indicated drying and storage conditions. Rough rice was dried from 22 to 12% moisture. Each value is the average of two replications.
[b] Sealed vial.

stored in sealed vials developed a significant percentage of fissured grains. In this case, the outer layers of the grain stayed in equilibrium with the limited environment. Hence, cells near the grain surface continued to receive moisture from the inner cells, causing moisture buildup at the grain surface. When the compressive stresses at the surface exceeded the tensile strength in the central portions of the grain, the kernel fissured. For rice samples stored at 75% rh, the percentage of fissured grains was the highest. In this case, the grain surface readsorbed moisture from the environment while moisture from the center of the grains was migrating to the surface. According to Kunze and Choudhury (1972), this moisture adsorption causes swelling of the cells in the surface layers, which further produces moisture stresses within the kernel. These stresses, which were compressive at the surface layers, were balanced by tensile stresses in the inner portions because the kernel itself was a free body. Kernel failure occurred whenever the compressive stresses at the surface layer developed to the extent that resulting tensile stresses at the center exceeded the tensile strength of the central portion of the grain.

For the Brazos variety, storage temperature had a significant effect on the percentage of grains which fissured. This was consistent for any level of storage rh (Fig. 6). The difference in percentage of fissured grains due to difference in storage temperature (10 versus 45° C) increased with the increase of drying temperature. For example, samples dried at 40° C and stored at 45° C and 11% rh had only 3.5 percentage points less fissured grains than samples stored at 10° C at the same rh (Table II). But samples dried at 60° C and stored at 45° C and 11% rh had 27.5 percentage points less fissured grains than samples stored at 10° C at the same rh. Chen and Kunze (1983) reported that both Labelle and Brazos had higher head yield when they were stored at a high temperature (30 versus 20° C).

For Labelle, the storage temperature effect was significant for samples stored at 11% rh only (Table I).

For a given drying treatment and storage condition, fissured grains would be expected to increase with time until the sample equilibrated to the storage environment. For example, Labelle rice dried at 60° C and stored at 45° C and 43% rh showed 50% fissured grains after 9 hr of storage, 56% fissured grains after 24 hr, 60% after 48 hr, and 66% after 72 hr (Table I). Because each fissured-grain count for the next longer period was made with a completely different grain sample, the fissured grain counts were often quite variable. For example the 24-hr count might have been below the 9-hr count, or the 72-hr count below the 48-hr count. Such variations are readily observed in Table I and II. If fissured kernels were counted after 9, 24, 48, and 72 hr in a single sample of grains, then the number of fissured grains could only increase or remain constant with increasing hours of storage.

The bending tests were run only with samples dried at 60° C because this temperature provided the highest percentage of fissured grains in storage.

Tables III and IV show the force in Newtons (N) required to break Labelle and Brazos kernels at the indicated storage time, temperature, and relative humidity after the grains had been dried at 60° C to 12% moisture.

Plots of breaking force (N) versus storage rh for samples of Brazos rough rice dried at 60° C are shown in Fig. 7. Values of breaking force were pooled for storage time. For breaking force, each data point is the average of 16 grains (four grains per sample for four samples). The plot for the Labelle variety was very similar. Force to break grains generally was less for samples in which the

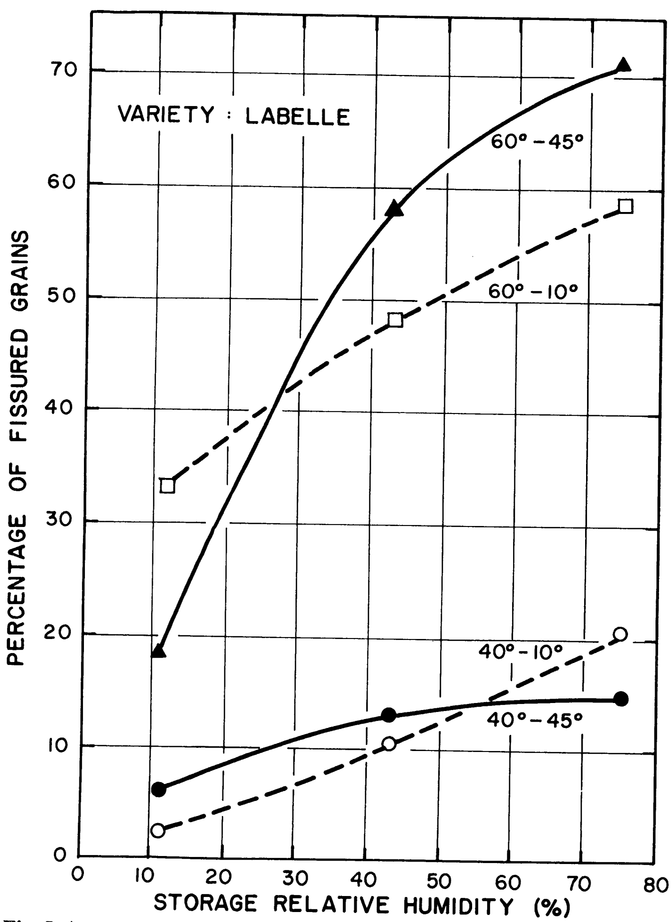

Fig. 5. Average percentage of grains that developed fissures during the four storage periods after rice was dried from 22 to 12% moisture, with the first temperature shown, and stored at the second temperature and the indicated relative humidity. Each data point represents two replications with 100 grains.

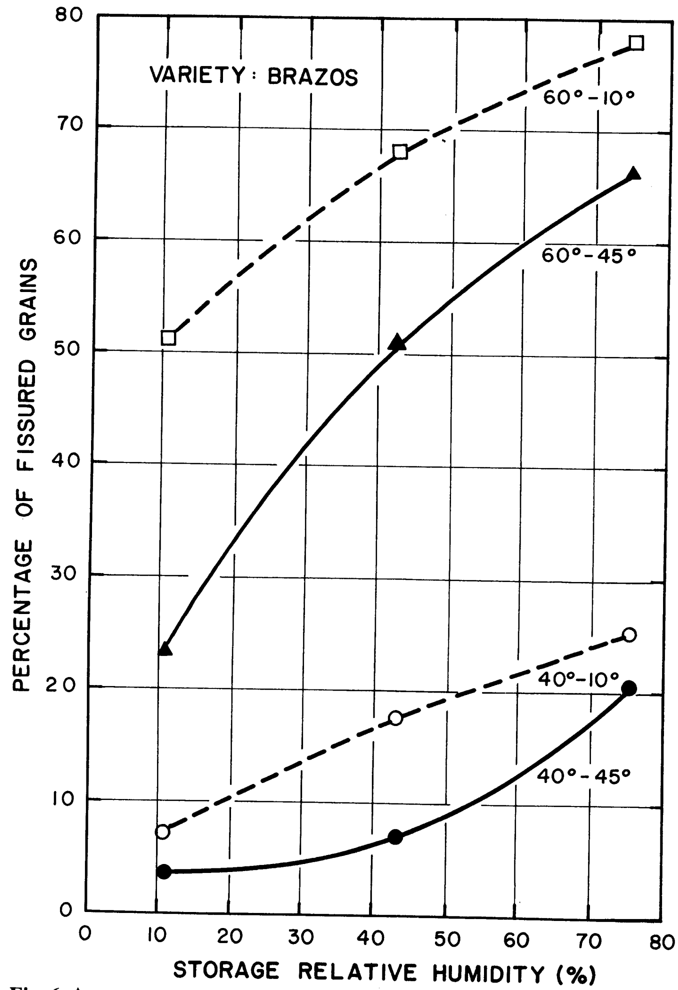

Fig. 6. Average percentage of grains that developed fissures during the four storage periods after rice was dried from 22 to 12% moisture, with the first temperature shown, and stored at the second temperature and the indicated relative humidity. Each data point represents two replications with 100 grains.

storage rh was high. Of the conditions used, the optimum storage condition immediately after drying was 45° C and 11% rh for both varieties. In this condition, the pooled values of breaking forces for the Labelle and Brazos samples were the highest—35.7 and 34 N, respectively, (Tables III and IV). The difference in pooled values of breaking forces between samples stored in sealed vials at 10 and 45° C was only 1.5 N for the Labelle variety. For the Brazos variety, the difference was 4.9 N.

Plots of breaking force versus percentage of fissured grains are shown in Figs. 8 and 9 for the Labelle and Brazos varieties, respectively. A linear relationship between breaking force and percentage of fissured grains was assumed with a resulting correlation coefficient of −0.73 for Labelle and −0.82 for Brazos rice.

CONCLUSIONS

Drying temperature (drying rate) had a significant effect on fissuring of rough rice in the sealed vial storage. An increase of drying temperature from 25 to 60° C for the 45° C storage produced an average increase of 54 and 47.5 percentage points more fissured grains in the Labelle and Brazos varieties, respectively. Because the 25° C (77° F) drying temperature still produced some fissured grains in the sealed storage vials, the lowest acceptable temperature is recommended for commercial rice drying. After drying, the fissured grains increased slightly at the 40° C (104° F) drying

TABLE III
Force Required to Break Four Good Grains of Labelle Variety at the Indicated Storage Time, Temperature, and Relative Humidity[a]

Storage Temperature (°C)	Storage Time (hr)	Breaking Force (N) at Storage Relative Humidity			
		11%	43%	75%	Control[b]
10	9	26.7	9.6	17.0	26.4
	24	33.3	23.5	24.4	27.9
	48	37.2	20.9	23.1	27.3
	72	33.1	26.9	21.9	25.9
	Mean	32.6	20.2	21.6	26.9
45	9	27.4	31.8	23.1	24.7
	24	35.8	32.1	22.5	22.7
	48	38.3	31.7	21.3	25.2
	72	41.2	29.7	23.9	28.9
	Mean	35.7	31.3	22.7	25.4

[a] Grains were dried at 60° C from 22 to 12% moisture.
[b] Sealed vial.

TABLE IV
Force Required to Break Four Good Grains of Brazos Variety at the Indicated Storage Time, Temperature, and Relative Humidity[a]

Storage Temperature (°C)	Storage Time (hr)	Breaking Force (N) at Storage Relative Humidity			
		11%	43%	75%	Control[b]
10	9	31.5	21.3	29.7	26.6
	24	34.5	23.6	12.8	27.4
	48	32.7	29.8	25.2	23.8
	72	31.6	23.7	25.4	19.8
	Mean	32.6	24.6	23.3	24.4
45	9	37.4	40.6	20.0	33.8
	24	28.0	30.5	18.5	27.1
	48	33.5	28.5	25.7	28.8
	72	37.1	30.5	32.5	27.7
	Mean	34.0	32.5	24.2	29.3

[a] Grains were dried at 60° C from 22 to 12% moisture.
[b] Sealed vial.

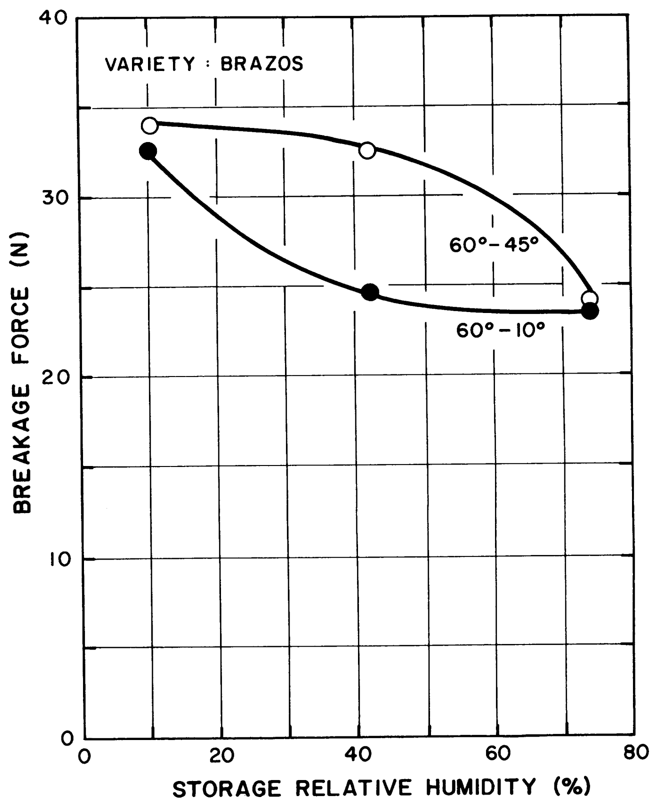

Fig. 7. The average force required to break good grains (four per sample, four samples) subjected to the indicated drying and storage treatments. Generally, force to break grains was less for samples stored in the higher relative humidities. Rice was previously dried from 22 to 12% moisture.

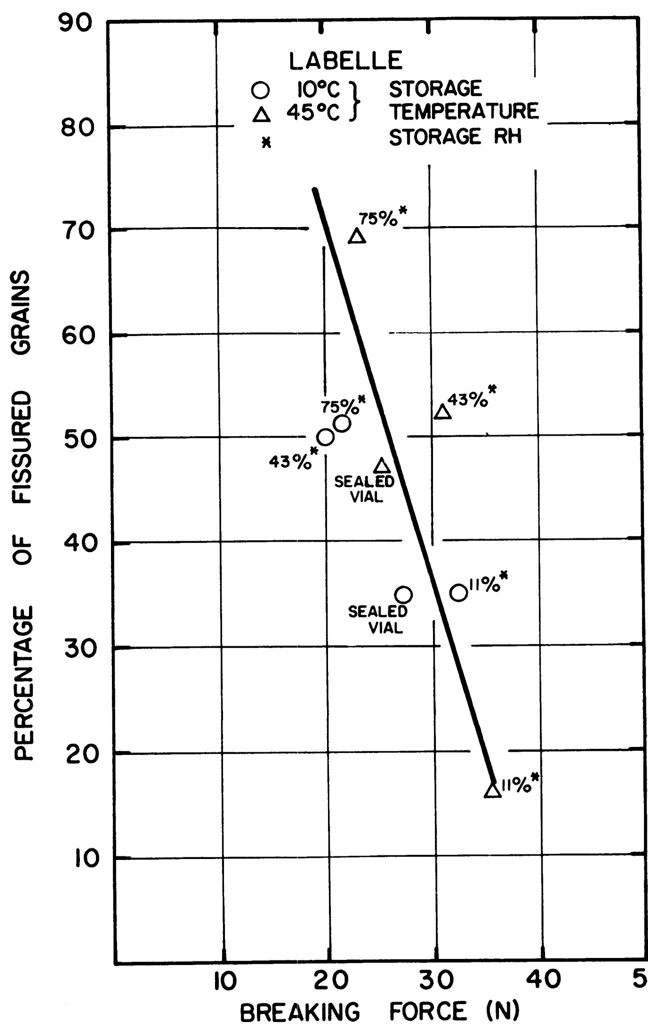

Fig. 8. Relationship between average force to break rice grains (16 kernels) after storage periods of 9, 24, 48, and 72 hr, and the average percentage of grains (100 kernels) that fissured within the same storage periods. Grains were previously dried from 22 to 12% moisture at 60° C.

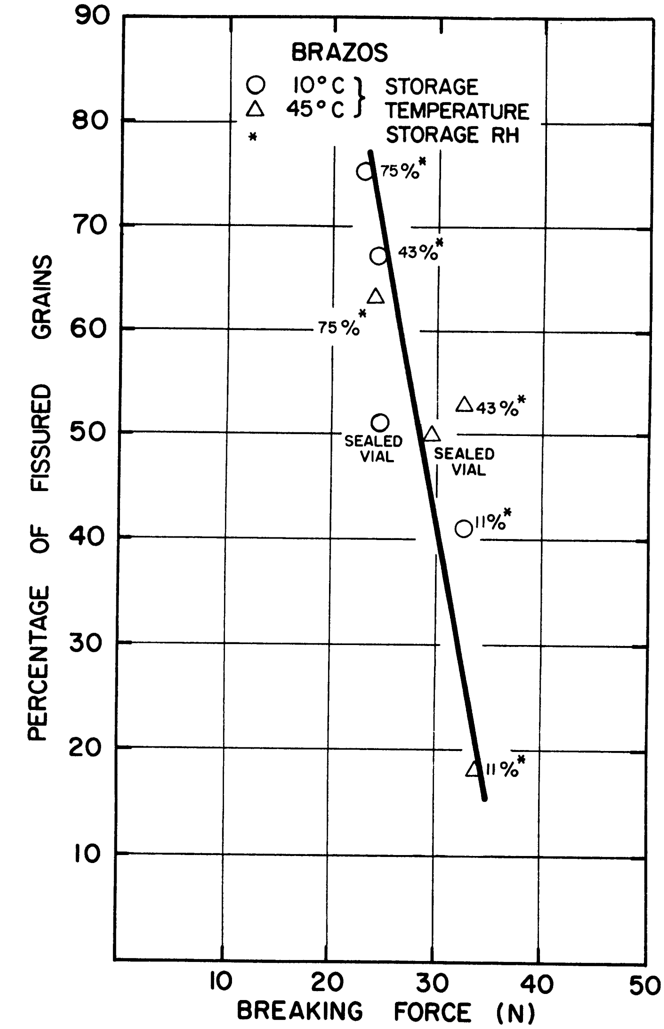

Fig. 9. Relationship between average force to break rice grains (16 kernels) after storage periods of 9, 24, 48, and 72 hr, and the average percentage of grains (100 kernels) that fissured within the same storage periods. Grains were previously dried from 22 to 12% moisture at 60°C.

temperature, but at the 60°C (140°F) temperature, the increases were dramatic. These post-drying fissures justify the universal practice of not sampling rice for quality immediately after it has been dried.

Effect of storage relative humidity on the fissuring of rough rice was significant at each storage temperature. When the control rice was dried at 60°C and sealed in vials, the high storage relative humidity (75%) produced an average of 14–16 and 12.5–15.5 percentage points more fissured grain in the Labelle and Brazos samples, respectively, than the controls. Low storage relative humidity (11%) helped to prevent fissures in rough rice during storage. Grouped samples (200 grains at each storage temperature) of Labelle and Brazos showed 11.5–36.5 and 14.5–27 percentage points fewer fissured grains, respectively, at the 11% rh storage than in the control condition.

If high temperatures (above 40°C) are used in commercial drying, operators should temper or aerate their rice after drying with a low rh air. This would prevent moisture buildup at the grain surface as the moisture gradient reclines toward a condition of equilibrium.

Effect of storage temperature was important for Brazos rice because an average of 25.5% fewer grains fissured in storage at 45°C than at 10°C when grains were dried at 60°C and stored in the three relative humidities. After drying, rice should be cooled slowly while it is tempered. Storage temperature also had an effect on dried Labelle rice, but the results were less consistent.

The breaking strength of rough rice was inversely proportional to the percentage of fissured grains at the end of any storage period after drying. Fissured grains increased with both high drying temperatures and high storage rh.

Although fissured grains generally increased with storage time, the increase was not consistent because fissured grain counts at the four time intervals were made on samples that were independent of each other.

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