Environmental Conditions and Stress Cracks in Milled Rice[1]

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ABSTRACT

Research showed a relation between rate of stress-crack damage and change in equilibrium moisture content (ΔEMC) of rice due to changes in temperature and relative humidity. This relation was found to be an exponential function expressed by the formula:

$$\text{(Rate of damage) } Y = 0.950 + 0.0564\,(\Delta EMC - 2.0)^4$$

where the rate of damage is a weighted factor giving greatest emphasis to damage occurring in the shortest time. The accuracy of this equation in predicting damage is indicated by a multiple regression coefficient of 0.707 which is highly significant at 99% confidence level. The results also showed that (a) high-moisture rice is more susceptible to damage than low-moisture rice, and (b) rice subjected to change in relative humidity of 20% or more is subject to stress-crack development in a relatively short period of time (less than 15 min.).

For some time, personnel in the rice industry have observed that rice develops stress cracks when subjected to gross environmental changes. Stress cracks ultimately lead to reduction in head rice (whole kernels) and lowering of market value. Milled rice is usually stored at 10–15% moisture content and at 5°–32°C. The equilibrium relative humidity (r.h.) of air surrounding rice held under these conditions would range from 35 to 75%. During transfer from one location to another, the stored rice may be subjected to extreme temperatures from 0° to 35°C. and r.h. from 30 to 95%. Very little research has been reported regarding specific temperature-humidity relationships which cause formation of stress cracks. Some workers report that rapid drying may lower yields of head rice (1.2); others, that increases in moisture content may do the same (3,4,5). Many workers report increases or decreases in head yields because of variation of air temperature, humidity, dew, etc., during harvesting and drying.

In some cases, mechanical handling equipment was erroneously considered to be the contributing cause of damage, simply because many of the environmental conditions could not be controlled. A recent, comprehensive study by Kunze and Hall (6) indicates that moisture adsorption causes internal cracking of brown rice. Their study also indicates (a) that rapid moisture desorption could cause external cracks initially, which, after extended periods of time, result in internal fissuring; and (b) that a much higher change in r.h. from high to low (desorption) than from low to high (adsorption) could be tolerated without damage.

Recently, the industry has shown an increasing interest in bulk shipment of milled rice. This increases the hazards of physical damage because the

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rice may be subjected to rapid changes in temperature or humidity, since it is often conveyed in thin layers. New drying techniques (7) also may increase the possibilities of damage. The objective of this research was to determine the interrelationships of changes in temperature and relative humidity which cause stress cracks to develop in milled rice. With knowledge of these relationships, damage could be reduced or prevented.

EQUIPMENT AND PROCEDURES

After various procedures for conditioning the rice samples and exposing them to a new test atmosphere had been considered, it was decided that (a) the samples would be hygroscopically equilibrated with the use of saturated salt solutions held at the desired temperatures; (b) the samples would be exposed to a controlled test atmosphere; and (c) damage would be evaluated by photographic means for speed of observation.

Test Equipment

A 10-cu.-ft. reach-in environmental chamber capable of maintaining any temperature from 3° to 35°C. and any r.h. between 20 and 90% was obtained for this study (Fig. 1). A number of modifications were made to

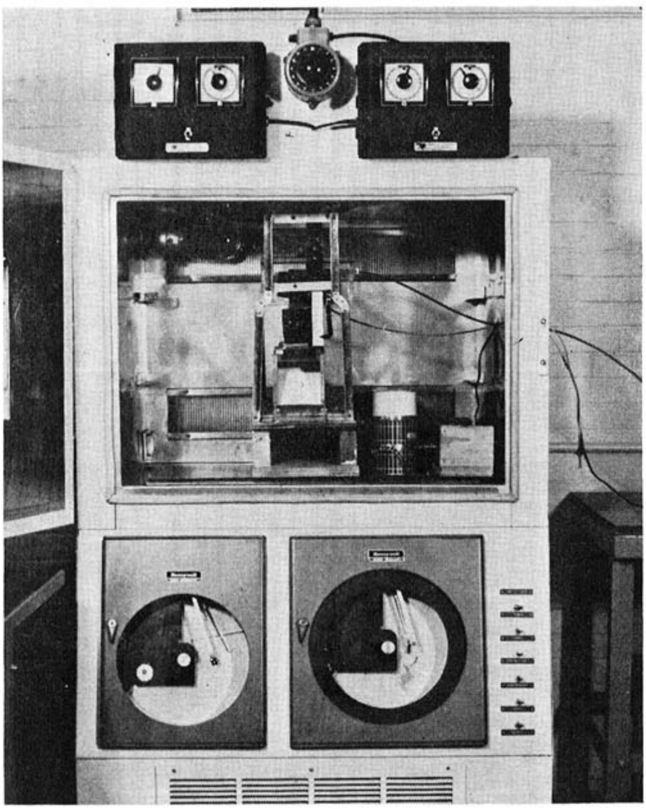

Fig. 1. Environmental chamber showing auxiliary controls at top, remote control camera and conveyor, and Thermos bottles in place for a test.

obtain the desired degree of control. It was found that the response time of the temperature and r.h. controls was too slow to prevent serious overshooting. A hot-gas bypass system was installed in the liquid line of the refrigeration system to permit short-cycling (down to ⅓ sec.) the refrigeration "on" time. The "on" and "off" time was controlled by adding two recycling time switches with a range of ⅓ sec. to 30 sec., one for dehumidifying and one for cooling. These controls prevented serious overshoot by allowing the controls sufficient time to respond to a change in temperature or r.h. Further refinement of control was obtained by adding a heat-balance voltage control which allowed selection of the proper heater power to just offset heat loss in dehumidifying.

Preliminary experiments showed that stress-crack damage could occur in 4 min. or less if the rice was subjected to extreme changes in r.h. Therefore, it was necessary to devise equipment suitable for observing the damage at specific time intervals. It was found that a photographic technique employing polarized light from underneath (Fig. 2) emphasized the stress cracks.

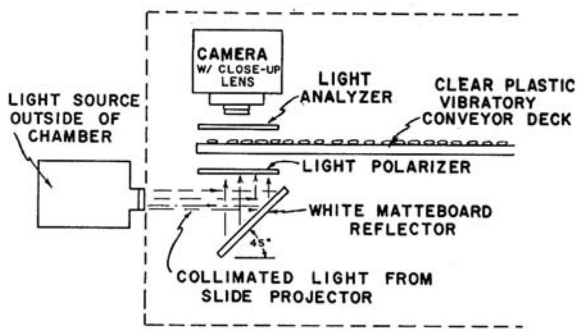

Fig. 2. Schematic diagram of lighting and photographic arrangement for observing stress-crack damage in milled rice.

A remote-control vibratory conveyor equipped with a clear plastic deck was used to convey the rice in a single-grain layer underneath the camera. One sheet of polarizing plastic, the polarizer, was placed immediately below the plastic deck, and one sheet, the analyzer, approximately ½ in. above the deck, so that the rice kernels moved between the two sheets of polarizing material. A white matte board at a 45° angle to the deck and to the collimated light source was used to direct light from outside the environmental chamber up through the rice. A 35-mm. remote-control camera equipped with close-up lens to give direct magnification of 1.5× was used to photograph the rice.

Materials

Two varieties of rice, Belle Patna, a long-grain variety, and Nato, a medium-grain variety, were used for this study. Both samples were commercially milled from freshly harvested rice previously selected to be of high quality. The samples were preconditioned by storage at 20°C. and 60% r.h. This caused the rice to equilibrate at a moisture content of approximately 12.5%.

Procedure

Figure 3 is a flow diagram of the test procedure. Rice samples were sorted by hand to remove any imperfect kernels—cracked, broken, or dis-

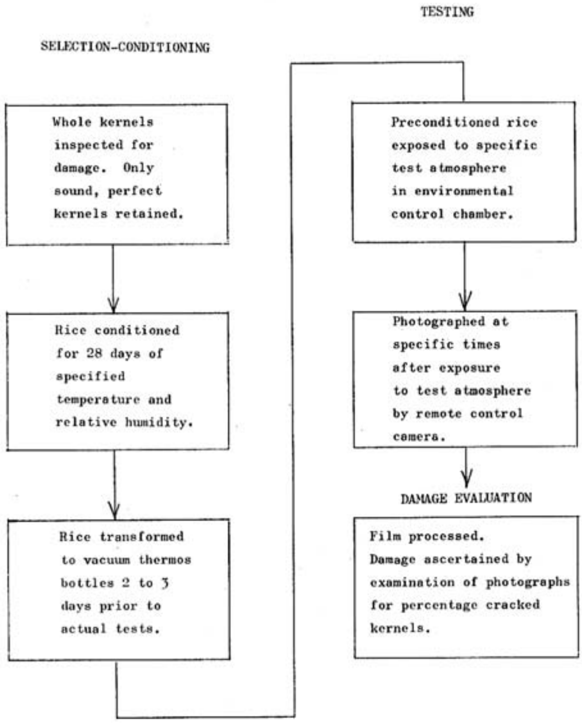

Fig. 3. Flow diagram of test procedure.

colored. The rice was conditioned for 28 days prior to testing in small wire baskets suspended in airtight jars containing saturated salt solutions, which provided the desired constant r.h. conditions. The jars were kept in walk-in refrigerators at the desired temperature. The samples were moved from storage to the conditioning jars in small steps of change in r.h. to prevent any damage. Three conditioning temperatures (5°, 20°, and 35°C.) and three conditioning r.h.'s (34, 55, and 75%) were used. Several days before the test, individual samples were moved from the conditioning jars to Thermos bottles containing the same saturated salt solution, so that the sample could be maintained at the desired temperature and r.h. while they were being moved from walk-in-refrigerator to test chamber. Immediately before the test, the Thermos bottles containing samples were moved to the test chamber.

The procedure was as follows: A preconditioned sample of rice was removed from the Thermos bottle and exposed to the test atmosphere in a single-grain layer. It was then photographed at 4, 8, and 15 min. Damage (percent cracked kernels) was then determined from the photographs by a count of kernels showing any signs of stress cracks. Each test was replicated twice with each of the two varieties.

To perform this research, it was necessary to determine hygroscopic equilibria for milled rice over the range of temperatures and r.h.'s used in this study. Karon and Adams (8) reported values for various fractions of rice but included values for only one temperature, 25°C. Hogan and Karon (9) made investigations at elevated temperatures, 80° to 111°F., but made observations for rough rice only. Experiments were performed to determine the equilibrium moisture content (EMC), wet basis, over a range of 12 to 97% r.h. at three temperatures (5°, 20°, and 35°C.). The rice was equilibrated over saturated salt solutions as previously described. After 30 days of conditioning, the EMC was determined by a modified procedure used by Karon and Adams (8). The desired EMC was approached from a beginning EMC of approximately 12.5%. That is, low EMC's were approached from the wetter side and high EMC's, from the drier side. Two replications of each of the two varieties were made. Both varieties were well milled.

RESULTS AND DISCUSSION

Hygroscopic Equilibria

Results of the tests to determine EMC of milled rice at three temperatures are shown in Fig. 4. The results of Karon and Adams (8) for polished

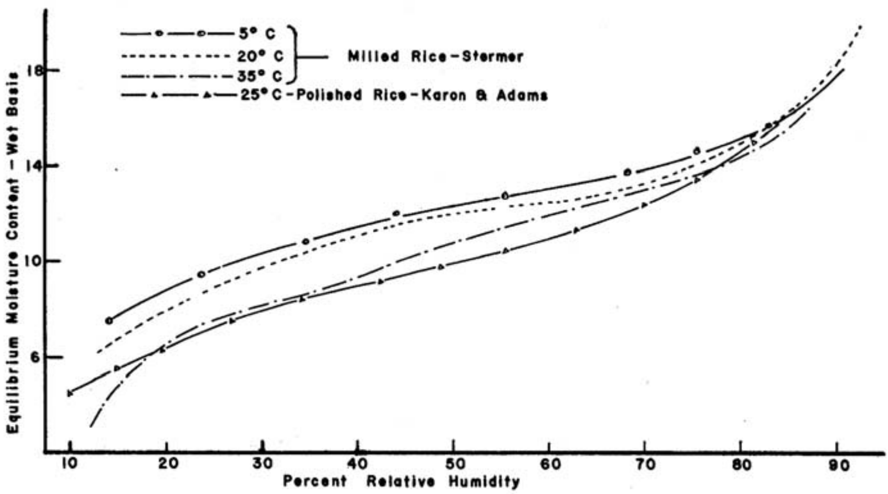

Fig. 4. Hygroscopic equilibria of milled rice.

rice are shown for comparison. No direct comparison can be made, since a different temperature and kind of rice was used; however, the results appear to agree favorably. Analysis of variance showed no significant difference between varieties. A standard error of the mean of 0.261% was obtained.

Stress-Crack Damage

Two kinds of damage were observed: that due to moisture desorption (drying) and that due to moisture adsorption (wetting) (Fig. 5). For desorption, most of the cracks are irregular; for adsorption, the cracks are

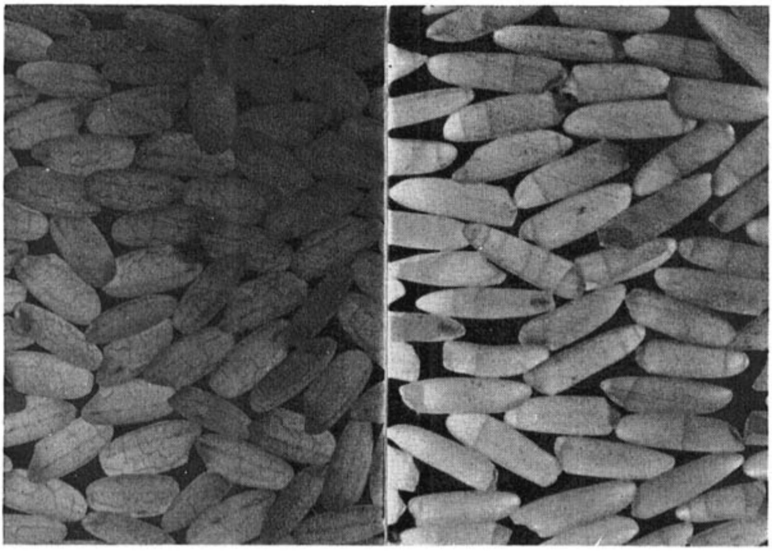

Fig. 5. Stress-crack damage in milled rice: left, moisture desorption (drying) damage; right, moisture adsorption (wetting) damage.

straight. At this time, damage from moisture adsorption is thought to be more serious, since visible evidence of damage from drying seems to disappear. However, in limited mechanical-breakage tests, rice showing either kind of stress-crack damage was easily shattered. Further tests are needed to determine how much either kind of stress crack weakens the kernel.

Previous research by Kunze and Hall (6) showed a relation between stress-crack damage and the magnitude of the change in r.h. The results obtained from the present research failed to show a highly significant correlation between stress-crack damage and either changes in r.h. or vapor pressure. The data showed a relation between stress-crack damage and change in EMC which the rice would attempt to undergo for a given change in environmental conditioning. For example, if a sample is equilibrated to 30% r.h. at 20°C., it would reach an EMC of approximately 9.3% w.b. If the sample of rice is then moved to an atmosphere of 70% r.h. and 20°C., it would eventually reach a new EMC of 13.0% w.b. This would represent a relatively large change in equilibrium moisture content; adsorption would occur and stress cracks probably would develop. Many other factors such as changes in relative humidity, temperature, and vapor pressure were compared with the stress-crack damage in simple correlation and multiple regression analyses. These studies showed that a mathematical relation between stress-crack damage and ΔEMC exists. Damage that takes place during a relatively short time, such as might occur during loading, is of greater practical importance than damage that takes place during a longer period.

Therefore, an equation was developed for rate of damage, which gave greatest emphasis to damage occurring in the shortest time.

$$\text{Rate of damage} = 2X_1 + X_2 + 0.66X_3$$

where X_1 = percent of kernels damaged in 4 min.;
X_2 = percent of kernels damaged in 8 min.;
X_3 = percent of kernels damaged in 15 min.

When rate of damage was plotted against change in moisture content (Fig. 6), the curve showed that (a) damage occurred sooner during moisture

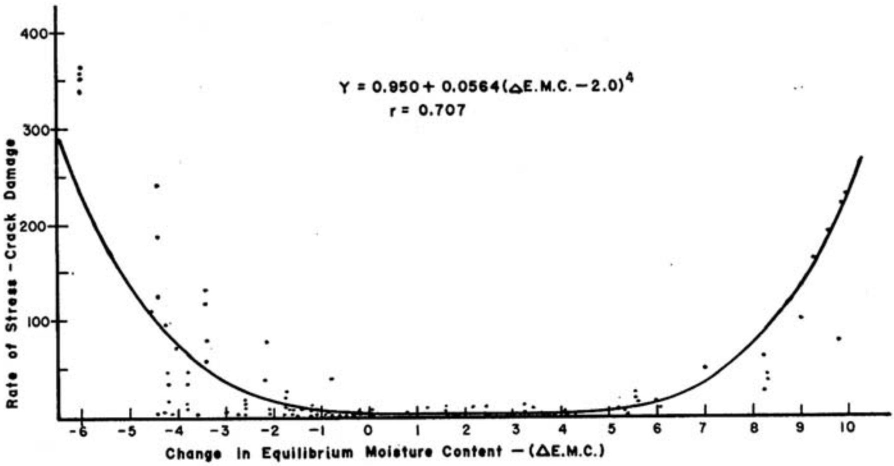

Fig. 6. Relation of stress-crack damage to changes in equilibrium moisture content.

desorption than during moisture adsorption, and (b) the rate of breakage was exponentially related to the change in moisture content which the rice was attempting to undergo. It is hypothesized that the results disagree somewhat with those of Kunze and Hall (6) because of the kind of rice; their experiments were conducted with brown rice, whereas the results reported here are for well-milled rice. The bran layer on brown rice is known to offer some protection from damage by rapid desorption and adsorption.

The relation between rate of damage and a given change in environmental conditions is expressed in the following regression equation:

$$(\text{Predicted rate of damage})\ Y = 0.950 + 0.0564(\Delta\text{EMC} - 2.0)^4$$

The accuracy of this equation in predicting damage is indicated by a multiple regression coefficient of 0.707 which is highly significant at the 99% confidence level.

A factorial analysis of variance and Duncan's multiple range test were used to determine the variables that contribute significantly to stress-crack damage (Table I).

To test the susceptibility of different rice varieties to stress-crack damage, 10 varieties, all well milled with a laboratory mill, were tested at two sets of conditions. The conditioning atmosphere and test atmosphere

TABLE I
FACTORS THAT CONTRIBUTE SIGNIFICANTLY (95% CONFIDENCE LEVEL) TO STRESS-CRACK DAMAGE IN RICE

FACTOR	VARIABLES[a]		
Variety	Nato[b] a		Belle Patna[b] b
Conditioning temperature	35°C. a	5°C. a	20°C. b
Conditioning humidity	75% a	55% b	34% b
Test temperature	35°C. a	20°C. b	5°C. c
Test humidity	30% a	50% b 90% bc	70% c

[a] In order of most to least stress-crack damage. Variables followed by same letter were not significantly different.
[b] Nato, medium-grain; Belle Patna, long-grain.

were representative of conditions that caused medium stress-crack damage in previous studies. These results are shown in Table II.

TABLE II
SUSCEPTIBILITY OF RICE VARIETIES TO STRESS-CRACK DAMAGE
(95% Confidence level)

VARIETY	DESORPTION DAMAGE[a]	VARIETY	DESORPTION DAMAGE	VARIETY	ADSORPTION DAMAGE	VARIETY	ADSORPTION DAMAGE
Blue Belle[b]	a	Belle Patna	c	Nato[b]	a	Bluebonnet	b c
Nato	b	Gulfrose	c d	Belle Patna	a	Gulfrose	c d
Saturn	b c	Kokatto Rose	c d	Blue Belle	a	Saturn	c d
T.P. 49	c	Vegold	d	Vegold	a b	C. P. 231	c d
Bluebonnet	c	C.P. 231	d	T.P. 49	b c	Kokatto Rose	d

[a] Varieties with same letters not significantly different.
[b] In order of most to least susceptible.

In summary, the important findings to date were: (a) high-moisture rice is more susceptible to damage than low-moisture rice; (b) rice subjected to a relatively small change in r.h. (20%) is subject to severe damage when the temperature of the new atmosphere is relatively high, 80°F. or more; and (c) the amount and rate of damage appear to be directly related to the magnitude of change in moisture content the rice is attempting to undergo. Therefore, either high- or low-moisture rice would be more susceptible to damage than medium-moisture rice, since it would normally be subjected to a greater change. Some practical aspects of this study are as follows: (a) determination of safe drying rates for a given lot of rice; (b) determination of conditioning requirements for a lot of rice by either aeration or other means before transfer from one set of conditions to another—for example, from storage elevator bins to a ship's hold in bulk; and (c) maintenance of proper relative humidity-temperature conditions in rice-milling or processing plants to prevent development of stress cracks.

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