Effect of Environmental Changes on Rice Yield and Particle Size of Broken Kernels[1]

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ABSTRACT

Cereal Chem. 60(3):238-241

Rough rice direct from the field or from storage usually provides a biased sample for moisture adsorption experiments because these samples contain kernels with fissures from previous environmental exposures. Control samples showed 11.1 percentage points more total yield than head rice yield for Labelle, and 20.7 percentage points more for Brazos rice. A sudden exposure of rough rice to a relative humidity increase of 30 percentage points or more caused a further reduction in head rice yield. Rice variety and grain type are also factors that influence the loss of grain quality. Rough rice samples at 9.4% moisture (dry basis) showed lower head yields at 20 than at 30°C, but temperature had little or no effect on rough rice samples at 11.9% moisture (dry basis). The weight ratio of small kernel fragments to large kernel fragments in a milled sample was less responsive to environmental exposures than was the head yield.

Rice is a hygroscopic grain that adsorbs or desorbs moisture, depending on the environment to which it is exposed. The interest of the grower or processor normally is to dry the grain. Yet numerous opportunities exist for a dried grain to fissure because of moisture adsorption between the time of maturation in the field and before milling. Low-moisture grains may increase in moisture from changes of temperature and relative humidity that occur in the field. Immediately after harvesting, the mixture of high- and low-moisture grains in the combine hopper provides an environment for the low-moisture grains to readsorb moisture from the humid interstice air. In deep-bed dryers, the drying air enters the bottom of the grain bed and quickly becomes humid. Any low-moisture grains ahead of the drying front readsorb moisture until the drying front reaches them. Dried rough rice on the surface in storage bins, in loading or unloading operations, or in transport readsorb moisture if it is exposed to humid air.

Fissured grains caused by moisture adsorption from environmental exposures or from the blending of high- and low-moisture rice were discussed by Kondo and Okamura (1930), Stahel (1935), and Calderwood (1979). According to an analysis by Kunze and Choudhury (1972), kernel failures can occur if the compressive stresses at the surface layers develop to the extent that the resulting stresses at the center exceed the tensile strength of the central portions of the grain. Swamy and Bhattacharya (1980) reported that grain breakage during milling seemed to originate almost entirely from defective grains. Prasad et al[2] found that volumetric expansion of brown rice for a one percentage point increase in moisture was about 100 times that for a 1°C increase in temperature. Therefore, moisture stresses appear to be a major cause of fissured grains.

The objective of this research was to investigate the effects on head rice yield and broken kernel particle size when rough rice samples at moisture contents of 9.4 and 11.9% dry basis (db) were given a four-day exposure to relative humidity environments higher than the equilibrium relative humidity at temperatures of 20 and 30°C. The treated rice was dried back down to approximately 11.9% moisture db (23°C, 52% relative humidity [rh]) before milling.

MATERIALS AND METHODS

Long grain Labelle and medium grain Brazos from the 1978 rice crop were used. This rice was held in controlled storage at 12°C and 67% rh. After removal from storage, the lots were aspirated to remove immature grains, hulls, and other light material. Brown rice kernels were removed by hand.

One lot of cleaned, long-grain rice of about 10 kg was divided into two groups (A and B). Another lot of cleaned, medium-grain rice of the same amount was divided into two groups (C and D). Groups A and C were equilibrated to 9.4% moisture content db (8.6% wet basis) in a controlled-environment chamber at 23°C and 34% rh. Groups B and D were equilibrated to 11.9% moisture db (10.7% wet basis) in a laboratory at ambient air conditions of 23°C and 52% rh. The equilibrating process lasted for three weeks.

After equilibration and before exposure, each of the groups (A, B, C, and D) was stored in a sealed container. Exposures were made in an environmental chamber in which temperature and rh were controlled within 1°C and 3%, respectively.

Sixteen samples of approximately 250 g each were taken from each group. Two samples were exposed to each of the following

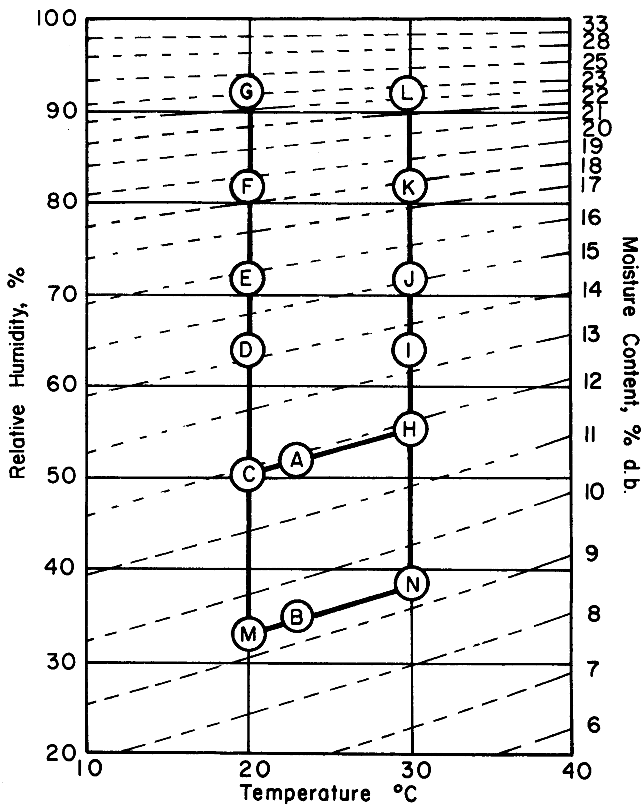

Fig. 1. A hygroscopic equilibria chart for rough rice on which the initial rice conditions and the conditioning processes are shown. Initial conditions of samples at the two moisture levels are represented by A and B. Postulated transient temperature conditions are C and H, and M and N. Samples were conditioned to points D, E, F, and G at 20°C and I, J, K, and L at 30°C.

[1] Approved for publication as Technical Article 17617 of the Texas Agricultural Experiment Station.

[2] Prasad, S., Mannapperuma, J. D., and Wratten, F. T. 1975. Thermal and hygroscopic expansion of brown rice. Presented at the Southwest Region Meeting of the American society of Agricultural Engineers, April 3–4, Fountainhead State Park, OK.

temperature and humidity environments: 20° C (68° F) at 64, 72, 82, and 92% rh; and 30°C (86°F) at 64, 72, 82, and 92% rh. These environments included conditions that cause rough rice to fissure and, thereby, decrease head rice yield. Test grains were spread into thin layers on screen-bottom trays to permit uniform moisture adsorption. An exposure time of four days was used to allow the grains to pick up about 97% of the moisture that would eventually be adsorbed if the exposure were prolonged indefinitely (Breese 1955). Moisture contents after the respective exposures are shown in Fig. 1. Also, these exposures were used to simulate rh changes for low-moisture rice in the field. A shorter exposure period may have been adequate. After exposure, the samples were dried in a controlled-environment laboratory (23°C and 52% rh) for at least three weeks more. Then, the rough rice in each sample was divided into two 125-g subsamples and shelled with a Satake rubber roll sheller, and the resulting brown rice was milled with a McGill no. 2 mill operated with the weight controlling the milling pressure located at the end of the lever arm. Labelle samples were milled for 45 sec and Brazos samples for 60 sec to give an equal degree of milling. Each milled subsample was separated into three fractions with a cylindrical separator (Hart Uni-Flow cylinder tester). The fractions were: head rice; large brokens, equivalent to second heads; and small brokens, equivalent to screenings and brewers rice. The sorting procedure developed by Chen[3] was used. The experiment involved 32 treatments, with four observations nested in each treatment.

Particle sizes, weight, and weight percentages of sorted fractions of milled rice were investigated. Four untreated subsamples, two of the long and two of the medium grain, were used as controls. They remained in the laboratory at approximately 23°C and 52% rh from the beginning of the experiment until they were processed at 11.9% moisture (db).

Test Code

A code was developed to represent the different conditions for the milling-quality tests. The rice varieties Labelle and Brazos were represented by Lb and Br, respectively. Initial moisture contents are represented by Hi for 11.9% and by Lo for 9.4% db samples. The temperature and the rh in the environmental chamber are represented by the last two numbers, respectively. As an example, Br Hi-20-72 was used to represent Brazos rice at high initial moisture (11.9%) at 20°C and 72% rh.

RESULTS AND DISCUSSION

Whole Kernel (Head) Yield

Grains that are most sensitive to fissuring from moisture adsorption are often fissured before they are milled. Therefore, rough rice from the field or from storage usually provides a biased sample for moisture adsorption experiments because the head yield is already different from the total milling yield. In this research, the control sample of the Labelle variety showed an initial difference between head and total yield of 11.1 percentage points (Table I). For the Brazos variety this difference was 20.7 percentage points, or nearly twice as great (Table II). The specific causes for these head-yield reductions are not known, but some of the losses can be attributed to exposure of low-moisture rice to moisture adsorption environments in the field, in the mass of freshly harvested rice, or in the rice-drying process. Previous research showed that fissured grains are also influenced by rice variety and grain type, rate of drying, and adjustment of mechanical equipment.

Grains sensitive to a moisture-adsorption environment apparently were already fissured before our experiments. The magnitude of the damage imposed by our rh exposures was somewhat dependent on the previous exposures to which the rough rice had been subjected. The head and total yield difference in a control sample gives a rough measure of the extent to which the sample was initially biased. Our research showed that responses were achieved from exposures to moderate rh increases (30–40%), even with initially biased samples. If the sample grains had previous exposures, then the rh increases in our experiments were second- or third-generation exposures that showed the magnitude of rh change necessary to produce additional fissured grains. Smaller rh increases than reported here might cause the most sensitive grains to fissure in a high-quality rough rice sample.

The data in Tables I and II are the milling results for both varieties after they were subjected to the temperature humidity treatments. Milling yields are shown as grams of milled rice per 100 g of rough rice. Each value in the tables is an average of four replications. Analyses of variance were performed on all the data with a statistical analysis system (SAS). The same analysis was also applied to each rh level. The results of the analysis of variance indicate that the initial moisture content, the relative humidity, and the temperature significantly affected the head rice yield.

[3]Y. L. Chen. 1980. Effects of environmental changes on milling quality of rough rice. Unpublished Ph.D. thesis, Texas A&M University.

TABLE I
Milling Results from Different Temperature and Relative Humidity Treatments of Labelle Rough Rice[a]

	Sample Wt (g)		Milling Yields (g/100 g)		
Treatment[b]	Rough Rice	Brown Rice	Total	Head	Ratio of Brokens[c]
Hi-20-64	121.5	96.1	68.8	58.3	0.42
Hi-20-72	123.4	98.5	69.4	58.8	0.42
Hi-20-82	122.8	96.8	68.3	57.0	0.45
Hi-20-92	128.2	101.5	68.8	54.5	0.42
Hi-30-64	127.2	100.3	68.9	58.4	0.44
Hi-30-72	122.1	96.5	69.0	58.6	0.45
Hi-30-82	127.6	101.6	69.2	58.0	0.44
Hi-30-92	124.0	98.0	68.6	54.5	0.44
Lo-20-64	128.5	101.2	68.0	55.3	0.40
Lo-20-72	125.9	99.0	68.4	50.6	0.42
Lo-20-82	121.5	93.0	66.8	23.7	0.44
Lo-20-92	129.7	101.6	68.3	3.8	0.60
Lo-30-64	130.5	103.1	68.1	56.0	0.39
Lo-30-72	124.9	98.4	68.3	52.8	0.40
Lo-30-82	128.5	101.7	68.5	32.7	0.43
Lo-30-92	125.3	98.5	68.6	7.6	0.48
Control	130.6	106.1	70.9	59.8	0.42

[a]Each value is the average of four replications.
[b]Hi = 11.90% db; Lo = 9.35% db.
[c]The weight ratio of the small rice fragments to the large fragments in a milled rice sample.

TABLE II
Milling Results from Different Temperature and Relative Humidity Treatments of Brazos Rough Rice[a]

	Sample Weight (g)		Milling Yields (g/100 g)		
Treatment[b]	Rough Rice	Brown Rice	Total	Head	Ratio of Brokens[c]
Hi-20-64	124.6	101.4	72.4	54.5	0.06
Hi-20-72	122.5	99.7	72.2	53.6	0.06
Hi-20-82	121.9	98.8	71.7	52.3	0.06
Hi-20-92	126.9	103.0	71.9	43.4	0.06
Hi-30-64	127.1	103.4	72.1	52.3	0.05
Hi-30-72	123.1	100.1	72.2	51.8	0.05
Hi-30-82	125.0	101.3	71.3	51.0	0.06
Hi-30-92	123.2	100.3	72.0	44.0	0.05
Lo-20-64	127.3	103.2	72.0	47.7	0.05
Lo-20-72	125.8	102.4	71.9	36.1	0.06
Lo-20-82	132.4	107.2	71.5	16.2	0.10
Lo-20-92	130.4	105.6	70.0	4.0	0.22
Lo-30-64	130.4	105.9	72.1	51.0	0.06
Lo-30-72	125.5	101.9	71.9	43.5	0.05
Lo-30-82	128.2	104.1	71.8	25.1	0.08
Lo-30-92	125.3	101.8	71.0	8.3	1.19
Control	131.4	106.4	71.2	50.5	0.06

[a]Each value is the average of four replications.
[b]Hi = 11.90% db; Lo = 9.35% db.
[c]The weight ratio of the small rice fragments to the large fragments in a milled rice sample.

Temperature Effect

The data were grouped for analyses according to each rh. The experiment showed that temperature level had a consistent effect on the head yield for the 9.4% moisture samples. The head yields were higher at 30 than at 20°C for every level of rh and for both varieties (Fig. 2). The average difference was about five percentage points for a given rh exposure. The grains adsorbed less moisture during exposure in the environment chamber at higher temperature for a given rh. For example, in a separate four-day exposure period, low-moisture Labelle rough rice samples adsorbed 4.29 g of water per 100 g of dry matter at 20°C and 64% rh, whereas similar rice samples adsorbed only 3.69 g of water at 30°C and 64% rh. The smaller moisture adsorption caused less damage. Another reason could be that, at higher temperature, the grain had more capacity for flow and deformation within the kernel structure. The stresses caused by the moisture gradient were more readily released, thus causing less damage to the grain[4].

For the 11.9% moisture samples, the effects of temperature level on head yield were small and inconsistent. This indicates that the tests were probably run under conditions that were beginning to affect head rice yield. The effects were generally small because the environmental changes, both at 20 and 30°C, apparently did not produce moisture gradients great enough within the grains to cause much damage.

Relative Humidity Effects

For 11.9% initial moisture samples, there was no significant decrease in head yield in either variety until the exposure was to a 92% rh (Fig. 2). For samples with 9.4% initial moisture, the head yields already started to drop when either variety was exposed to a 64% rh. For exposures to higher rh environments, the head yields for both varieties dropped abruptly and were reduced to just a few percentage points after exposure to 92% rh.

[4]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.

When equilibrium moisture content (EMC) lines for rough rice are superimposed on a psychrometric chart, the EMC lines are neither parallel with each other nor with the rh lines. This is illustrated with a hygroscopic equilibria chart for rough rice in Fig. 1. Because the lines are not parallel, rice grains from a given atmosphere subjected to two different temperatures and moved to the same high relative humidity experienced different moisture gains and subsequently caused different amounts of rice to fissure. Relative humidity is defined as the ratio of the actual partial pressure of water vapor in air at a given temperature to the saturation pressure at the same temperature. It is not the most desirable measure for scientific purposes, but its use is common.

When an 11.9% sample was conditioned to 20°C and 64% rh, the process essentially followed the A-C-D lines on Fig. 1. Likewise, when a 9.4% moisture sample was conditioned to 30°C and 92% rh, it followed the B-N-H-I-J-K-L process lines.

The rh at points C, H, M, and N were 50, 55, 33, and 39%, respectively. The chart shows that the 11.9% moisture rice at 20°C (point C) was consistently subjected to about five percentage points greater rh change than rice at 30°C (point H). Similarly, the 9.4% samples were consistently subjected to a six percentage point greater change at 20 than at 30°C (points M and N).

For the 11.9% moisture samples, an rh increase between 27 and 32 percentage points for the temperatures of 30 and 20°C had little effect on head yield. An rh increase between 37 and 42 percentage points, however, had a definite effect since an average reduction of six percentage points in head yield was observed. For the 9.4% moisture samples, an rh increase as small as 31 percentage points for the same temperature range caused a loss of about four percentage points in head yield. Greater rh increases caused much greater losses.

The results show that rh changes had a definite effect on head rice yield, and drier rice was more subject to head rice yield losses. The results are consistent with observations made by Kondo and Okamura (1930), Stahel (1935), Kunze and Hall (1965), and Calderwood (1979).

Ratio of Brokens

Ratio of brokens was defined as the weight ratio of the small rice fragments to the large fragments in a milled rice sample. Thus, a high ratio is indicative of more small particles or fewer large particles in a sample.

If both large and small kernel particles increase by the same weight percentage in a milled sample, there will be less head rice,

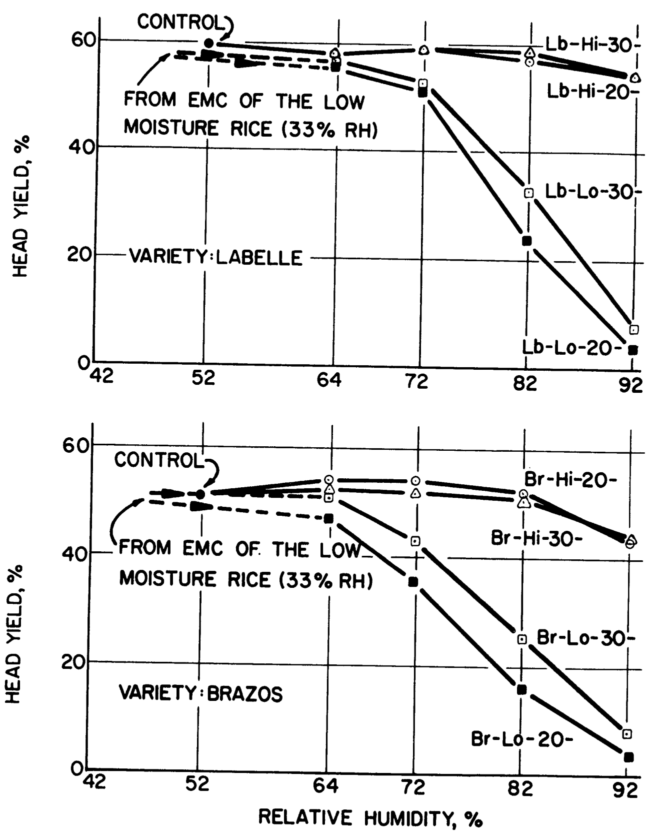

Fig. 2. Relative humidity and temperature effects on head yield for the indicated variety.

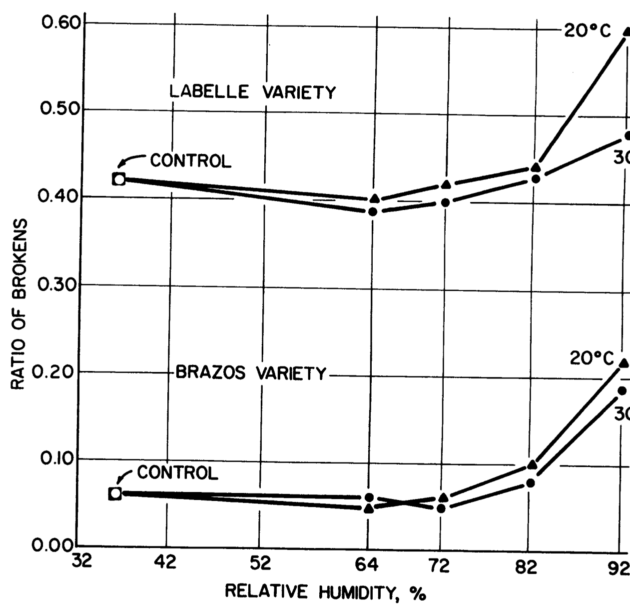

Fig. 3. Effects of relative humidity exposures at indicated temperatures on the ratio of brokens for 9.4% moisture rice samples of the indicated variety.

but the ratio of brokens will not change. In such a case, the ratio is a very insensitive measure. If an environmental exposure would cause only large grain fragments or only small grain fragments to develop, then the ratio of brokens would be a more effective measure because it would readily change. However, if large kernel fragments increase because of an environmental exposure, this is readily reflected in the head rice yield. Large fragments may be an initial step in the production of small fragments. Even though small kernel fragments can be produced without reducing the number of head rice kernels (¾ or larger), the weight of the small kernel fragments would increase and thereby decrease the weight of the resultant head rice yield. Therefore, the weight of head rice yield is a primary measure of rice quality, and the weights of the large and small kernel fragments are secondary measures that may be indicative of the treatments or exposures to which the rice grains have been subjected.

The ratios resulting from the milling quality tests for different treatments for both varieties are shown in Tables I and II. The data show that the 11.9% moisture samples were not affected by the rh changes as far as the ratio of brokens was concerned. However, the 9.4% moisture samples were significantly affected at both temperatures (Fig. 3). The initial or control point for each variety represents the ratio of brokens in the control sample and an rh (36%) that is the average equilibrium rh for the low-moisture grains at the 20 and 30°C temperatures. The ratio of brokens for both varieties was slightly affected at the 82% rh exposure and was overwhelmingly affected at the 92% rh exposure. Thus, compared with the rh effect on head rice yield, the ratio of brokens was less sensitive to rh increases. For example, at the 82% rh exposure, the head yield was reduced from 59.8% for the control to 28.2% (average of 23.7 and 32.7) for the 9.4% moisture Labelle samples. But the ratio of brokens remained at about 0.44, compared to 0.42 for the control samples (Table I).

Exposures to the 64% rh caused the ratio of brokens to decrease in three of the four cases shown in Fig. 3. In the fourth case, the decrease became apparent with the 72% rh exposure. The ratio of weights of small broken fragments to large broken fragments decreased, thereby causing a reduction in the ratio of brokens. The head yield shows a reduction in every case in which the ratio of brokens decreased (Table I). The reduced head yields, along with the reduced ratio of brokens, indicates that these exposures to small rh increases produced primarily large broken grain fragments in the milled rice samples.

The ratios were generally higher for 20°C treatments than for 30°C treatments. This was because at 20°C the rice samples took up more moisture than at 30°C during exposure to a given rh. Less moisture adsorbed by rice samples at 30°C may have caused fewer small particles to develop in the milled rice samples. More flow deformation at a higher temperature also may have helped to prevent the production of small particles.

The ratio of brokens for Labelle was generally much higher than the ratio for Brazos. This could have been caused by one of three factors: the long grain developing more fissures across its long dimension, thereby causing the kernel to break up into a greater number of smaller particles because of its smaller diameter; the Labelle variety being intially less biased (difference in total yield and head yield was only 11.1 percentage points); and the separating procedure and equipment, which was the same for both varieties. The change in ratio was of more interest than the value of the ratio itself.

The ratio of brokens results are consistent with the work of Kunze and Hall (1965), who stated that under small humidity changes, the fissures that developed were large (major) and extended over the grain cross section. In cases of large humidity changes, the impending damage by major fissures was often preceded by small fissures near the grain tips. Kunze (1977) implied that those small fissures near the grain tips may be the source of the small kernel fragments often found in milled rice samples.

ACKNOWLEDGMENTS

We acknowledge the Texas A&M University Agricultural Research and Extension Center at Beaumont for supplying the needed rice. Particular recognition is given to Bill D. Webb, rice chemist, for the use of milling equipment in his Rice Quality Laboratory and to David L. Calderwood, agricultural engineer, for his time, interest, and assistance. Both are with USDA-SEA-AR at the Beaumont Center.

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[Received July 29, 1982. Accepted December 15, 1982]