NOTE

Environmental Conditions Causing Milled Rice Kernel Breakage in Medium-Grain Varieties

Brian J. Lloyd[1] and Terry J. Siebenmorgen[1,2]

Cereal Chem. 76(3):426–427

Milled rice kernels have been shown to rapidly fissure and eventually break when exposed to certain air conditions (Stermer 1968, Kunze and Hall 1967, Siebenmorgen et al 1998). Milled kernels rapidly gain or lose moisture from the environment depending on the air temperature and relative humidity (RH) of the surrounding air, as well as the moisture content (MC) of the kernels (Kunze and Choudhary 1972, Lu et al 1993). This moisture migration into or out of the kernel causes tensile or compressive stresses to occur in the starchy endosperm of the milled kernel (Stermer 1968). Depending on the moisture gradient between the kernel and the equilibrium MC of the surrounding air, these stresses can cause kernels to fissure during postmilling operations. This, in turn, can lead to kernel breakage and a significant reduction in head rice yield (HRY) (Autrey et al 1955). Past research (Siebenmorgen et al 1998) identified critical parameters causing milled rice kernel breakage in long-grain varieties. A test apparatus and an experimental procedure were developed that quantified kernel breakage as a function of air temperature and RH, kernel MC, exposure duration, and kernel temperature in long-grain varieties. As a continuation of identifying factors that lead to milled rice breakage, the relative fissuring response of two medium-grain varieties with a range of MC exposed to various air conditions representing milling environments were determined.

MATERIALS AND METHODS

Two medium-grain rice varieties (Bengal and Orion) were grown in foundation-seed production fields, harvested, and dried at the University of Arkansas Rice Research and Extension Center at Stuttgart, AR. From each variety, 45-kg samples were placed in three different controlled air environments to condition the rice to MC levels of 10.4, 12.5, and 14.8%. MC was determined at the rough rice stage with an individual kernel moisture meter (model CTR-800A, Shizuoke Seiki Co., Yamana, Japan). White, milled rice MC was estimated to be ≈1.5% higher than the corresponding rough rice MC (Lu and Siebenmorgen 1992). Samples of 150 g of rough rice were hulled in a laboratory-scale paddy husker (type THU, Satake, Houston, TX). The resulting brown rice was then milled in a McGill No. 2 laboratory mill (Rapsco, Brookshire, TX) to a degree of milling of ≈90 as determined using a milling meter (MM-1B, Satake). Broken kernels were removed from the milled samples by a shaker-sizer (model 61-115-60, Grainman, Miami, FL) fitted with #10 round-hole screens. The remaining head rice, defined as "unbroken kernels of rice and broken kernels of rice that are at least three-fourths of an unbroken kernel" (USDA 1983), was sealed in plastic bags and stored for ≈24 hr before air exposure tests.

Rice Exposure Apparatus

Head rice was exposed to a range of environments using an apparatus specifically designed to condition milled rice. A complete description and diagram of this apparatus is given in detail by Siebenmorgen et al (1998). This apparatus circulated a temperature-controlled and RH-controlled air stream through each sample at a velocity that gently fluidized the kernels (≈2.44 m/sec). This ensured that the air surrounding the milled rice kernels was not allowed to stagnate during the exposure period. An air-control unit for air temperature and RH (Parameter Generation and Control, Black Mountain, NC) maintained accurate exposure conditions (±0.5°C ± 0.5% RH) during each test run. The air exposure tests were divided into two regimes.

Maintaining constant kernel MC and temperature while varying RH. To determine the effect of air RH on milled rice breakage, head rice samples were selected from the 12.5% MC lot of each variety and exposed to air streams varying in RH from 25 to 82% at 4 percentage point intervals, but all at 30°C. For each air stream, two 10-g head rice samples of each variety were exposed to an air stream at a specific RH at 30°C for a duration of 20 min. A replicate of each exposure condition was also completed. After exposure, the conditioned samples were sealed in plastic bags for 24 hr before testing for the presence of fissures.

Maintaining constant temperature and RH while varying kernel MC levels. To determine the effect of kernel MC on breakage, two 10-g head rice samples of Bengal from the 10.4, 12.5, and 14.8% MC lots were exposed to a high RH air stream (30°C, 75% RH) for 20 min. The same procedure was also applied using a low RH air stream (30°C, 23% RH) for 20 min. A replicate at both high and low RH air conditions was made. After the 20-min exposure, samples were sealed in plastic bags for 24 hr before testing for fissures.

Breakage Tests

A mechanical roller mechanism was used to measure the extent of fissuring damage to the exposed samples,(Siebenmorgen et al 1997). This device consists of two cylinders rotated by a small electric gear motor. One cylinder surface is hard plastic while the other is covered with neoprene rubber. A spring force holding the rollers a prescribed distance apart applied a compressive force of ≈9 N to each kernel as the kernels singly passed between the rollers; the stronger, structurally sound kernels remained intact, while the weaker, fissured kernels would break. Each tested sample was then collected, and the broken kernels removed using the sizing device. The mass percentage of the original head rice sample that was broken by the rollers was reported as the milled rice breakage.

RESULTS AND DISCUSSION

Kernel Damage at Different RH Levels

Medium-grain rice kernels at a typical milling MC of 12.5% were very susceptible to fissuring at both high and low RH levels (Fig. 1). At low RH conditions (<40%) desorption fissures, indicated by an irregular pattern of surface cracks, caused dramatic breakage. At high RH conditions (>75% RH) adsorption fissures, indicated by straight-line cracks perpendicular to the major axis of the kernel, also produced a high breakage percentage (>30% breakage). At the midrange RH conditions of ≈50–70%, samples experienced the minimal amount of damage of ≈15% breakage. These results indicate that a "milling window" of optimal postmilling air conditions for medium-grain varieties to minimize breakage in this RH range. A fifth-order polynomial trendline was used to show the relationship between breakage of medium-grain rice at 12.5% MC and 30°C to

[1] Research assistant and professor, respectively, Biological and Agricultural Engineering Department, University of Arkansas, Fayetteville, AR 72701.
[2] Corresponding author. E-mail: tjs@engr.uark.edu Phone: 501/575-2841. Fax: 501/575-2846

Publication no. C-1999-0417-04R.

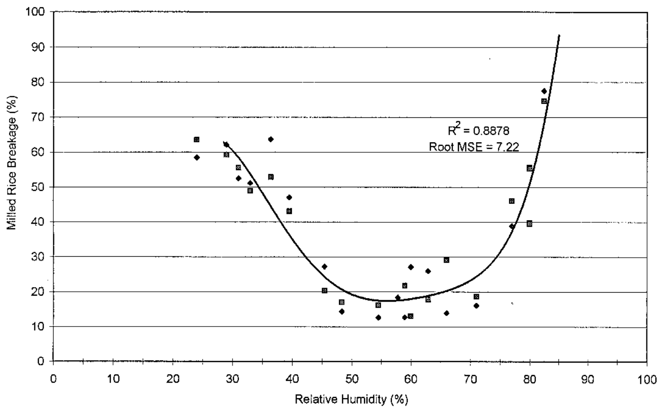

Fig. 1. Medium-grain milled rice kernel breakage resulting from 20 min of exposure to air at 30°C and 25–82% RH at a constant rough rice kernel moisture content of 12.5% (wb). Trendline used a best-fit polynomial. Each data point represents average of two replicates (◆ = Bengal, ■ = Orion).

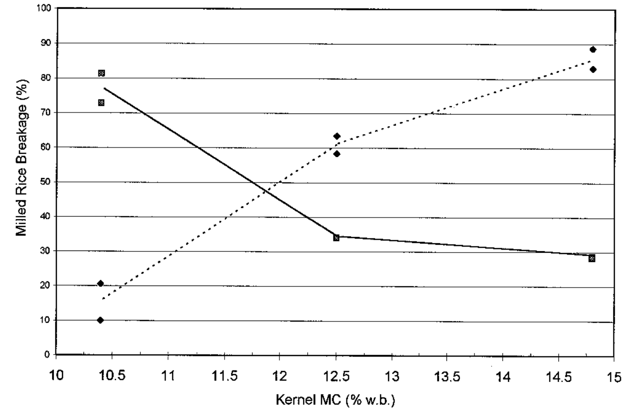

Fig. 2. Medium-grain rice (Bengal) kernel breakage resulting from 20 min of exposure to air environments of high and low relative humidities (30°C, 75% RH [■]) (30°C, 23% RH [◆]) over a range of rough rice moisture contents.

TABLE I
Statistical Comparison of Breakage Dependence on Relative Humidity (RH) Using General Linerar Models (GLM) Procedure

Treatment	DF	Mean Squared	*F* Value	*Pr* > *F*
RH	17	785.48	9.50	0.044
Variety	1	0.46	0.01	0.094
RH × Variety	15	29.73	0.36	0.922

RH values of 28–85% (Fig. 1). The trendline on Fig. 1 shows the slopes of the lower and higher RH values where breakage increases. The slope of the curve on the lower RH side (<45%) is not as great as the higher RH side (>75%). The severity of the onset of breakage with respect to RH was attributed to the type of kernel fissure that each condition caused. As the RH decreased, more and more moisture was removed from the outer surface of the milled kernel resulting in a greater percentage of surface fissures and a greater percentage of breakage. High RH conditions caused the outer surface of the milled kernel to swell placing the outer surface in compression, while inner regions experience an equal but opposite tension stress (Kunze and Hall 1965, Kunze and Choudhary 1972). The fissure occurs when the ultimate tension stress of the starch crystalline matrix is exceeded and a fissure, which originates from the center of the kernel, propagates outwardly perpendicular to the longitudinal axis. High RH fissures were theorized to be a more severe fissure caused by higher stress since fissure-causing stresses originate in the center of the kernel instead of on the kernel surface (Kunze and Hall 1965).

Similar trends in milled rice breakage resulting from various post-milling air environments were reported by Siebenmorgen et al (1998) for long-grain varieties. However, the medium-grain milling RH window of minimal breakage is narrower. This result was anticipated because medium-grain kernels are thicker than long-grain kernels, and typically have greater minor and intermediate diameters. Thus, the distance from the surface to the kernel center is greater, and moisture migration into or out of the kernel cannot occur as rapidly in medium-grain as in long-grain rice varieties. These moisture gradients within kernels create stresses that lead to fissuring (Kunze and Choudhary 1972). The optimal RH that minimized damage for the medium-grain varieties tested was ≈55% at 30°C. The general linear models procedure (GLM, SAS Institute, Cary, NC) was used to show that medium-grain variety had no significant effect on the level of breakage over the RH range (Table I).

Kernel Damage at Different MC Levels

The research with long-grain varieties (Siebenmorgen et al 1998) showed that the amount of fissuring was dramatically affected by the MC of the rice; the greater the moisture gradient between the rice and the exposure air, the greater the amount of breakage produced. Similar trends were measured in this study. Figure 2 shows that kernel MC drastically affects the amount of fissuring at high and low RH conditions. Samples at low MC (10.4%) experienced more breakage at the high RH condition (75%), and samples at high MC (14.8%) experienced more breakage at the low RH conditions. Figure 2 shows that with exposure to the low RH environment, an increase in one percentage point in MC corresponded to an increase of ≈10–30 percentage points in breakage for MC levels in the range of 10–15%.

CONCLUSIONS

Medium-grain milled rice is susceptible to fissuring caused by rapid moisture transfer. The range of exposure RH at which minimal breakage occurred was narrower for the two tested varieties than that reported in similar experiments with long-grain varieties. The least amount of breakage occurred in the RH range of 50–70% RH at air temperature of 30°C for rice at 12.5% MC. Varietal effects did not cause any significant differences in breakage. Also, the MC of the milled rice was a critical parameter in determining the extent of damage at a given environmental condition. High MC rice was more susceptible to damage at low exposure RH, and low MC rice was more susceptible at high RH.

ACKNOWLEDGMENTS

We wish to acknowledge the corporate sponsors of the University of Arkansas' Rice Processing Program, the U of A Center for Food Processing and Engineering, and the Arkansas Science and Technology Authority for financially contributing to this project.

LITERATURE CITED

Lu, R., and Siebenmorgen, T. J. 1992. Moisture diffusivity of long-grain rice components. Trans. ASAE. 35:1955-1961.

Lu, R., Siebenmorgen, T. J., and Archer, T. R. 1993. Absorption of water in long-grain rough rice during soaking. J. Food Proc. Eng. 17:141-154.

Kunze, O. R., and Choudhary, M. S. U. 1972. Moisture adsorption related to the tensile strength of rice. Cereal Chem 49:684-696.

Kunze, O. R., and Hall, C. W. 1967. Moisture adsorption characteristics of brown rice. Trans. ASAE 10:448-450, 453.

Siebenmorgen, T. J., Nehus, Z. T., and Archer, T. R. 1998. Milled rice breakage due to environmental conditions. Cereal Chem. 75:149-152.

Siebenmorgen, T. J., Nehus, Z. T., and Archer, T. R. 1997. A mechanical method to determinefissures in milled rice kernels. Appl. Eng. Agric. 13:637-639.

Stermer, R. A. 1968. Environmental conditions and stress cracks in milled rice. Cereal Chem. 45:365-373.

USDA. 1983. Standards for Rice. (Rev.) Federal Grain Inspection Service: Washington, DC.

[Received June 22, 1998. Accepted January 11, 1999.]