

Milled Rice Breakage Due to Environmental Conditions¹

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ABSTRACT

Cereal Chem. 75(1):149–152

Milled, long-grain rice was exposed to air at temperatures (T) of 20, 30, and 40°C, and relative humidities (RH) ranging from 25 to 85%. The kernels then were subjected to a breakage test to determine the extent of damage that occurred during each exposure condition. Increasing air T levels produced higher amounts of broken kernels across the RH range.

Milled rice at higher moisture content (MC) levels sustained more extensive stress crack damage at low RH conditions and less stress crack damage at high RH conditions relative to milled rice at lower MC levels. Varietal differences were also present, but were overshadowed by MC effects.

Rice is a hygroscopic grain that will readily gain or lose moisture when exposed to varying environments. Moisture changes can induce tensile and compressive stresses within the kernel and often lead to stress crack development. A stress crack is a kernel failure that results from the adsorption or desorption of water by the rice kernel.

Kunze and Hall (1965) and Kunze and Choudhary (1972) detailed the physics of the stresses and strains developed within the rice kernel due to moisture adsorption and desorption, respectively. Kunze and Hall (1965) proposed that when rice adsorbs moisture, the exterior layers swell, creating compressive forces at the surface. Opposite forces are accordingly produced inside the kernel causing the interior cells to act in tension and pull apart. If the internal tensile strength is exceeded, fissures will form in a straight line perpendicular to the longitudinal axis of the kernel.

Kunze and Choudhary (1972) suggested that when the rice kernel loses water, the surface layers contract and tensile stresses are produced. If the tensile strength is exceeded, a pattern of cracks will form over the surface of the kernel.

Stermer (1968) developed an equation relating stress crack formation to the change in the equilibrium moisture content (EMC) of milled rice kernels. The change in EMC was induced by changing the surrounding air temperature (T) and relative humidity (RH). Stermer used polarized light to accentuate stress cracks in the milled rice. Then the samples were photographed and the damage was assessed by visually inspecting the pictures. Stermer found that: 1) rice at high MC levels was more likely to crack in low EMC environments than was low MC rice, and 2) the amount and rate of damage was directly related to the magnitude of change in MC that the rice kernel was exposed to.

Previous researchers (Stermer 1968, Kunze and Hall 1967) have reported kernel damage by visually inspecting kernels for fissures and surface cracks. However, the development of a stress crack does not necessarily give a measure of the strength reduction of the kernel because some cracked kernels will withstand the forces applied to them while being transported or stored. Henderson (1954) showed that “checked” kernels do not always break when milled. Matthews et al (1970) concluded also that cracked kernels were not always broken during the milling process.

A goal of this overall research project was to develop a rapid and repeatable method to quantify the amount of kernel damage resulting from exposure to various environments. To fulfill this need, a mechanism was devised that applied pressure to each individual rice kernel as it passed between two rollers. The extent of damage incurred by kernels exposed to different air conditions was then recorded as the mass percentage of the original sample that was broken by the rollers. This mass percentage is herein referred to as milled rice breakage. The construction details and test performance of this mechanism are given in Siebenmorgen et al (1997). Head rice, defined as “unbroken kernels of rice and broken kernels of rice which are at least three-fourths of an unbroken kernel” (USDA 1983), is generally worth twice as much as broken kernels. Thus, there is a significant financial loss associated with the breakage of milled rice.

Much of the prior work related to moisture sorption damage in rice has focused on rough or brown rice, rather than on milled rice. The objective of this research was to quantify the extent of kernel damage incurred by milled rice of various long-grain varieties over a range of MC levels when exposed to air at various T and RH levels. This research extends the earlier work of Stermer (1968) by: 1) using an improved method of quantifying the presence of stress cracks in milled rice kernels; 2) more accurately delineating the stress crack response of milled rice at given MC levels to T and RH levels of the exposure air; 3) using an exposure medium consisting of a flowing stream of air instead of a stagnant environment.

MATERIALS AND METHODS

Testing Apparatus

The experimental procedure consisted of exposing head rice at various MC levels to a stream of air at various T and RH conditions. An apparatus was developed to ensure that the air immediately surrounding individual kernels was not allowed to stagnate during the exposure period. A system was constructed to allow

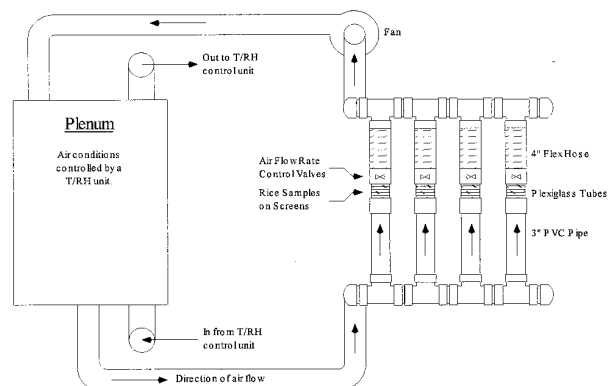


Fig. 1. Rice exposure apparatus.

¹ Published with the approval of the Director of the Agricultural Experiment Station, University of Arkansas. Mention of trademark or proprietary products does not constitute a guarantee or warranty by the University of Arkansas and does not imply its approval to the exclusion of other products that may also be suitable.

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control of the air conditions and flow rate through the apparatus and around the kernels guaranteeing uniform exposure of the kernels to the stream of air (Fig. 1).

An air-control unit for T and RH (Parameter Generation and Control, Black Mountain, NC) was used to maintain the desired exposure air conditions for each test run. The air-control unit was coupled to an insulated chamber (114 × 56 × 102 cm or 45 × 22 × 40 in.). Four vertical 7.6 cm (3 in) diameter polyvinyl chloride pipe sections were teed into a horizontal pipe plumbed into the side of the insulated chamber. Rice exposure chambers were constructed within the four pipe sections by replacing a short portion of the pipe with a Plexiglas tube with mesh screen on the bottom. Each tube contained one milled rice sample. The Plexiglas tube allowed observation of the rice sample during testing. Above each Plexiglas tube section, a valve was installed to enable air flow adjustment to produce uniform flow through the four samples. The valve in each tube was adjusted to allow just enough air flow to fluidize all kernels.

A centrifugal duct fan was used to pull conditioned air from the insulated chamber, through the milled rice samples, and return it to the insulated chamber forming a closed loop. The chamber was likewise in a closed loop with the air-control unit. Once the desired air conditions were reached with the air-control unit, there were only slight deviations in T and RH values ($\pm 0.5^\circ\text{C} \pm 0.5\% \text{RH}$) throughout the testing period. The centrifugal fan provided sufficient air flow to fluidize all four samples being tested simultaneously. This setup will be referred to as the rice exposure apparatus (REA) (Fig. 1).

Experimental Procedure

Five long-grain rice varieties (Alan, Cypress, Katy, Lemont, and Newbonnet) were used. The rough rice was procured from farm bins where it had been dried and stored for approximately three months. After the rice was hulled and milled to a certain degree, milled rice MC was measured for each of the varieties by drying triplicate 15-g samples of ground material in a convection oven at 130°C for 24 hr.

Just before milling, $\approx 45 \text{ kg}$ (100 lb_m) of rough rice was hulled using a commercial-scale husker with paddy separator (model APS30 CXM, Satake, Houston, TX). The resulting brown rice was milled in a single pass through a pearler (BA-7, Satake). Degree of milling (DOM) was determined using a milling meter (MM-1B, Satake). All samples used in this study were milled to a ≈ 90 DOM. After milling, some of the rice was placed in sealed plastic bags and was allowed to temper for at least one day before testing in the REA. The remaining rice was taken directly from the mill and immediately placed into the REA at set air conditions. The rice handled in this manner is referred to as “not tempered”.

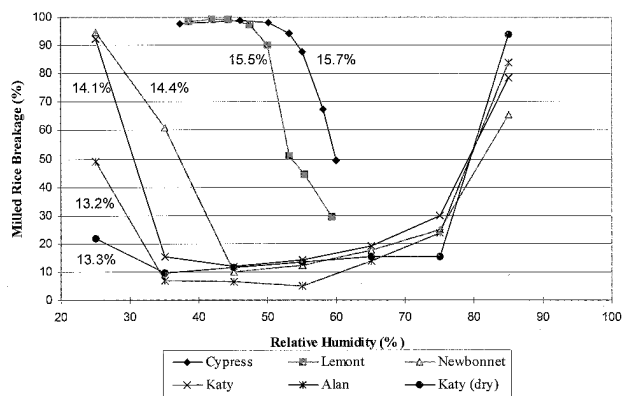


Fig. 2. Milled rice breakage incurred by 20 min of exposure to air at 30°C and a range of relative humidities for five varieties of rice at the indicated milled rice moisture contents. Data represent samples exposed at least one day postmilling (tempered).

Milled rice samples were exposed in the REA for durations of either 10, 20, 30, or 40 min, with each duration being randomly assigned to one of the four exposure tube chambers. Upon removal from the REA, the exposed rice was placed in a sealed plastic bag for at least a 24-hr period before being subjected to a breakage test. The purpose of waiting one day before breakage testing was to allow the internal stresses to be relieved. If the samples were subjected to breakage testing immediately after being removed from the REA, the percent broken was much higher than if tested the next day. It was theorized that stresses set up in the kernels due to moisture adsorption or desorption were still present for some time after exposure. Similar trends were shown in rough rice (Sharma and Kunze 1982), causing the kernels to be more likely to break when force was applied. By waiting the additional day before breakage testing, the estimates of breakage reported are intended to be more representative of those occurring in actual rice milling plants.

Breakage Tests

A mechanical device was developed and implemented to measure the extent of damage incurred by kernels exposed to the different air conditions (Siebenmorgen et al 1997). The device used two cylindrical rollers that were rotated by a small electric motor-gear box. Springs mounted at both ends of one of the rollers applied a compression force to each individual rice kernel as it passed between the rollers. The stronger kernels would remain intact, while the weaker of the cracked kernels would break. After passing between the rollers, the sample was collected and the broken rice removed using a shaker-sizer (Seedbuco, Chicago, IL). The mass percentage of the original sample that was broken by the rollers was reported as the milled rice breakage.

RESULTS AND DISCUSSION

Effects of RH on Milled Rice Breakage

Milled rice breakage increased dramatically at low ($<40\%$ in most instances) and high ($>75\%$) RH levels (Figs. 2 and 3). Milled rice with MC levels $\leq 14\%$ exposed to air at mid-range RH conditions (40–75%) and T of 20 and 30°C , experienced little more damage than those kernels receiving no exposure, which showed a milled rice breakage level of $\approx 10\%$ when passed through the roller mechanism. However, when the T was increased to 40°C , the RH range with minimal breakage was narrowed to 40–65%.

These results indicate that, for a given MC and air T, there is a safe RH range in which milled rice can be exposed without producing an increase in fissured or cracked kernels that will likely break in subsequent handling operations. This could be

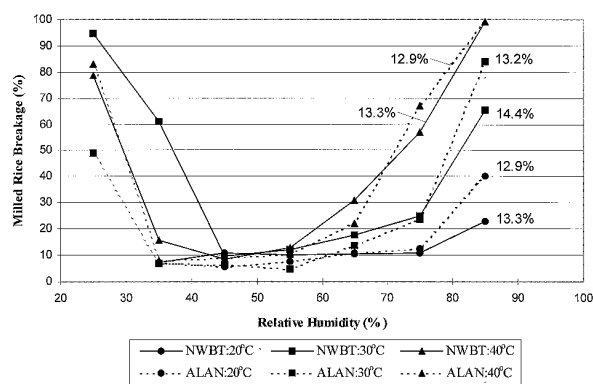


Fig. 3. Milled rice breakage incurred by 20 min of exposure to air at 20, 30, and 40°C and a range of relative humidities for Newbonnet and Alan varieties of rice at the indicated milled rice moisture contents. Data represent samples exposed at least one day postmilling (tempered).

important in such instances as rice mills where the postmilling treatment typically includes sufficient exposure to air which, if outside of the safe RH range, could produce stress cracks. Other situations, such as in end-use processing plants, also could produce stress cracks if kernels are exposed to these high or low RH levels.

Air T Effects on Milled Rice Breakage

Figure 3 illustrates the increase in breakage associated with an increase in exposure air T. The effects are most evident at the high RH levels. Henderson (1954) showed that checking resulted from an increase in T. He theorized that when the outer portions of the kernel increased in T, they expand, while the central portions pull apart and fissure. Lu et al (1993) found that the rate of water uptake increased with temperature in rough rice. In a related study, Banaszek and Siebenmorgen (1990) showed that high adsorption rates resulted in high head rice yield reductions in rough rice. These studies support the data of Fig. 3 in that the milled rice breakage level increased with exposure air T at the same RH level.

Effects of MC on Milled Rice Breakage

At low RH levels (<40%), milled rice at higher MC levels experienced more damage than milled rice at low MC levels for a given variety, as shown in Fig. 2. This trend was reversed at high RH levels (Fig. 2) in that milled rice breakage varied inversely with MC. Figure 2 illustrates that, at the mid-range RH levels, milled rice at >15% MC had more than twice as many broken kernels as the rice at 13–14% MC. At the lower RH levels, the breakage percentage for all varieties increased as MC increased. At the higher RH levels, the pattern was reversed as milled rice breakage increased for all varieties with decreases in rice MC.

Because of the observed strong influence of MC on milled rice breakage, tests were conducted to isolate the effects of MC on breakage within a variety. As such, 1,000 g of rough rice of Cypress, Lemont, and Newbonnet were placed on screened trays in a room maintained at 23°C and 50% RH and gently equilibrated to different MC levels. Samples of each then were milled in a McGill No. 2 laboratory miller and the resulting milled rice was treated in the same manner as outlined above. Figures 4 and 5 reveal distinct differences in the level of milled rice breakage at various MC levels.

Figure 6 shows the relationships between milled rice breakage and milled rice MC for Cypress, Lemont, and Newbonnet samples exposed for 40 min to low RH (25%) air immediately after milling. The data show a clear trend of increasing breakage with MC at this low RH level. Figure 6 also indicates the sensitivity of milled rice breakage to MC level: an increase of one percentage point in MC corresponded to an increase of ≈40–50 percentage points in milled rice breakage for MC levels in the range of 12–14%. The trends shown in Fig. 6 for samples exposed immedi-

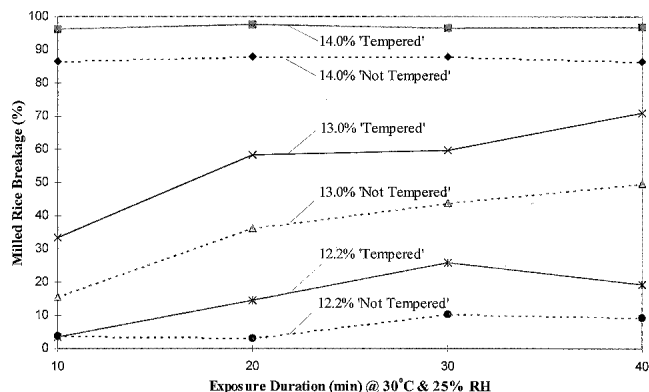


Fig. 4. Breakage vs. exposure duration for Cypress variety at the indicated milled rice moisture content levels for rice exposed immediately after milling (not tempered) or after one day postmilling (tempered).

ately after milling (not tempered) were very similar to those for rice exposed one day postmilling (tempered).

These results are congruent with the results of Stermer (1968) mentioned earlier, as well as with trends observed in rough rice by Siebenmorgen and Jindal (1986) and Banaszek and Siebenmorgen (1990). In general, the level of breakage was strongly dependent upon the difference in EMC between the kernel and that corresponding to the exposure air.

Rate of Kernel Damage

Figures 4 and 5 show that nearly all of the milled rice breakage occurred within the first 20 min of exposure. In Figs. 4 and 5, the higher MC levels reached the maximum amount of damage in <10 min. Stermer (1968) reported that for large changes in EMC, stress-crack damage was evident in <15 min.

Kernel Damage as a Function of Milled Rice Temperature at Exposure

Kernels that were placed into the REA immediately after milling exhibited less breakage, as indicated by the breakage testing device, than those samples that were exposed a day after milling (Figs. 4 and 5). The difference in milled rice breakage between the two conditions was generally 10 percentage points or greater. In general, the curves were parallel; as the tempered rice increased in breakage, so did the rice that was not tempered, but at a lower milled rice breakage level.

The kernel may be in a more elastic state when it exits the milling chamber at high temperatures than after cooling. This could allow for moisture desorption to occur without cracking the kernel as extensively as at lower temperatures. Further investigation into the thermal and hygroscopic properties of milled rice is needed to fully explain this phenomenon.

Cultivar Effects on Milled Rice Breakage

Figure 6 illustrates differences in the amount of breakage incurred by three varieties over a range of milled rice MC levels. At a given MC level, Cypress and Lemont varieties experienced more damage than Newbonnet. Cypress and Lemont are both larger kernel varieties than Newbonnet (Helms et al 1995), which suggests that breakage may be a function of kernel size, with thicker kernels being more susceptible to moisture sorption damage than the thinner. This is supported by Jindal and Siebenmorgen (1994), who showed that, for a given lot of rough rice, the thicker kernels experienced a greater reduction in head rice yield when subjected to moisture adsorption than thinner kernels. Lan and Kunze (1996) showed that the amount of fissured grains in a rough rice sample, resulting from exposure to air at 24°C and 100% RH, varied depending on the variety being tested. Their results showed that samples of Lemont contained 70–80% fissured grains while only 20–25% of the Newbonnet kernels were fissured.

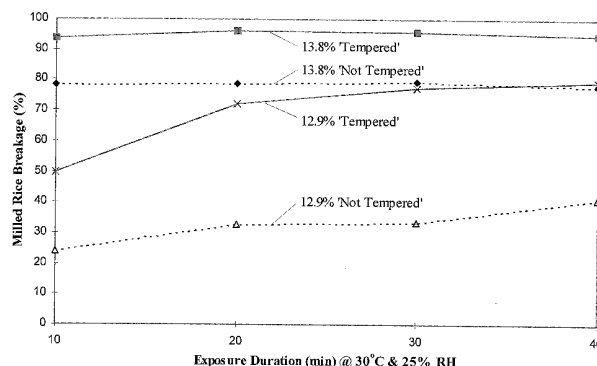


Fig. 5. Breakage vs. exposure duration for Lemont variety at the indicated milled rice moisture content levels for rice exposed immediately after milling (not tempered) or after one day postmilling (tempered).

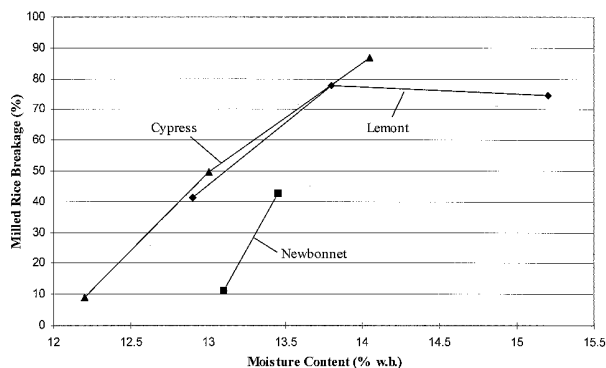


Fig. 6. Breakage vs. milled rice moisture content for rice of the indicated varieties exposed to air at 30°C and 25% RH for 40 min. Data represent rice exposed immediately after milling (not tempered).

CONCLUSIONS

Several factors that influence the amount of breakage milled rice kernels incur when exposed to a range of air conditions were identified in this study. Relative humidity of the exposure air and the MC of the milled rice had the greatest effect on kernel breakage. For milled rice at 13–14% MC, a RH range of 40–65% produced very little increase in milled rice breakage.

Temperature of the exposure air also was shown to affect kernel damage with higher T levels causing more breakage at a constant RH. Rice exposed immediately after milling showed lower breakage than samples exposed to the same air conditions a day later, which indicates that milled rice kernel T influenced the amount of breakage. Finally, the size difference between the milled rice varieties proved to have an effect on the amount of breakage; thicker kernels incurred a higher level of damage than thinner kernels.

ACKNOWLEDGMENTS

We wish to thank the University of Arkansas' Rice Processing Program Industry Alliance Group, the U of A Center for Food Processing

and Engineering, and the Arkansas Science and Technology Authority for financially contributing to this project.

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[Received February 24, 1997. Accepted September 22, 1997.]