Relative Humidity Effects on the Development of Fissures in Rice

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ABSTRACT

Rice grains may develop fissures due to internal stresses when subjected to moisture-adsorbing environments. Rough, brown, and milled rice grains were conditioned to three equilibrium relative humidities (erh) of 46, 62, and 80%, before being exposed to high relative humidity (rh) environments of 65, 86, and 100% for different periods. Grains equilibrated to 46 and 62% erh fissured when exposed to either 86 or 100% rh. For rice grains at 46% erh, the cumulative percentage of fissured grains (CPFG) increased as the exposure humidity increased, with all of the milled rice fissuring at 100% exposure humidity. The CPFG decreased sharply as the initial moisture level increased, with no grains developing fissures when rough rice at 80% erh was exposed to 100% rh. The cumulative number of fissures (CNF) in rice grains increased with exposure rh and exposure time. The regression equations to describe CPFG and CNF related to erh, exposure rh, and time were developed from the SAS Statistical program.

The rice grain is hygroscopic and responds dynamically and physically to moisture and temperature changes in the environment. A dry grain surface adsorbs moisture in a humid environment, while a wet surface desorbs moisture in a relatively dry environment. Moisture adsorption is associated with water reentering the grain. This occurs when the vapor pressure at the surface of a grain is lower than the vapor pressure in the surrounding air.

Kondo and Okamura (1930) were the first to show that a moisture-adsorbing environment caused low moisture grains to fissure. Moisture adsorption can occur in the field, in the holding bin of a combine, ahead of the drying front in a deep-bed dryer, or wherever low moisture grains are exposed to a humid environment (Kunze and Prasad 1978).

Kunze and Hall (1965) observed the development of fissures when brown rice grains, originally at storage moisture, were exposed to a more humid environment. An increase in rh of 20 percentage points or greater above the conditions for grains in moisture equilibrium was sufficient to initiate fissures. Kunze and Hall (1967) showed that the thermal gradients produced by a temperature difference of 34.4°C did not produce fissures in grains as long as the rice was maintained at a constant moisture content.

Stermer (1968) related stress cracks in milled rice to the changes in moisture content. He developed an exponential function that described the relationship between the rate of stress-crack damage and the change in equilibrium moisture content of milled rice due to changes in temperature and rh.

Nguyen and Kunze (1984) studied the effect of drying temperature and various postdrying treatments on the fissuring of rough rice. They noted that drying rate (drying temperature) and storage rh affect fissuring in rice after drying, with high drying temperatures and high storage rh producing more fissured grains.

Researchers (Craufurd 1963, Ban 1971, Kunze 1979, Sharma and Kunze 1982, and Sarker et al 1992) observed that fissures in rough rice may develop for two days or more after rapid drying. Therefore, these internal fissures do not develop from thermal stresses but rather from moisture stresses.

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The primary objectives of this research were to determine the influence of the initial moisture level or erh, exposure rh, and exposure time on the development of fissures in rice such as the cumulative percentage of fissured grains (CPFG) and the cumulative number of fissures (CNF).

MATERIALS AND METHODS

Lemont (23.0% amylose), a popular long grain rice variety, was used. Samples were obtained from the Texas Agricultural Experiment Station at Beaumont in 1992. Rough, brown, and milled rice samples were equilibrated to 46, 62, and 80% erh in a walk-in environmental chamber. After equilibration of the rice samples in all their forms, the respective rice groups were sealed in bottles and stored in an air-conditioned room at essentially 60% rh and 21°C.

Dynamic rh systems, using saturated salt solutions, produced the high relative humidities. Such systems were discussed in detail by Kunze (1964) and Hall (1980). Equilibrated rice samples were placed inside an airtight Plexiglas chamber and exposed to environmental conditions produced with saturated sodium nitrite solutions (65% rh), saturated potassium chromate solutions (86% rh), and water (100% rh). To confirm the accuracy of rh from a saturated salt solution, a digital rh meter was used to measure rh inside the chamber.

Fissure responses corresponding to the exposure conditions were observed. For each experiment, 30 unfissured rice grains were selected from the equilibrated samples. Rough rice was subjected to a high humidity environment for 12 hr or less. But brown and milled rice were subjected to a high humidity environment for only 5 hr because they adsorbed moisture faster and fissured sooner. The rice was inspected and the fissured grains were noted. All experiments were replicated three times. For brown and milled rice, data were taken every 5 min for the first 1 hr and every 15 min thereafter. For rough rice, data were taken every half hour for the first 2 hr and every 1 hr thereafter. A fiber optic light was used to inspect grains for fissures at various times during their exposure.

The SAS System under Windows 3.1 (Release 6.08, 1993) was used for data analysis. A schematic diagram of the experimental procedure and the equipment used during the moisture adsorption experiments can be found in Lan (1994).

RESULTS AND DISCUSSION

Rapid moisture adsorption by low-moisture rice may cause the grains to fissure. A single grain may develop a partial fissure, or perhaps several large fissures depending on the intensity of the water activity (moisture adsorption). However, from the experimental observations with the magnifier, most fissures were not completely through the cross-section of the grain. If a fissure was completely across the cross-section of the milled rice grain, such a grain should have fallen apart because there would be no structural component to hold the grain together. Rough and brown rice grains with large fissures break easily during milling and handling.

Rice Fissuring Experiments

Cumulative percentage of fissured grains (CPFG) was obtained by subjecting rice to a high rh environment. All of the milled rice developed stress fissures when grains at 46% erh were exposed to 100% rh (Fig. 1). This indicates the high potential for the development of stress fissures when any form of low moisture rice is subjected to high humidity conditions. The greater the rh increases, the higher the CPFG.

The data related to fissures in rough, brown, and milled rice are illustrated in Figure 2. The curves represent the responses of rice at 46% erh when exposed to 100% rh at 21°C. Rough rice finally had about one-half the CPFG of brown rice. Brown rice finally had about nine-tenths the CPFG of milled rice. Figures 1 and 2 show that the development of stress fissures started slowly but then increased rapidly. The value finally stabilized at a certain level. From the experimental observations, most of the fissured grains at 65 and 86% exposure rh were in the single- and double-fissured categories. As the exposure rh was increased, a greater percentage of multiple-fissured grains was produced.

The difference in CPFG among rough, brown, and milled rice showed that the husk had significant influence on the rate of moisture adsorption. The husk, as a physical barrier, reduced the amount of water available for diffusion through the bran into the endosperm. Due to the husk or bran, the rates of adsorption for rough rice and brown rice in a given environment were reduced, as well as the potential to fissure. The lower rate of adsorption allowed some moisture to diffuse deeper into the grain, thus reducing the intensity of tensile stresses induced at the center of the grain. If the rate of moisture adsorption was high (due to a large rh increase), an accumulation of moisture occurred at the surface layers of the grain. The accumulated moisture caused the surface layers to expand, producing compressive stresses which in turn induced tensile stresses at the center of the grain (Kunze and Choudhury 1972). When brown and milled rice were subjected to the high rh, the surface of rice grains contacted the high humidity environment instantaneously. Therefore, the vapor pressure difference was large between the moisture in the grain and that in the air. The moisture adsorption rate was, therefore, at its maximum and so was the potential to produce tensile stresses at the center and to produce internal fissures in the grain very quickly.

The initial moisture content or erh had a remarkable influence on stress fissure development. Figure 3 shows that rough rice at 46% erh had 49% fissured grains after the 12 hr of exposure to 100% rh. However, for rice grains at 62% erh, the CPFG decreased to only 29% after the 12 hr of exposure. Furthermore, no grains were fissured when rough rice at 80% erh was exposed to 100% erh.

Figure 4 shows that the forms of rice had a remarkable influence on the CNF in rice grains at 46% erh when exposed to 100% rh at 21°C. Rough rice had a lower CNF than brown rice. Brown rice had a lower CNF than milled rice. For rice samples at 46% erh when exposed to 100% rh at 21°C for 5 hr, the CNF decreased from 143 for milled rice to 32 for rough rice.

Figure 5 shows that the CNF increased as the exposure rh increased. For milled rice samples at 46% erh, the CNF increased from 24 to 143 when exposure humidities increased from 65 to 100%. For a given exposure rh, the CNF increased as the initial moisture content or erh decreased.

SAS Analysis for Fissure Development

The behaviors of rough, brown, and milled rice in CPFG and of milled rice in CNF related to initial moisture content or erh, exposure rh, and exposure time were obtained by statistical analyses:

$$CPFG_R = -0.222 - 0.005E_R + 0.005R_H + 0.016T \qquad R^2 = 0.9271 \quad (1)$$

$$CPFG_B = -1.071 - 0.027E_R + 0.025R_H + 0.338T - 0.037T^2 \qquad R^2 = 0.9056 \quad (2)$$

$$CPFG_M = -0.081 - 0.021E_R + 0.016R_H + 0.283T - 0.031T^2 \qquad R^2 = 0.9152 \quad (3)$$

$$CNF_M = -61.479 - 2.118E_R + 2.096R_H + 10.957T \qquad R^2 = 0.8222 \quad (4)$$

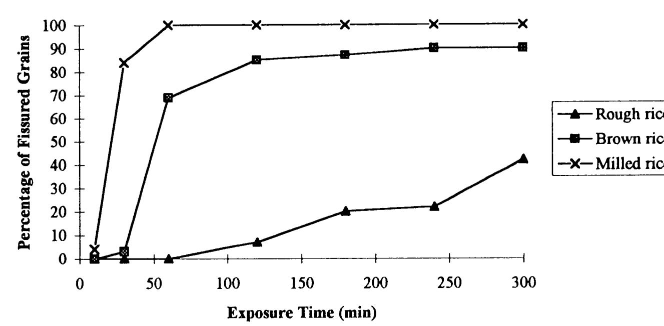

Fig. 2. Cumulative percentage of fissured grains for rough, brown, and milled rice at 46% equilibrium relative humidity when exposed to 100% rh at 21°C. Each point was the average of three replicates.

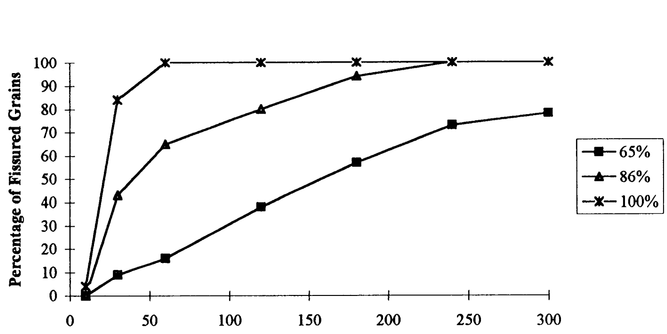

Fig. 1. Cumulative percentage of fissured grains for milled rice at 46% equilibrium relative humidity when exposed to 65, 86, and 100% rh at 21°C. Each point was the average of three replicates.

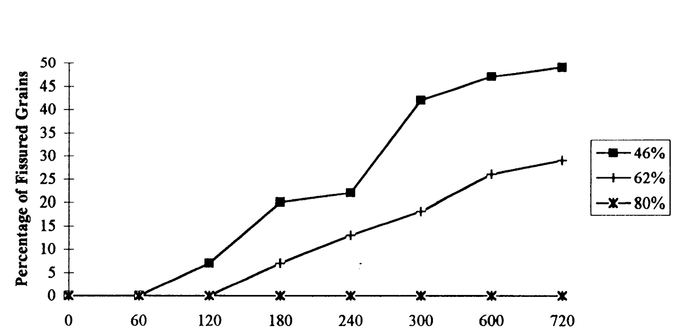

Fig. 3. Cumulative percentage of fissured grains for rough rice at 46, 62, and 80% equilibrium relative humidity when exposed to 100% rh at 21°C. Each point was the average of three replicates.

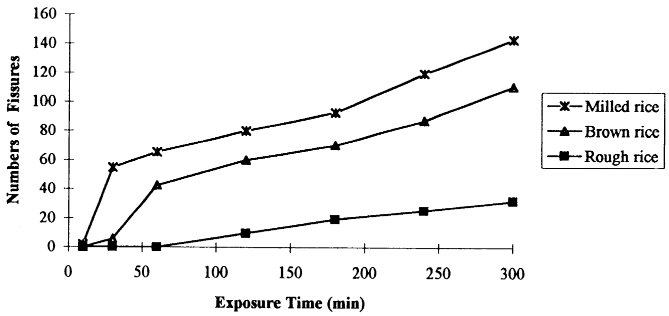

Fig. 4. Cumulative number of fissures that developed in 30 rough, brown, and milled rice grains at 46% equilibrium relative humidity when exposed to 100% rh at 21°C. Some grains had more than one fissure. Each point was the average of three replicates.

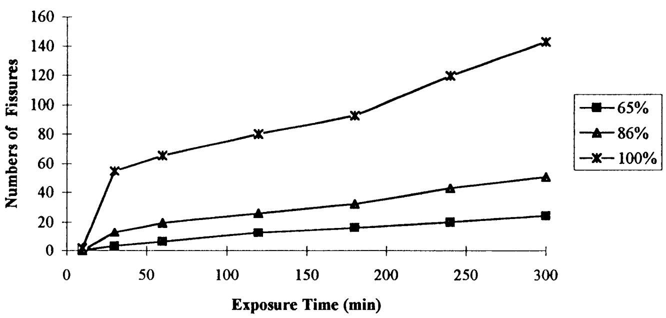

Fig. 5. Cumulative number of fissures that developed in 30 milled rice grains at 46% equilibrium relative humidity when exposed to 65, 86, and 100% rh at 21°C. Some grains had more than one fissure. Each point was the average of three replicates.

where E_R = equilibrium relative humidity (%); R_H = exposure relative humidity (%); T = exposure time (hr); R^2 = coefficient of determination.

The standard errors of estimating terms for rough rice are 0.139 for intercept, 0.001 for E_R, 0.002 for R_H, and 0.026 for T. Similar analyses were made for brown and milled rice. From regression equations, CPFG is dependent on the forms of rice, initial moisture content or erh, exposure rh, and exposure time. The lower the erh and the higher the rh, the higher the CPFG. Equation (4) shows that CNF is dependent on initial moisture content or erh, exposure rh, and exposure time. The lower the erh and the higher the exposure rh, the higher the CNF.

CONCLUSIONS

The CPFG for rice exposed to a higher rh environment was dependent on the forms of rice, exposure rh, and the initial moisture content or erh. Rough rice at 46% erh exposed to 100% rh for 5 hr finally had about one-half the CPFG of brown rice subjected to the same conditions. Brown rice finally had about nine-tenths the CPFG of milled rice for the same initial and final exposure conditions. Fissuring was probably complete for milled and brown rice, but not necessarily for rough rice. An increase in the initial moisture content or erh of the grain or a decrease in exposure rh resulted in a decrease in the CPFG. No fissures were observed when rough rice at 80% erh was exposed to 100% rh. The CNF for rice grains exposed to a higher rh environment increased as the exposure rh increased and erh or initial moisture content decreased.

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