NOTE

Impact of Soaking Temperature and Duration on Fissure Incidence of Rough Rice Kernels

James Patindol, Wallison Domingues, and Ya-Jane Wang†

ABSTRACT

Internal stresses owing to moisture and temperature gradients often result in the development of rice kernel fissures. Fissured rough rice kernels tend to break upon milling and potentially reduce the market value of rice. This work was conducted on the premise that fissures may be healed by soaking in water at a specific temperature and duration. Fissured rough rice kernels of a long-grain cultivar, Wells, were selected by X-ray imaging. Fissured kernels were soaked in a water bath at six soaking temperatures (22, 60, 65, 70, 75, and 80°C) and three soaking durations (1, 2, and 3 h) and then gently dried for characterization. X-ray images revealed that soaking at 75°C for 3 h healed up to 70.0% of the fissured kernels. Soaking at 22, 60, or 65°C did not result in healing. For normal kernels, soaking at different temperatures for 3 h created fissures. Bending tests using a texture analyzer showed that brown rice breaking force increased from 18.5 N (fissured kernels) to 43.7 N (healed kernels). Soaking rough rice in water at a temperature slightly above its onset gelatinization temperature may potentially heal fissures.

Rice (Oryza sativa L.) is predominantly consumed in the form of whole kernels; thus, it is important to maintain intact, whole kernels. Head rice is defined as milled rice kernels that are at least three-fourths the original length of the kernel (USDA 2005), and head rice yield is the mass percentage of head rice over original rough rice. Inferior head rice yield is strongly associated with prevalent kernel breakage during milling owing to fissures. Fissures develop when the compressive and tensile stresses inside the rice kernel exceed kernel mechanical strength (Kunze and Choudhury 1972). Fissures weaken kernel structure, reduce kernel tensile strength, contribute to kernel breakage during milling, and consequently result in head rice yield reduction (Siebenmorgen and Qin 2005).

Parboiling is a hydrothermal process involving soaking, steaming, and drying. Soaking is the first step of parboiling, in which rough rice or brown rice is soaked in excess water to reach approximately 30% moisture content to enable starch to gelatinize in the succeeding steaming step. During soaking, fissures may develop as a result of moisture content gradient inside the kernels from moisture absorption (Buggenhout et al. 2013). Recently, Leethanapanich et al. (2016) demonstrated that soaking alone at a temperature above the glass transition but below the gelatinization temperature of starch was capable of reducing rice chalkiness. Parboiling, as a whole, can reduce the percentage of fissured kernels (Buggenhout et al. 2013, 2014). However, the role of soaking in reducing fissures is not well understood owing to limitations in examining fissure incidence in rough rice, because its husk and bran layers are still intact. The aim of this study was to investigate the impact of soaking temperature and duration on the formation and healing of fissures as monitored by a digital X-ray imaging technique. The technique is capable of showing fissures in rough rice, thus providing a direct visualization of fissure incidence. In addition, kernel breaking force was determined to verify changes in rough rice mechanical strength consequent to soaking.

MATERIALS AND METHODS

Rough rice of Wells, a long-grain purline cultivar, was provided by the University of Arkansas Rice Processing Program. It was obtained from the 2013 crop in Stuttgart, AR, and dried to approximately 12% moisture content. Rice was cleaned with a dockage tester (model XT4, Cater-Day, Minneapolis, MN, U.S.A.), and kernels less than 1.88 mm in width were removed with a precision sizer (model ABF2, Cater-Day) fitted with a rotary screen with slots of 30 mm long and 1.88 mm wide. Its head rice onset gelatinization temperature \( T_g \) was 72.7°C, as determined by a differential scanning calorimeter (Diamond, Perkin-Elmer, Norwalk, CT, U.S.A.). Rough rice kernels were scanned in a digital X-ray imaging system (UltraFocus 60, Faxitron Biopix, Tucson, AZ, U.S.A.) to separate fissured from normal kernels.

Thirty-three kernels were used in each replicate, and three replicates were conducted for each soaking condition. Each fissured kernel was soaked in a screw-cap test tube containing 10 mL of preheated deionized water and was placed in a water bath. The dish was placed on top of a controlled-temperature hot plate to maintain the desired soaking temperature (22, 60, 65, 70, 75, and 80°C) for varying durations (1, 2, and 3 h). After soaking, kernels were gently dried in a chamber at 26°C and 65% relative humidity until approximately 12.0% moisture content. Immediately after soaking and after drying, rough rice kernels were rescanned in the X-ray imaging machine to visually inspect the effects of soaking and drying on fissured rough rice kernels. Normal, nonfissured kernels were also evaluated under the soaking temperature–duration combinations that healed fissured kernels.

Breaking force tests were performed with a texture analyzer (TA.XT2i, Texture Technologies, Scarsdale, NY, U.S.A.). The husk of the rough rice was removed manually, and the breaking force of the dehusked kernel (brown rice) was measured with a flat-faced loading head (thickness = 1.5 mm and width = 9.9 mm) using a three-point bending test (Siebenmorgen and Qin 2005). The distance between the two supporting points was set at 3.4 mm, and the deformation rate was 0.5 mm/s.

All measurements were conducted in triplicate, and statistical analyses of the data were carried out with JMP Pro 13 software (SAS Software Institute, Cary, NC, U.S.A.). Differences between means were detected by Tukey’s honest significant difference tests at the 5% level of significance.

RESULTS AND DISCUSSION

Table I summarizes the percentages of healed and fissured kernels after soaking fissured and normal kernels, respectively, at different temperatures and durations, as determined by digital X-ray imaging.
The results show that higher temperatures and longer durations of soaking resulted in a greater percentage of healing, although fissures were also created during soaking and more fissures formed at lower temperatures. Soaking of fissured rough rice kernels at 75°C (Fig. 1A) for 3 h healed 69.0% of the fissured kernels, whereas soaking at 80°C for 3 h resulted in hull splitting (bursting), indicating the kernel starchy endosperm absorbed an excessive amount of water.

Although 75°C was above the T_o of Wells (72.7°C), no gelatinization was observed by X-ray imaging in rice kernels soaked at and below 75°C up to 3 h, which was attributed to an annealing effect. An increase in T_o up to 7°C was observed when rice was soaked at 75°C for 3 h in a previous study (Leethanapanich et al. 2016) as a result of annealing. Therefore, starch in endosperm was not gelatinized when rice was soaked at 75°C but became gelatinized at 80°C. It was noted that some fissures were not observed right after soaking at 75°C for 3 h (Fig. 1B), but fissures reappeared after gentle drying (Fig. 1C). It is hypothesized that the healing of rice kernel fissures during soaking may only occur to fissures of a certain size because of limited starch swelling and rearrangement of protein bodies during soaking. Variation in the percentage of healed kernels under different soaking conditions may be related to the amount of water absorbed during soaking (Newton et al. 2011).

Table I: Impact of Soaking Temperature and Duration on Rough Rice Fissures

<table>
<thead>
<tr>
<th>Soaking Temperature (°C)</th>
<th>% Healed Kernels from Fissured Kernels</th>
<th>% Fissured Kernels from Normal Kernels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 h 2 h 3 h</td>
<td>0 h 2 h 3 h</td>
</tr>
<tr>
<td>22</td>
<td>0 0 0 d</td>
<td>ND ND 55.6a</td>
</tr>
<tr>
<td>60</td>
<td>0 0 0 d</td>
<td>ND ND 40.0ab</td>
</tr>
<tr>
<td>65</td>
<td>0 0 5.0d</td>
<td>ND ND 20.2bcd</td>
</tr>
<tr>
<td>70</td>
<td>0 0 24.0c</td>
<td>ND ND 9.1d</td>
</tr>
<tr>
<td>75</td>
<td>0 0 69.0a</td>
<td>ND ND 4.0e</td>
</tr>
<tr>
<td>80</td>
<td>0 47.5b 22.2c</td>
<td>ND 16.2cd 36.4abc</td>
</tr>
</tbody>
</table>

z Means in the same property with a common letter are not significantly different at P < 0.05. ND = not determined.

Fig. 1. Representative X-ray images of kernels before soaking (A), kernels right after soaking at 75°C for 3 h (B), and kernels after drying (C).

Fig. 2. X-ray images of kernels before and after soaking at 60°C for 3 h (A), before and after soaking at 65°C for 2 h (B), and before and after soaking at 70°C for 1 h (C).
TABLE II

<table>
<thead>
<tr>
<th>Soaking Temperature (°C)</th>
<th>Fissured Kernels</th>
<th>Normal Kernels</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 h</td>
<td>2 h</td>
</tr>
<tr>
<td>No soaking</td>
<td>18.5e</td>
<td>...</td>
</tr>
<tr>
<td>22</td>
<td>...</td>
<td>12.9e</td>
</tr>
<tr>
<td>60</td>
<td>...</td>
<td>14.5e</td>
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<td>65</td>
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<td>70</td>
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<td>27.3d</td>
</tr>
<tr>
<td>75</td>
<td>...</td>
<td>43.7a</td>
</tr>
<tr>
<td>80</td>
<td>...</td>
<td>37.6abc</td>
</tr>
</tbody>
</table>

*Means with a common letter are not significantly different at P < 0.05.

Figure 2 shows the increase in the amount of fissures when soaking was conducted below the T_g; 60°C for 3 h, 65°C for 2 h, and 70°C for 1 h. The incidence of fissuring increased, especially on the batches soaked for shorter durations, indicating that the soaking conditions caused hygroscopic stress to the kernels, resulting in increased fissure incidence instead of healing. The same phenomenon was observed when soaking was done for 1 and 2 h (results not shown).

The present study used digital X-ray imaging to follow the change of fissures in rough rice directly, instead of brown or milled rice by means of visual inspection or light illumination (Desikachar and Subrahmanyan 1961; Srinivas et al. 1978; Juliano and Perez 1993; Genkawa et al. 2011; Perez et al. 2011). Indudhara Swamy and Bhattacharya (2009) found that pre-existing as well as induced fissures from soaking healed after more than 24 h of soaking at room temperature based on milling breakage, which was not observed in this study after 24 and 48 h (results not shown). Nevertheless, the percentage of healing was cultivar-specific; two cultivars showed little improvement, and one cultivar showed increased milling breakage among the 10 cultivars evaluated.

The breaking force for untreated fissured kernels (brown rice) was 18.5 N compared with 35.4 N for normal kernels (Table II). Soaking changed breaking force to 12.6–43.7 N, which agreed with the results in Table I that fissures were healed or created depending on the soaking conditions and the breaking force negatively correlated with the percentage of fissured kernels. The greatest breaking force was noted for the batch soaked at 75°C for 3 h, which was even greater than that of the normal nonfissured kernels. Siebenmorgen and Qin (2005) classified kernels with respect to breaking force as weak (<20 N) or strong (>20 N) and correlated the percentage of strong kernels with an increase in head rice yield. The present results indicate that soaking alone could increase the kernel mechanical strength of fissured kernels if the soaking temperature was close to or slightly above the T_g, consequently increasing the percentage of strong kernels, and it may potentially increase head rice yield.

CONCLUSIONS

Digital X-ray imaging has enabled the visual observation of the occurrence and healing of fissures in rough rice kernels during soaking. Soaking of fissured rough rice in water at a temperature slightly above its onset gelatinization temperature may potentially repair fissures and improve kernel strength and, consequently, increase head rice yield.

ACKNOWLEDGMENTS

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LITERATURE CITED


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