Physical and Functional Characteristics of Broken Rice Kernels Created by Rapid Moisture Adsorption

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ABSTRACT

Fissuring caused by rapid moisture adsorption generates appreciable amounts of broken kernels on subsequent milling, thereby reducing the economic value of rice. This study investigated how rapid moisture adsorption affects the extent of kernel fissuring in rice lots, as well as the physical and functional characteristics of broken kernels that result from milling such lots. Pure-line, long-grain cultivar Roy J was conditioned to 9% and 12% initial moisture content (IMC) levels, soaked in water at 30 °C (86 °F) for 2 h, gently re-dried to 12.0% moisture content (MC), and then milled to a surface lipid content of 0.4%. Milled rice yield, head rice yield, number-percentage of fissured kernels, and number of fissures/kernel were determined. Physical and functional properties of the broken kernels were also determined. Results showed that as IMC prior to rewetting decreased, the extent of fissuring increased, and hence, subsequent breakage increased. Additionally, with decreasing IMC, the number of fissures/kernel increased, leading to the generation of greater amounts of small brokens. The functional properties of the flour produced from small brokens were significantly different from the functional properties of the flour produced from large brokens. However, the functional properties of the flour produced from medium-sized brokens were not significantly different from those of the flour produced from either the small or large brokens.

INTRODUCTION

Fissuring induced by rapid moisture adsorption in low-moisture content (MC) rice causes breakage and thus reduces milling yields considerably. Appreciable amounts of broken kernels of various sizes are generated during milling of such rice lots. The
United States Department of Agriculture classifies the largest, intermediate, and smallest broken kernels as second heads, screenings, and brewers, respectively (USDA, 2007). These brokens are often ground to produce rice flour, and are also used as a pet-food ingredient. In the United States, the demand for rice flour has recently increased, since rice is a major ingredient in gluten-free diets/formulations (Gallagher et al., 2003). The rapid growth in rice use in the pet-food industry has also contributed to the steady increase in the demand for brokens.

Fissuring due to moisture adsorption is a common problem faced by rice producers, primarily due to logistical harvesting considerations. Many researchers (Stahel, 1935; Kunze and Choudhury, 1972; Jindal and Siebenmorgen, 1986) have reported that fissuring generally occurred when rice kernels at or below 13% to 14% bulk initial MC (IMC, wet basis) rapidly adsorbed moisture from the environment. Mukhopadhyay and Siebenmorgen (2012) recommended that long- and medium-grain rice cultivars grown in the mid-South be harvested at MCs > 15% to avoid the risk of head rice yield (HRY) reduction due to rapid rewetting and resultant fissuring.

While several studies have addressed the impact of rapid moisture adsorption on milling yields, no research was found that investigated the impact of this phenomenon on the physical and functional characteristics of the broken kernels generated from rice lots that had been exposed to different levels of moisture adsorption. Thus, the objectives of this study were to evaluate the impacts of moisture adsorption on the extent of fissuring, as well as the particle-size distribution and functionality of the resultant broken kernels. Finally, the number of fissures/kernel at the rough-rice stage was correlated to the particle-size distribution of broken kernels produced during milling, the hypothesis being that kernels with multiple fissures break into smaller pieces during the milling process and thus alter the relative distribution of brokens into different classification grades.

PROCEDURES

Figure 1 shows the process flowchart for this study. Pure-line, long-grain cultivar Roy J was combine-harvested at 19.1% MC (wet basis) from Osceola, Ark., cleaned using a grain cleaner (MCI Kicker Grain Tester, Mid-Continent Industries Inc., Newton, Kan.), and stored in sealed containers at 4 °C (39 °F) until use. A 6-kg (13.2-lb) bulk lot was equilibrated at room temperature for 24 h before conducting experiments. This bulk lot was divided into three sublots (2 kg each), spread on screen-bottomed trays, and placed in a conditioning chamber where temperature and relative humidity were controlled by an air-control unit (Model 5580A, Parameter Generation & Control Inc., Black Mountain, N.C.) to condition two sublots to 12% IMC and the remaining sublot to 9% IMC. Subsequently, one of the 12%-IMC sublots (“12%-IMCcontrol”; Fig. 1) was used as a control, as well as to conduct a preliminary milling investigation as described below; whereas, the other two sublots (9%- and 12%-IMC) were rewetted in a water bath to induce fissures due to rapid moisture adsorption. For all three sublots, MC was determined by drying 15-g subsamples in a convection oven (Model 1370FM, Shellblue, Sheldon Mfg. Inc., Cornelius, Ore.) at 130 °C for 24 h (Jindal and Siebenmorgen, 1987).
Enumeration of Fissures and Determination of Milling Yields

The “9%-IMCrewetted” and “12%-IMCrewetted” sublots were placed in vinyl screen cloth bags and soaked for 2 h in a water bath (Model 280, Precision Scientific, Winchester, Va.) with the water held at 30 °C (86 °F) to induce fissures due to rapid rewetting (Mukhopadhyay and Siebenmorgen, 2012). The bags were then drained for 0.5 h, allowed to air-dry for 1 h, and slowly redried to 12% MC inside the above-mentioned conditioning chamber. From each of the three sublots, triplicate subsamples of 300 rough-rice kernels were randomly selected, manually dehulled, and examined visually for fissures using a fissure-inspection box (Model TX-200, Grainscope, Kett Electric Laboratory, Tokyo, Japan). Fissured kernels were enumerated and expressed as a number-percentage of the 300 rough-rice kernels. The number of fissures/kernel was also determined.

Additionally, triplicate, 150-g subsamples were dehulled and milled to a surface lipid content (SLC) of 0.4% to determine milling yields. In order to mill the three sublots to the desired SLC level, a preliminary milling investigation was conducted using the 12%-IMCcontrol sublot; ten 150-g subsamples (5 milling durations × 2 repetitions) were dehulled using a laboratory huler (Model THU-35A, Satake Engineering Co., Ltd., Tokyo, Japan) with a clearance of 0.048 cm (0.019 in.) between the rollers. These subsamples were milled for 10, 15, 20, 30, or 40 s using a laboratory mill (McGill No.2, Rapsco, Brookshire, Texas) with a 1.5-kg (3.3-lb) mass placed on the lever arm 15 cm (6 in.) from the center of the milling chamber. Then, the milled subsamples were passed through a sizing device (Model 61, Grain Machinery Manufacturing Co., Miami, Fla.), which separated head rice from broken kernels. Head rice SLC was determined by scanning 50 g of head rice using a near-infrared-reflectance spectrophotometer (Model DA7200, Perten Instruments, Hägersten, Sweden) (Saleh et al., 2008) and SLC was plotted as a function of milling duration. From the resulting curve, the milling duration necessary to reach an SLC of 0.4% was recorded and this duration (24 s in this case) was used to mill subsequent 150-g subsamples from the three sublots.

Physical and Functional Characteristics of Broken Kernels

The standard procedure for conducting a particle-size distribution analysis comprises a sieving procedure with at least a 100-g (0.22-lb) sample, although lesser sample amounts may be used if necessary (ASAE, 2003). The amount of broken kernels generated from the 9%-IMCrewetted sublot was sufficient to charge a sieve-set following the standard recommendation. However, additional subsamples of the 12%-IMCrewetted sublot had to be milled and separated to yield the suggested 100 g of broken kernels to charge the sieve-set. The 12%-IMCcontrol sublot generated negligible amounts of brokens; hence, sieve and viscosity-profile analyses were not conducted for this sublot (Fig. 1). A sieve shaker (RO-TAP, Model RX-29, Mentor, Ohio) with U.S. sieve numbers 10, 12, and 20, having square-openings of 2.00 mm (0.079 in.), 1.68 mm (0.066 in.), and 0.841 mm (0.033 in.), respectively, was used; brokens were shaken for 15 min. The sieves distributed the broken kernels into three fractions: “large” (retained on the 2-mm sieve), “medium” (passed through the 2-mm sieve but retained on the 1.68-mm sieve),
and “small” (passed through the 1.68-mm sieve but retained on the 0.841-mm sieve). Since a negligible mass of broken kernels (<1 g) passed through the 0.841-mm sieve, only the mass of breaks retained on that sieve was taken into account.

After the size-fractioning step, ~7 g of broken kernels was selected from each of the large-, medium-, and small-broken kernel fractions, and ground into flour using a cyclone sample mill (Udy Corp., Fort Collins, Colo.) equipped with a 0.5-mm (0.02-in.) screen. Moisture contents were determined by drying ~2 g of flour in the convection oven at 130 °C for 1 h (Juliano et al., 1985) prior to calculation of the exact masses of flour and water required to analyze viscosity profiles using a rapid visco-analyzer (Model RVA-4 Series, Newport Scientific Pvt. Ltd., Warriewood, NSW, Australia) per AACC Method 61-02 (AACC, 2000).

Data Analyses

All statistical analyses were performed using JMP® Pro software v.11.0.0 (SAS Institute, Inc., Cary, N.C.). Analysis of variance (ANOVA, α = 0.05) was conducted and means separated using the Fisher’s least significant difference test (LSD, P = 0.05).

RESULTS AND DISCUSSION

Enumeration of Fissures and Determination of Milling Yields

Figure 2 shows the number-percentage of fissured kernels, milled rice yield (MRY), and HRY for the 9%- and 12%-IMCrewetted sublots, along with the control (12%-IMCcontrol) sublot. The rapid moisture-adsorption treatment through soaking produced dramatic fissuring. Basically all the kernels in the 9%-IMCrewetted subplot developed fissures, whereas, only 29% of kernels from the 12%-IMCrewetted subplot fissured; both were significantly greater than the number-percentage of fissured kernels in the control subplot (only 0.2%). The extent of fissuring is reflected in the milling yields, in that the 12%-IMCrewetted sublot had a significantly lesser MRY, as well as HRY, than the control. The 9%-IMCrewetted sublot had a significantly lesser MRY compared to both the control and the 12%-IMCrewetted sublots. The decrease in MRY for the rewetted sublots suggest that with severe fissuring and breakage, some endosperm leaves with the bran stream during milling, thus decreasing the total mass of rice produced through milling. The severe fissuring incurred in the 9%-IMCrewetted sublot resulted in a HRY near 0%.

Figure 3 shows the frequency distribution of fissures/kernel for the 9%- and 12%-IMCrewetted sublots. In general, brown rice kernels from the 12%-IMCrewetted subplot had fewer fissures/kernel compared to those from the 9%-IMCrewetted sublot. Most of the fissured kernels (96%) from the 9%-IMCrewetted sublot had multiple fissures/kernel, with only 0.2% and 3.4% of the kernels having 1 and 2 fissures/kernel, respectively. However, for the 12%-IMCrewetted sublot, only 2.2% of the kernels had 3, 4, or 6 fissures/kernel; whereas 19.9% and 6.8% of the kernels had 1 and 2 fissures/kernel, respectively. These findings indicate that the lesser the IMC of the rice prior to rewetting, not only was there more fissuring and consequent breakage in kernels,
but also the number of fissures incurred per kernel was greater, as is evident from the frequency distributions for the two rewetted sublots in Fig. 3.

Physical and Functional Characteristics of Broken Kernels

As seen in Fig. 3, 96% of the kernels from the 9%-IMCrewetted subplot had 3 to 7 fissures/kernel compared to only 2.2% of the kernels from the 12%-IMCrewetted subplot. Thus, it was expected that more kernels from the 9%-IMCrewetted subplot would break into smaller pieces during milling as compared to those in the 12%-IMCrewetted subplot. Figure 4 confirmed this; the 9%-IMCrewetted subplot generated a significantly greater mass percentage of small brokens as compared to the 12%-IMCrewetted subplot. Figure 4 also shows that the mass percentage of medium brokens was significantly greater in the 12%-IMCrewetted subplot than that in the 9%-IMCrewetted subplot. These results indicate, however, that although there were dramatic differences in the number of fissures/kernel in the two rewetted sublots (Fig. 3), this was not entirely reflected in the differences in size distribution of the resultant broken kernels from each subplot (Fig. 4).

Peak viscosity, final viscosity, and setback of the large-, medium-, and small-broken kernel fractions were not affected by differences in IMC levels prior to rewetting. Thus, viscosity data of brokens from the 9%- and 12%-IMCrewetted sublots were pooled and differences in functional properties were analyzed based on the size fractions of brokens. Figure 5a shows that large brokens had a significantly greater peak viscosity than that of the small brokens. However, peak viscosity of medium brokens was not significantly different from either small or large brokens. The small brokens had a significantly greater final viscosity compared to both large and medium brokens; but, the final viscosity of medium and large brokens were not significantly different (Fig. 5b). Figure 5c shows that the small brokens had the maximum setback, significantly greater than that of large brokens. As observed for peak viscosity, setback of medium brokens was not significantly different from either small or large brokens. In general, although there were differences in functional properties of the flour produced from small and large brokens, the functional properties of flour produced from medium brokens was not tremendously different from that of either small or large brokens.

SIGNIFICANCE OF FINDINGS

This study showed that the lesser the IMC of rice before rewetting, the greater the number of kernels that developed fissures, and the greater the number of fissures induced per kernel. Further, kernels with multiple fissures broke into smaller pieces during milling, and thus, generated a greater mass percentage of small brokens. Additionally, the functional properties of broken rice kernels were impacted by the broken-size fractions.

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LITERATURE CITED


Fig. 1. Process flowchart for the experiment.
* Not analyzed for the 12%-IMC-control sublot owing to insufficient sample sizes.
Fig. 2. Milled rice yield (MRY), head rice yield (HRY), and fissured kernels for cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. The control was gently dried from 19.1% harvest MC to 12% MC and milled. Milled rice yield and HRY are expressed as mass percentages, whereas fissured kernels is expressed as a kernel-number percentage. Within MRY, HRY, and fissured-kernel sets, values followed by the same letter are not significantly different (P > 0.05). Bars are based on the mean values of three milling/fissure-count repetitions.

Fig. 3. Frequency distribution of fissures/kernel for cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then manually dehulled. Fissures were enumerated on 300 randomly selected brown rice kernels. Bars are based on the mean values of three fissure-count repetitions.
Fig. 4. Mass percentages of small, medium, and large brokens produced from cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. The sieves distributed the brokens into three fractions: “large” (retained on the 2-mm sieve), “medium” (passed through the 2-mm sieve but retained on the 1.68-mm sieve), and “small” (passed through the 1.68-mm sieve but retained on the 0.841-mm sieve). Within a brokens-fraction, values followed by the same letter are not significantly different (P > 0.05).
Fig. 5. Peak viscosity (a), final viscosity (b) and setback (c) of small, medium, and large brokens produced from cultivar Roy J sublots after being conditioned to 9% and 12% initial moisture contents (IMCs), soaked in water at 30 °C for 2 h, redried to 12% MC, and then milled. Since IMC did not affect pasting properties, results for the two rewetted sublots were pooled. For each viscosity parameter, values followed by the same letter are not significantly different ($P > 0.05$).