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Correlating fissure occurrence to rice quality for various drying and tempering treatments

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ABSTRACT

When a rice kernel fissures, it can break in subsequent food processing operations and lose its commercial value. Head rice yield (HRY) is a measure of the percent of kernels that remain whole (at least three-fourths of original length) after rice has been milled. Our experiment was designed to test the effect of a rapid state transition during drying and tempering processes using cultivars Bengal and Cypress. 'Bengal' is a medium-size kernel and 'Cypress' is a long-size, thinner grained cultivar. Immediately after drying, the rice samples were separated into four sub-samples and tempered for 0, 80, 160, or 240 minutes at the temperature of the drying air. Tempering is a process to allow kernel moisture content gradients to decrease, thereby reducing the stress within the kernel. From each sample, 400 kernels were randomly selected, visually observed, and the percentage of fissured kernels determined. Results showed that the percentage of fissured kernels generally decreased with tempering. However, some samples still showed many fissures even after extended tempering, yet had a high HRY. While HRY is currently the primary index of rice quality, it is known that fissured kernels can severely and detrimentally affect end-use processing operations such as cooking or puffing. Thus, the tempering duration required for preventing kernel fissuring might be longer than the tempering duration required for maintaining a high HRY.

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Meet the Student-Author

I am a senior in chemical engineering at the University of Arkansas. I am originally from Mexico City but went as an exchange student to Canada for high school and then started my undergraduate work here. I have received several awards and scholarships and I am member of national societies such as Golden Key.

In the Food Science Department I have been given the opportunity to work in research of rice. I have found this experience enormously beneficial. It has given me skills in scientific procedures and broadened my trains of thought. I have also become more aware of the importance of this discipline in which my major knowledge can be applied.

I plan to join the workforce after my graduation in December 2001 so I can gain enough experience to decide which career I want to pursue and then maybe obtain a master's degree.

Monica Jimenez

INTRODUCTION

Rice kernel fissuring and breakage is a major problem in the rice industry. Fissured kernels will cause HRY reduction and thus decrease the value of the rice crop. Broken kernels are typically worth approximately half the value of whole kernels. Kunze and Hall (1965) stated that a rice kernel with two or three cross-sectional fissures has lost its commercial value.

The main component of rice is starch, which has, like other polymers, a glass transition temperature (Tg). According to the glass transition hypothesis, when heated above Tg, the kernel changes from a "glassy" to a "rubbery" state. During this transition, the material properties change dramatically which can result in fissuring.

Several researchers (Kunze, 1979; Nguyen and Kunze, 1984) have found that kernels do not fissure until after the drying process has ceased. Previous research (Cnossen et al., 1999) on drying and tempering of rice, conducted by the University of Arkansas Rice Processing Program, concluded that high drying air temperatures can be used without incurring HRY reduction as long as proper tempering techniques are used. High tempering temperatures were shown to be very effective in maintaining high HRY. However, Siebenmorgen et al. (1998) and Matthews et al. (1970) concluded that some fissured kernels would not break during the milling process and remain as head rice. During further processing (cooking, puffing, etc.) these kernels may break and reduce the quality of the final product.

An understanding of the effect of various drying and tempering treatments on fissure occurrence and the relation between fissures and breakage will provide end-users, such as cereal and cooked-rice product manufacturers, with information to optimize their processing operations. Because of the paramount importance of milling quality and kernel physical quality, understanding this relationship would greatly improve the value of rice, and thus the sustained profitability of rice production.

The objectives of this study were to: 1) determine the effect of various drying and tempering treatments on fissure occurrence based on the glass transition hypothesis and 2) correlate fissure occurrence data and HRY data to determine optimum drying conditions and minimum tempering durations to maximize both HRY and kernel physical integrity.

MATERIALS AND METHODS

The cultivars Bengal (medium-grain) and Cypress (long-grain) at two harvest moisture contents (HMC), high (19% to 20%) and low (17% to 18%), were harvested from University of Arkansas Research and Extension Centers at Stuttgart and Keiser, Ark. in 1999 and 2000. The samples were dried under three conditions, as shown in the experimental design (Fig. 1), for three durations aiming at removing 3.0, 4.5 and 6.0 percentage points MC (PPMC). Immediately after drying, the rice batch was divided into four sub-samples. One sample was immediately cooled by placing it in an equilibrium moisture content (EMC) chamber set at 21°C and 50% relative humidity, and left to gently dry to 12.5% MC. The other samples were tempered in a sealed bag for 80, 160, or 240 minutes at the temperature of the drying air before being taken out of the sealed bag to cool and then dry in the EMC chamber. The different drying durations created different MC gradients inside the kernel; subsequently, the different tempering durations allowed different MC gradient relaxation. This resulted in various levels of fissuring when the kernel was cooled and forced to undergo a transition from the "rubbery" to the "glassy" state. A control sample was put in the EMC chamber to gently dry to 12.5% MC, resulting in minimal fissuring and a high HRY. After storage for two months at 21°C, the rice was hulled with a laboratory huller. The immature and chalky kernels were separated and 400 brown rice kernels were randomly picked from each sample for the determination of the percentage of fissured kernels. One person using a light box visually observed the kernels for fissuring. Kernels were characterized as having surface cracks or internal fissures. Surface cracks were defined as fissures that appear on the outer surface of the kernel and internal fissures were defined as fissures that cut the kernel transversally or axially from one side to the other. After fissure counting, the kernels were returned to the dried sample to be milled, and HRY was determined using a FOSS Graincheck 310 image analyzer (Foss North America, Minneapolis, Minn.). A statistical analysis was not performed due to the fissure counting work being very time consuming, resulting in a limited number of samples.

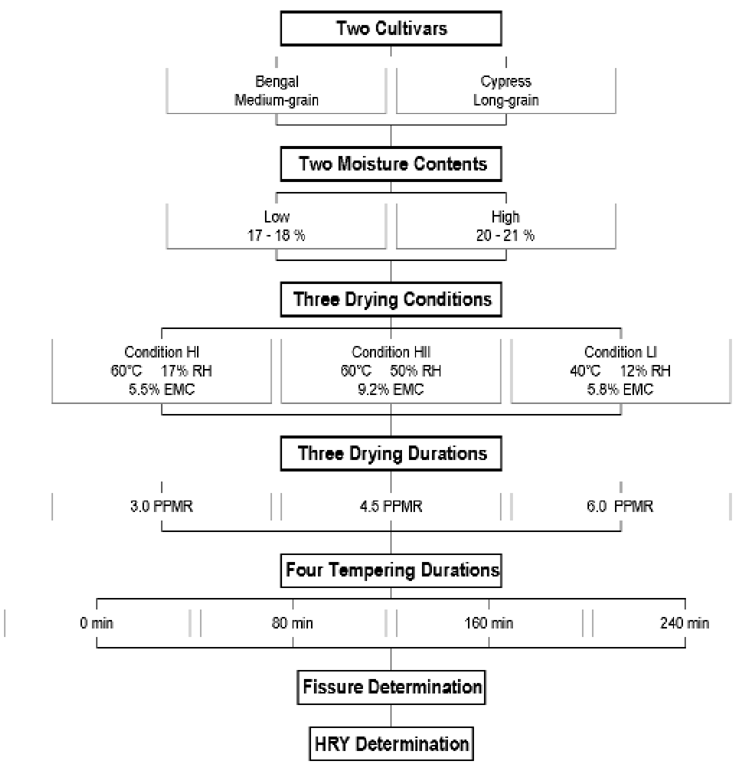

Fig. 1. Experimental design. RH is the relative humidity of the drying air. EMC is the equilibrium moisture content of the drying air. PPMR is the percentage points of moisture the drying durations were aiming to remove in one drying pass. HRY is head rice yield.

RESULTS AND DISCUSSION

Cnossen and Siebenmorgen (2000) concluded that if rice is tempered above the Tg line sufficiently long enough to reduce MC gradients, a state transition would not cause HRY reduction if irreversible damage has not yet occurred. Insufficient MC gradient reduction before a state transition will produce fissures and consequent HRY reduction. Fig. 2 shows the percentage of fissured kernels and the HRY versus tempering duration for Bengal (1999 harvest). A dramatically lower HRY was observed in the sample that was not tempered compared to a gently dried control sample. For the 3.0 PPMC drying duration, 80 minutes of tempering was sufficient to prevent fissuring and maintain an HRY equal to that of the control sample. The samples tempered for 160 and 240 minutes did not show a higher HRY. When removing 4.5 PPMC, 160 minutes of tempering was necessary to maintain an HRY near that of the control sample.

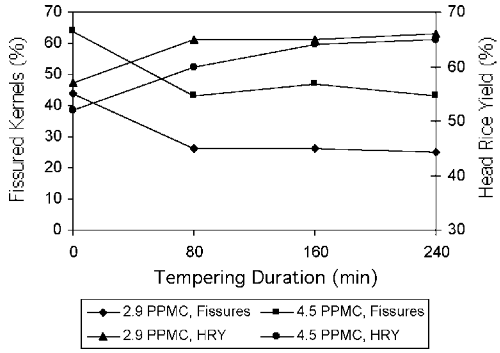

Fig. 2. Percent fissured kernels and head rice yield (HRY) versus tempering duration for Bengal rice harvested in 1999 and dried for two different durations (PPMC is the percentage points MC removed in one drying pass) with 60°C and 50% RH drying air. The percentage of fissured kernels and the HRY of the control sample were 24% and 65%, respectively. The harvest moisture content was 17.5%.

Tempering for 80 minutes reduced the number of fissured kernels. However, longer tempering did not further reduce the number of fissured kernels. Although the samples tempered for 160 and 240 minutes had an HRY equal to that of the control sample, these samples still had a higher number of fissured kernels (47 and 43%, respectively) than the control sample (24%). Thus, a large percentage of the fissured kernels did not break in the milling process.

The number of fissured kernels having internal fissures decreased with increasing tempering duration and increased with increasing moisture removal rates (Table 1). The two drying conditions above Tg (60°C) showed similar trends for percentage fissured kernels and HRY. The drying condition below Tg (40°C) showed a lower number of fissured kernels but a higher number or kernels having surface cracks. This condition did not cause HRY reduction compared to a gently dried control sample and tempering did not have any effect on HRY.

For all three drying conditions, surface cracks increased with increasing tempering duration (Table 1). These will normally appear as a result of drying the surface too severely, and the number of surface cracks would therefore be expected to increase with increasing drying duration; however the data do not reflect this.

For Cypress (1999 harvest), removing 4.0 PPMC did not cause any HRY reduction compared to the control sample, even with no tempering (Fig. 3). When removing 5.1 PPMC, the HRY did not further improve after 80 minutes of tempering. For both drying durations up to 160 minutes of tempering was required to minimize fissuring.

Cypress had much lower fissuring than Bengal. Due to a thinner kernel, Cypress is more resistant to fissuring. The number of kernels having surface cracks increased with increasing tempering duration and increasing drying duration in contrast to Bengal.

Table 1. Percent fissured kernels, percent kernels having surface cracks, and head rice yield for Bengal harvested in 1999 and dried under three drying air conditions, for three durations, and tempered for four durations. The harvest moisture content was 17.5%. The percentage of fissured kernels, the percentage of kernels having surface cracks, and the HRY of the control sample were 24, 4, and 65%, respectively.

Drying duration	Tempering duration (min)	Fissured kernels (%)	Surface cracks (%)	Head rice yield (%)
Drying air condition HII (60°C, 50% RH)				
2.9 PPMC[x]	0	44	1	57
	80	26	8	65
	160	26	9	65
	240	25	14	66
4.5 PPMC	0	64	6	52
	80	43	6	60
	160	47	4	64
	240	43	12	65
5.3 PPMC	0	69	3	32
	80	55	3	53
	160	53	6	57
	240	49	6	60
Drying air condition HI (60°C, 17% RH)				
3.5 PPMC	0	45	7	55
	80	31	9	65
	160	24	1	65
	240	28	6	66
4.6 PPMC	0	68	2	37
	80	47	6	60
	160	49	2	63
	240	40	8	64
5.8 PPMC	0	81	2	32
	80	65	0	47
	160	49	3	59
	240	57	5	59
Drying air condition LI (40°C, 12% RH)				
3.1 PPMC	0	21	11	65
	240	24	13	65
4.4 PPMC	0	31	19	65
	240	24	28	65

[x] PPMC is percentage points moisture content reduction in one drying pass.

Table 2. Percent fissured kernels, percent kernels having surface cracks, and head rice yield for Cypress harvested in 1999 and dried under three drying air conditions, for three durations, and tempered for four durations. The harvest moisture content was 18.0%. The percentage of fissured kernels, the percentage of kernels having surface cracks, and the HRY of the control sample were 3, 4, and 63%, respectively.

Drying duration	Tempering duration (min)	Fissured kernels (%)	Surface cracks (%)	Head rice yield (%)
Drying air condition HII (60°C, 50% RH)				
2.8 PPMC[x]	0	3	2	...63
	80	4	6	...62
	160	3	8	...63
	240	2	6	...63
3.9 PPMC	0	7	X[y]	...62
	80	4	X	...62
	160	3	X	...61
	240	2	X	...61
5.8 PPMC	0	8	11	...60
	80	6	19	...62
	160	7	18	...62
	240	6	24	...61
Drying air condition HI (60°C, 17% RH)				
2.5 PPMC	0	5	1	...63
	80	2	5	...63
	160	1	6	...63
	240	4	7	...63
4.0 PPMC	0	7	7	...61
	80	5	9	...63
	160	3	21	...62
	240	4	23	...63
5.1 PPMC	0	14	8	...54
	80	7	15	...61
	160	5	28	...61
	240	7	31	...62
Drying air condition LI (40°C, 12% RH)				
2.6 PPMC	0	2	4	...62
	240	3	5	...62
4.5 PPMC	0	2	23	...62
	240	3	38	...62

[x] PPMC is percentage points moisture content reduction in one drying pass. [y] Not measured.

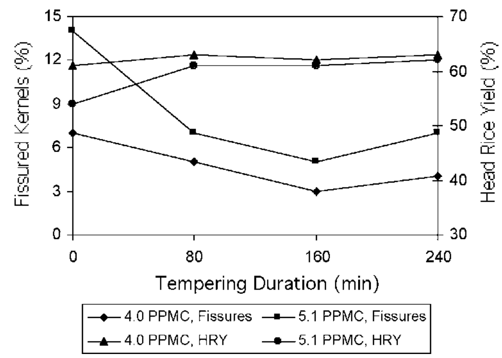

Fig. 3. Percent fissured kernels and head rice yield (HRY) versus tempering duration for Cypress rice harvested in 1999 and dried for two different durations (PPMC is the percentage points MC removed in one drying pass) with 60°C and 17% RH drying air. The percentage fissured kernels and the HRY of the control sample were 3% and 63%, respectively. The harvest moisture content was 18.0%.

However, no tempering was required to maintain an HRY equal to the control sample (Table 2).

For both Bengal and Cypress the 2000 samples showed similar trends as the 1999 samples (data not shown). For Cypress harvested in 2000, no tempering was required to maintain a high HRY when removing 4.7 PPMC, and only 80 minutes of tempering was necessary to maintain an HRY equivalent to the control sample when removing 6.1 PPMC.

The rice samples harvested in 2000 had a higher HMC than those harvested in 1999. The results showed that more moisture can be removed and shorter tempering durations are required to maintain a high HRY when harvesting at a higher MC. However, HMC did not seem to have an effect on the tempering duration required to minimize fissuring levels.

We conclude that kernels that fissure during drying and tempering do not necessarily break in the milling process and that the tempering durations required for preventing kernel fissuring might be longer than the tempering durations required for maintaining HRY.

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