

Influence of Storing Rough Rice with High Moisture Content on Subsequent Drying Characteristics and Milling Quality

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ABSTRACT

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The objective of this research was to determine the influence on drying characteristics and resultant milling quality of storing high moisture content (MC) rough rice (*Oryza sativa* L. 'Bengal' and 'Cypress') under various conditions and durations before drying. Immediately after harvest, drying experiments were performed with samples of both cultivars using two drying air conditions: 52°C with 25% rh and 60°C with 17% rh. Rough rice from each cultivar also was stored for 27 and 76 days at –9 or 4°C. After storage, all samples were dried under the same two drying

air conditions as at harvest. Head rice yields (HRY) were determined for all dried samples. There were no significant differences between the drying rates or resultant HRY of Bengal or Cypress rice samples stored for either 27 or 76 days at both storage temperatures and then dried compared with the HRY of samples dried immediately after harvest. This research shows that it may be possible to store high MC rice for extended periods of time without detrimental effects on HRY.

Immediately after harvest, on-farm and commercial rice driers as well as research laboratories conducting rice drying research face a busy drying season. All would benefit if the possibility existed to delay drying by storing rough rice at high moisture content (MC) for a period of time before drying. High MC storage of rough rice under specified conditions could extend the drying season, provided the drying characteristics and resultant milling quality of the rice, specifically head rice yield (HRY), remain unchanged during storage.

HRY is the weight percentage of rough rice that remains as head rice (kernels that are three-quarters of the length of the original rice kernel) (USDA 1997) and it is used by the rice industry as an important indication of rice milling quality (Cnossen and Siebenmorgen 2000). Although there are many factors that influence HRY, the treatment of the rice during drying and storage can be controlled to maximize HRY. During drying, temperature and drying duration, tempering conditions, MC after drying, and relative humidity (rh) all affect HRY (Cnossen and Siebenmorgen 2000; Schluterman and Siebenmorgen 2004).

To determine the effects of storage, previous research focused primarily on storing rough rice at 2–38°C after drying (Villareal et al 1976; Kitamura et al 1977; Chrastil 1990; Daniels et al 1998; Pearce et al 2001). These authors showed that storage temperature and storage MC had significant effects on rice quality indices such as HRY and cooking properties. Daniels et al (1998) also showed that storage conditions influenced functional properties such as viscosity.

Storing rough rice at high MC before drying has received relatively little attention. Dillahunty et al (2000) and Bailey (1940) measured the respiration rate of rough rice over a range of MC and temperatures and reported an exponential increase in respiration rate with MC increase. Other studies have shown the potentially deleterious effects of prolonged storage of rough rice at high MC and temperatures including increased respiration, endosperm yellowing, and changes in the viscosity of milled rice starch slurries (Bason et al 1990; Dillahunty et al 2001). The objective of

this study was to investigate the effects of storing rough rice at high MC and low temperature on rice drying characteristics and milling quality.

MATERIALS AND METHODS

Harvest

Two rice cultivars, Bengal (medium grain) and Cypress (long grain) were harvested at the Rice Research and Extension Center at Stuttgart, AR, in August 2001. These two rice cultivars were selected because they are both commonly grown in the mid-South rice-growing region of the United States. Immediately after harvest, the rice was transported to the University of Arkansas Rice Processing Laboratory, Fayetteville, and cleaned using a dockage tester (Carter-Day Co., Minneapolis, MN). Upon arrival at the laboratory, bulk sample MC values were determined by drying 15–16 g of rough rice in a convection oven for 24 hr at 130°C (Jindal and Siebenmorgen 1987). The MC of Bengal was 24.8% (all MC values are expressed on a wet basis unless otherwise noted) and the MC of Cypress was 20.4%. Individual kernel MC measurements also were performed using an individual kernel moisture meter (CTR-800E, Shizouka Seiki Co., Shizouka, Japan) immediately after harvest and after each storage duration. After cleaning, samples of both cultivars were dried immediately, and the remaining rice was dried after certain storage durations.

Storage

Immediately after harvest, samples of Bengal and Cypress rough rice (23 kg) were placed in sealed plastic containers, which in turn were placed in a walk-in cooler or a freezer. The walk-in cooler had an average temperature of 3.6°C but varied between 1.7 and 5.4°C. The average temperature in the freezer was –9.4°C with a range of –8.3°C to –10.0°C. From an economic point of view, 4°C may be realizable for the industry to temporarily store rough rice. The –9°C storage condition was included as a possible storage environment for research samples. It also was included to evaluate the potential effects of aerating commercial rice during storage with air at temperatures below freezing.

Each of the four sublots of rough rice (two cultivars × two storage environments) was stored for two durations, 27 and 76 days. After storage, ≈8 kg of each of the four stored lots were removed from the containers and equilibrated for 5–12 hr at room temperature before drying.

Drying

Immediately after harvest, samples of both cultivars were dried using two air conditions. Both were chosen based on previous research (Fan et al 2000). The first condition was 52°C and 25% rh

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and is representative of conditions used in commercial drying. The resulting rough rice equilibrium moisture content (EMC), as predicted by the Chung equation (ASAE 1998), was 6.8%. The second condition was 60°C and 17% rh, corresponding to a rough rice EMC of 5.5%. This condition is at the upper extreme of commercial drying and temperature levels, but was shown to have potential for use if combined with a tempering treatment (Cnossen and Siebenmorgen 2000). These two conditions were used for all drying experiments. Each drying run for a cultivar × storage temperature × storage duration × drying air condition was performed twice.

The drying experiments conducted immediately after harvest represented the drying characteristics of rice that was not stored before drying (drying experiments of day 0). After 27 and 76 days of storage, samples of the stored rough rice were equilibrated to a laboratory temperature of ≈25°C and then dried under the same drying air conditions as at day 0.

The drying air conditions were maintained by temperature and rh control units (Parameter Generation & Control, Inc., Black Mountain, NC) and monitored by a dew point monitor (Hygro-MZ, General Eastern, Woburn, MA). Air from each rh control unit was supplied to laboratory drying chambers, each consisting of 16 trays (15 × 25 cm) with perforated bottoms. Each tray was filled with a uniform layer of ≈110 g of rough rice. The 16 trays were arranged as two eight-tray sets. In each eight-tray set, one tray was designated to be weighed at each defined drying duration (0, 10, 20, 30, 45, 60, 90, and 120 min) to measure the weight loss due to drying. Drying durations were assigned randomly to trays to minimize drying chamber location effects. After a certain drying duration, paired trays from each eight-tray set were combined to form one sample for milling. The combined samples were immediately placed in a conditioning chamber at 21°C to cool and slowly dry to an MC of ≈12.5%. This conditioning produces a reduction in HRY if sufficient MC gradients are present in the kernels during cooling (Cnossen and Siebenmorgen 2000). After conditioning for four to five days, the samples were stored in sealed plastic bags in a cooler at 4°C for 1–2 months before milling.

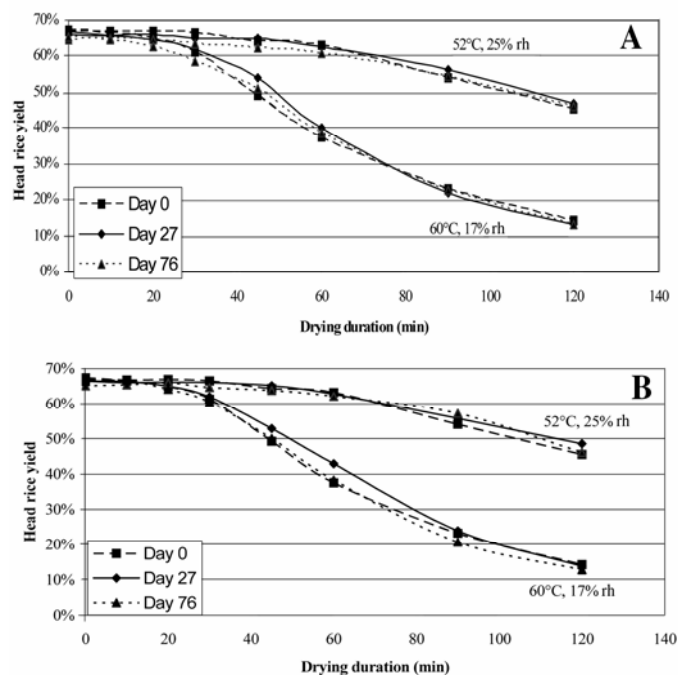


Fig. 1. Head rice yield response of Bengal stored at -9°C (A) and 4°C (B) for 0, 27, or 76 days and dried for various durations at two drying air conditions. Samples were placed in a 21°C chamber immediately after drying. Each data point represents the average of two head rice yield measurements for each sample in replicate drying runs.

Milling

Upon removal from cold storage, samples first were equilibrated to room temperature before hulling and milling. Approximately 150 g of dried rough rice was dehulled with a rice machine (Satake Engineering Co., Tokyo). The resultant brown rice was milled with a McGill no. 2 laboratory mill (Rapsco, Brookshire, TX). A weight of 1.5 kg was placed on the lever arm of the mill 15 cm from the centerline of the mill chamber. All samples were milled for 30 sec. The milled samples were aspirated (South Dakota seed blower, Seedburo, Chicago, IL) for 30–60 sec to clean the rice by removing any loose bran remaining on the surface of the kernels after milling.

The mass of head rice in each milled rice sample was determined with a vision analysis system (Graincheck 2312, Foss Tecator, Höganäs, Sweden). Head rice includes milled kernels that are at least three-fourths of the original kernel length (USDA 1997). HRY then was calculated as the mass percentage of rough rice that remained as head rice after milling.

For a selection of samples, the degree of milling (DOM) of the head rice was determined with a milling meter (MM 1B, Satake Engineering Co.). The DOM is an indication of how well samples were milled. Higher DOM values indicate more thoroughly milled rice.

Rice samples were not physically separated into head rice and broken kernels by the vision analysis system; therefore, the head rice from the samples was separated with a double-tray shaker table (Grainman, Grain Machinery Mfg., Miami, FL) before determining the DOM. The range of DOM for Bengal head rice was 73–90 with an average of 82. Cypress head rice showed a higher DOM range of 99–115 with an average of 102.

Statistical Analysis

JMP software (v. 5.0.1.2, SAS Institute, Cary, NC) was used to fit a regression model to data from each drying treatment for both Bengal and Cypress using standard least squares with effect screening. The effects of storage temperature, storage duration, drying duration, and the interactions of these factors were tested.

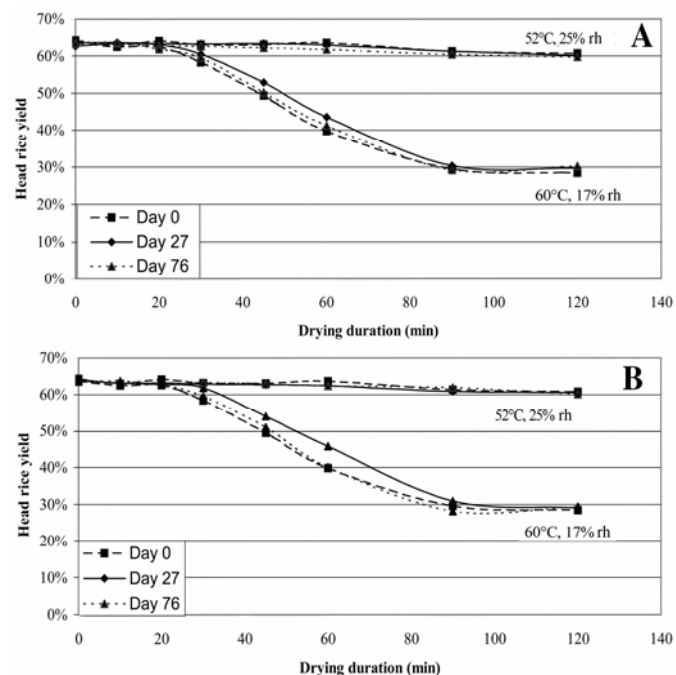


Fig. 2. Head rice yield response of Cypress stored at -9°C (A) and 4°C (B) for 0, 27, or 76 days and dried for various durations at two drying air conditions. Samples were placed in a 21°C chamber immediately after drying. Each data point represents the average of two head rice yield measurements for each sample in replicate drying runs.

RESULTS AND DISCUSSION

Experimental Observations

Physical differences were observed between the rough rice samples that were dried immediately after harvest and those that were stored before drying. The rough rice stored at -9°C showed ice crystals between the rice kernels after 76 days of storage. However, no ice crystals were observed after 27 days of storage. Additionally, mold was visible on Bengal (storage MC 24.8%) after 27 and 76 days of storage at 4°C , whereas no mold was observed on Cypress (storage MC 20.4%). At -9°C , no mold growth was found on Bengal or Cypress at any storage duration.

The MC of the stored rice samples was measured immediately after each storage duration using both the oven-drying procedure and the CTR-800E moisture meter described above. The MC of both cultivars increased only slightly during storage. The maximum increase in MC for Bengal was 0.5 percentage points and for Cypress it was 0.9 percentage points. The expectation was that the MC range within each sample would decrease after storage. However, there were no observable differences between the range of kernel MC for the freshly harvested rice and the stored rice. These results were consistent for both cultivars stored at both temperatures.

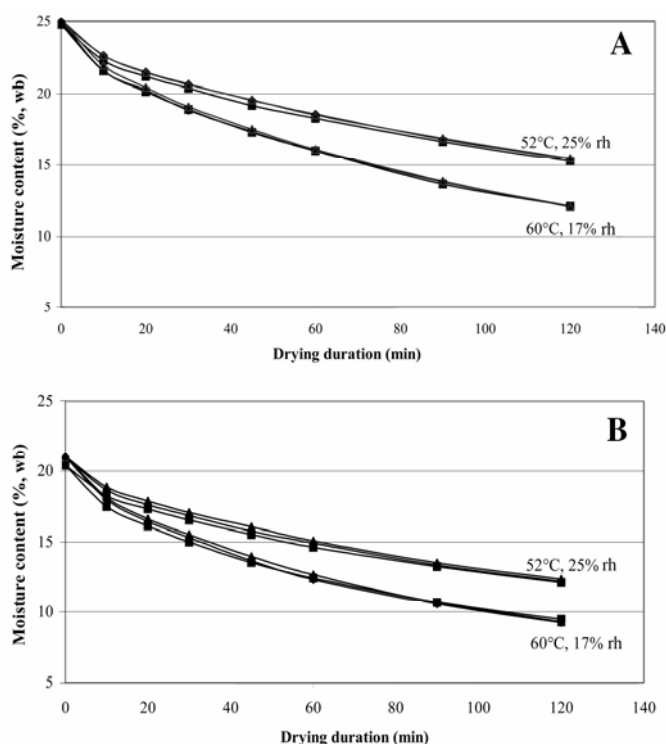


Fig. 3. Moisture content vs. duration for Bengal (A) and Cypress (B) at two drying air conditions for rice stored for 0, 27, and 76 days in a freezer at -9°C before drying. Each data point represents the average of two measurements for each sample in replicate drying runs.

Head Rice Yield

HRY trends of Bengal (Fig. 1) and Cypress (Fig. 2) samples that were dried immediately after harvest closely resembled those of previous research (Fan et al 2000). When drying under the air condition of 52°C and 25% rh, the HRY for Cypress remained almost constant, even for extended drying durations. The HRY of Bengal decreased for this same air condition as the drying duration exceeded 20 min before cooling to 21°C . Bengal is a medium-grain rice cultivar, therefore, its features include a short, thick kernel. Previous research has shown that this type of kernel is more susceptible to fissuring than long-grain cultivars such as Cypress, which has longer, thinner kernels (Kunze 1983; Jindal and Siebenmorgen 1994; Fan et al 2000).

The more severe drying air condition of 60°C and 17% rh caused a greater decrease in HRY for both Bengal and Cypress than did the lower temperature drying condition. The greater decrease of Bengal HRY over that of Cypress was more apparent after 60 min of drying for both drying air conditions.

The HRY trends for samples that had been stored for 27 and 76 days in the storage environments of -9°C and 4°C before drying were similar to the HRY response of the samples dried immediately after harvest (day 0) (Fig. 1A and B for Bengal) (Fig. 2A and B for Cypress).

For both drying conditions for Bengal and Cypress, the drying duration had a significant effect on HRY ($P < 0.05$) for the overall data set, which is to be expected based on the dramatic effects of drying on HRY (Table I, Figs. 1 and 2). However, the storage temperature and duration treatments, and the interaction of these treatments with drying duration, did not significantly affect HRY. Thus, the HRY response resulting from drying rice after storing for either 27 or 76 days at either -9°C or 4°C was not significantly different than the response resulting from drying immediately after harvest.

Drying Rate

Drying rate calculations were based on the weight loss of designated samples during drying under each drying air condition. The drying curves for Bengal and Cypress dried immediately after harvest and after 27 and 76 days of storage at -9°C are shown in Fig. 3A and B; similar trends were observed at 4°C . As expected, the more severe drying air condition of 60°C and 17% rh caused faster drying than that of 52°C and 25% rh. There was a slight difference between Bengal and Cypress in the amount of moisture that was removed under each drying condition after a given drying duration, although this could be attributed to the difference in the initial MC of the two cultivars. After 30 min of drying at 52°C and 25% rh, ≈ 4.5 percentage points of MC were removed from Bengal, whereas 4.1 percentage points of MC were removed from Cypress. After drying for 30 min under the more severe drying air condition (60°C , 17% rh), ≈ 6 percentage points of MC were removed from Bengal and 5.6 percentage points were removed from Cypress. The moisture removed after 30 min of drying under the two drying air conditions was independent of the storage environment before drying, as is indicated by the drying constant comparisons for the various drying curves.

TABLE I
Sum of Squares (SS) and P Values (Prob) for Head Rice Yield of Bengal and Cypress Rice Dried at Two Drying Conditions

Effect	Bengal				Cypress			
	52°C, 25% rh		60°C, 17% rh		52°C, 25% rh		60°C, 17% rh	
	SS	Prob > F	SS	Prob > F	SS	Prob > F	SS	Prob > F
Storage Temp (ST)	6×10^{-5}	0.8017	3×10^{-4}	0.1877	9×10^{-5}	0.1445	6×10^{-7}	0.9613
Storage Duration (SD)	8×10^{-5}	0.2809	4×10^{-5}	0.6315	9×10^{-5}	0.1386	9×10^{-4}	0.0639
Drying Duration (DD)	2×10^{-1}	<0.0001	2	<0.0001	9×10^{-3}	<0.0001	1.16	<0.0001
DD \times SD	4×10^{-4}	0.4723	2×10^{-3}	0.2033	4×10^{-4}	0.2865	2×10^{-3}	0.4300
DD \times ST	1×10^{-4}	0.9237	8×10^{-4}	0.5881	7×10^{-5}	0.9731	3×10^{-4}	0.9843
R^2 (overall model)	0.99	...	0.99	...	0.86	...	0.99	...

Because the drying method used in this research can be considered as thin-layer drying, the Page equation was used to quantify the drying response for calculating the drying rate constant (ASAE 1999)

$$MR = \frac{MC - EMC}{IMC - EMC} = e^{-k \times t^n} \quad (1)$$

where MR is the moisture ratio; MC is the moisture content of rice after drying duration t ; EMC is the rough rice equilibrium MC associated with the drying air; IMC is the initial MC of the rice, all expressed on a dry basis; n is a dimensionless constant. The drying rate constant k (min^{-1}) reflects the rate of moisture removal from kernels.

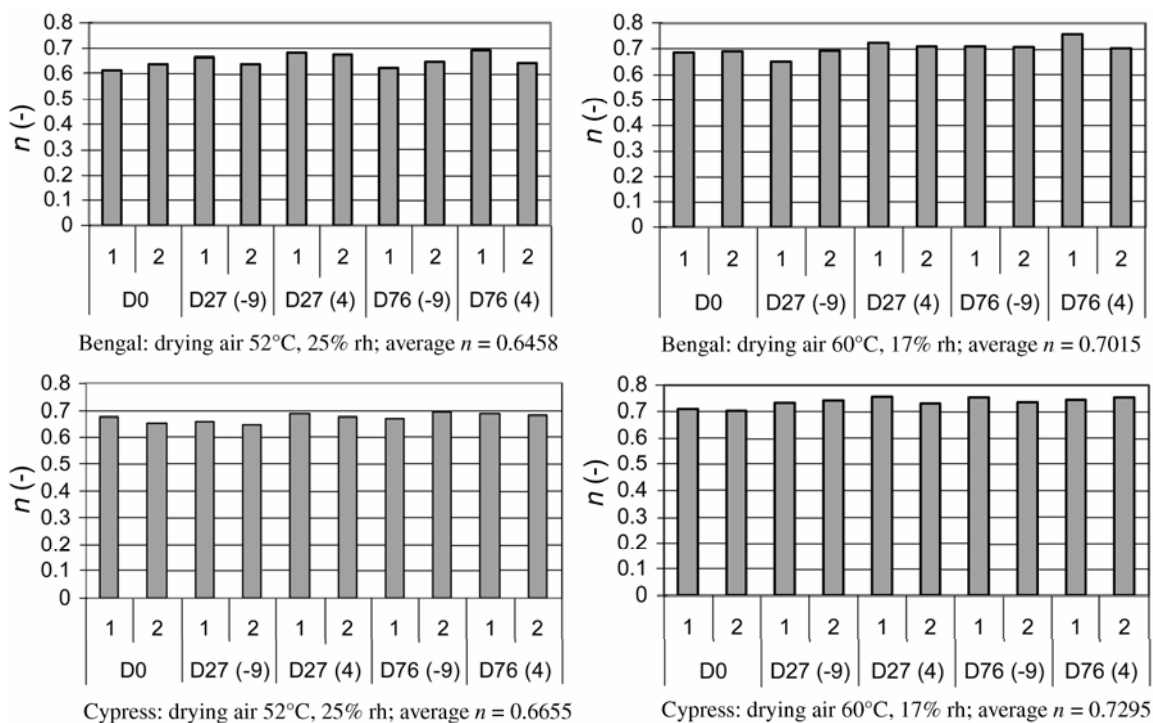


Fig. 4. Values of constant n (Eq. 3) for indicated experimental conditions. D0, D27, and D76 represent 0, 27, and 76 days of storage, respectively. Storage temperatures of -9°C and 4°C are represented as -9 and 4 . Calculations were performed for each storage condition (duration and temperature) in replicate drying runs (1 and 2).

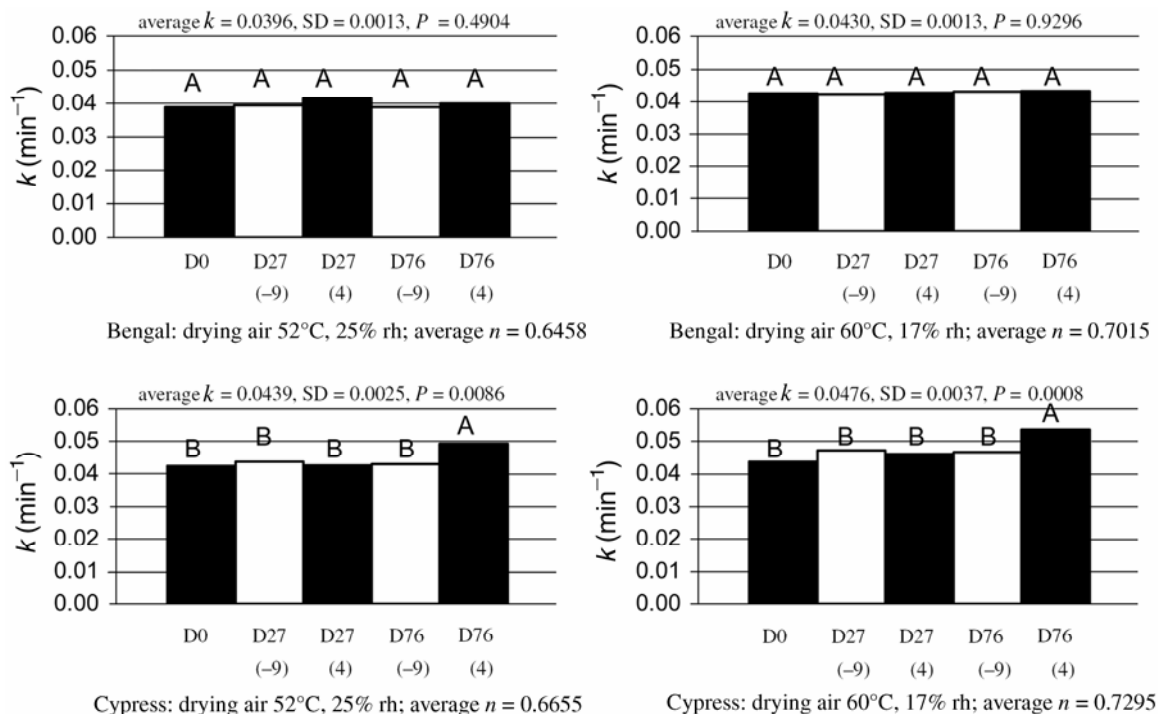


Fig. 5. Mean values of drying rate constant k and statistical analysis results for the indicated experimental conditions. D0, D27, and D76 represent 0, 27, and 76 days of storage, respectively. Storage temperatures of -9°C and 4°C are represented as -9 and 4 . Each bar represents the mean k values of two replicate drying runs. The n values for each cultivar-drying air condition are taken from Fig. 4.

Equation 1 can be written as

$$\ln(MR) = -k \times t^n \quad (2)$$

or

$$\ln[-\ln(MR)] = \ln(k) + n \times \ln(t) \quad (3)$$

The n and k values from Equation 3 were calculated for each drying run (Microsoft Excel 2000; Microsoft Corporation, Redmond, WA). Calculated n values for all drying runs are presented in Fig. 4. For each of the four cultivar-drying air condition data sets, the n values varied little across storage environment and duration. With this observation and the need to compare drying rate constants across storage treatments, an average n value for each cultivar-drying air condition data set was determined based on the calculated n values; these average n values are listed in Fig. 4. Using these average n values, Equation 2 was used to calculate the drying rate constant k for each drying run. Using an average value for n for each cultivar-drying air condition made it possible to compare drying rate constants among the storage treatments within that particular cultivar-drying air condition combination. However, the effects of the two cultivars or the two drying air conditions could not be compared because n values were not necessarily constant across the four cultivar-drying air condition data sets.

The average k values for all treatment combinations, as well as the average and standard deviation of the k values for each cultivar-drying air combination, are presented in Fig. 5. The standard deviation and P values in Fig. 5 show that there was slightly higher variability in k values for Cypress rice than for Bengal; this is due to slightly higher yet significant k values for the Cypress rice that had been stored at 4°C for 76 days. This trend was not observed with the Bengal rice. The reason for this slight increase with the Cypress samples stored at 4°C for 76 days is unknown; however, the laboratory records indicate a slightly higher (1–2°C) drying air temperature during these runs that could have produced greater drying rates.

CONCLUSIONS

Two conclusions can be drawn from this research. First, there were no differences in the HRY responses for Bengal or Cypress rice that was stored for 27 or 76 days at –9°C or 4°C and then dried compared with samples dried immediately after harvest. Thus, storage of rough rice at conditions varying from below to just above freezing did not cause deterioration in quality (expressed by HRY) in the Bengal or Cypress rice.

Second, no differences in the drying rate were found for either cultivar or drying air condition among rice lots stored for 27 or 76 days at –9°C or 4°C. An apparent, slight increase in drying rate constant for Cypress rice dried after storage for 76 days at 4°C is attributed to a slight increase in the drying temperatures used for those particular drying runs. Thus, from an overall standpoint, and

within the experimental treatment ranges of this study, it is concluded that storage temperature or duration had no influence on drying characteristics.

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