

# A STUDY OF HEAD RICE YIELD REDUCTION OF LONG- AND MEDIUM-GRAIN RICE VARIETIES IN RELATION TO VARIOUS HARVEST AND DRYING CONDITIONS

J. Fan, T. J. Siebenmorgen, W. Yang

**ABSTRACT.** *In this research, the effects of harvest moisture content (HMC), harvest location, variety difference, and heated-air drying conditions on head rice yield reduction (HRYR) of long-grain (Kaybonnet and Cypress) and medium-grain (Bengal) varieties were investigated. The rice was harvested at moisture contents (MCs) of approximately 16 to 26% from two locations (Stuttgart and Keiser, Arkansas). The rough rice was dried under three conditions: 43.5°C, 38% relative humidity (RH), 9.5% equilibrium moisture content (EMC); 51.7°C, 25% RH, 7.3% EMC; and 60°C, 17% RH, 5.8% EMC. The results indicated that variety, HMC, drying condition, and drying duration had significant interactive effects on the HRYR during drying. Medium-grain Bengal rice exhibited more HRYR than did long-grain Cypress or Kaybonnet rice under a given drying condition. The results further indicated that a decrease in MC of rice at the early drying stages did not substantially affect the HRY until a certain MC level was reached. It appeared in this study that the amount of moisture that could be removed without affecting HRY increased as harvest MC increased.*

**Keywords.** *Head rice yield, Drying, Harvest moisture content, Rice variety.*

**R**ough rice should be dried to a certain moisture content (MC), typically 12 to 13%\*, prior to storage. Drying creates moisture and temperature gradients within a kernel, which induces the development of tensile stress at the surface and compressive stress at the interior of the kernel (Sharma and Kunze, 1982). Improper drying operations result in extensive kernel fissuring with a significant HRYR during subsequent milling. Arora et al. (1973) showed that severe kernel cracking occurs when the temperature difference between the drying air and the rice kernel exceeds 43°C. They suggested drying air temperature should be held below 53°C to minimize the effect of thermal expansion on rice fissuring. Schulman et al. (1993) studied the HRY of two long-grain varieties (Millie and Newbonnet) dried at different air temperatures and relative humidities. They observed that the HRY changed little with drying duration when drying with air conditions corresponding to higher EMC. However, the HRY was reduced significantly when EMCs were lower. Sarker et al. (1996) reported that a high initial MC and/or high drying air temperature produced a great number of fissured kernels. A related investigation (Chen et al., 1997) indicated that HRYR could be related to

the drying rate constant, obtained by a thin-layer drying model, and drying duration.

A number of studies have shown the significance of MC of rough rice in determining rice kernel fissure and milling quality (Kunze and Prasad, 1978; Banaszek and Siebenmorgen, 1990). Kunze and Prasad (1978) reported that kernel fissures created during drying are primarily associated with reabsorption of moisture by kernels. Low moisture kernels are more vulnerable to fissuring when they absorb moisture from high RH environments. Sharma and Kunze (1982) showed that only a small number of kernels fissured during drying, but most kernel fissuring occurred within 48 h after drying. There is limited information available regarding the influence of drying and the associated MC change on the reduction in HRY.

The objective of this research was to study the milling behavior, reflected by head rice yield reduction, of long- and medium-grain rice varieties as affected by various harvest and drying conditions.

## MATERIALS AND METHODS

### HARVEST

Three rice varieties were studied: one medium-grain variety (Bengal), and two long-grain varieties (Cypress and Kaybonnet). The grains were harvested at various MCs ranging from 16 to 26% from the Rice Research and Extension Center at Stuttgart, Arkansas, and the Northeast Research and Extension Center at Keiser, Arkansas, in the autumn of 1996. Details of rice lots used in these drying tests are summarized in table 1. The rice was grown under the management procedures recommended by the Arkansas Cooperative Extension Service.

After harvest, the rice was immediately transported to the University of Arkansas Rice Processing Lab and cleaned using a dockage tester (Carter-Day Dockage Co., Minneapolis, Minn.). Top and middle screen sizes used for both long- and medium-grain varieties were U.S. Standard

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\* Unless otherwise specified, moisture content is expressed on a wet basis.

**Table 1. Harvest locations, dates, and harvest moisture contents (HMCs) of the rough rice used in the drying tests**

Location	Harvest Date (DD-MM-YY)	Variety	HMC (% w.b.)
Stuttgart, Ark.	04-09-96	Kaybonnet	19.1
		Bengal	25.9
	06-09-96	Cypress	24.6
	09-09-96	Bengal	22.5
		Cypress	19.8
	13-09-96	Bengal	17.4
	Cypress	16.5	
Keiser, Ark.	18-09-96	Kaybonnet	19.5
	27-09-96	Bengal	22.4
	02-10-96	Cypress	20.9
	04-10-96	Cypress	17.4

Sieve No. 28 and No. 25, respectively, while the bottom screen size for the long- and medium-grain varieties was a No. 22 and No. 4, respectively. (NOTE: Sieve sizes are defined in American Society for Testing and Materials Standard E11.)

#### DRYING

Drying was conducted using three relative humidity and temperature control units (Climate-Lab-AA, Parameter Generation and Control, Inc., Black Mountain, N.C.). Each control unit supplied air to one of three drying chambers. The control units were separately set to drying condition A (43.5°C, 38% RH), condition B (51.7°C, 25% RH) or condition C (60.0°C, 17% RH), with corresponding EMCs of 9.5%, 7.3%, and 5.8%, respectively. Conditions A and B were close to actual conditions used in on-farm and commercial drying (with or without tempering after drying). Condition C is not currently used in practice, but previous research has shown that it can be used with a high temperature tempering treatment to prevent HRYR (Cnossen et al., 1999). Each drying chamber consisted of sixteen, 15 × 25 cm screen trays. For each drying run, about 300 g of rough rice was spread uniformly onto each tray to form a layer of 2 cm. Samples were removed at set durations to produce various levels of moisture removal. The drying duration for each drying air condition was as follows: 0, 10, 20, 30, 60, 90, 120, 180 min for condition A, and 0, 10, 20, 30, 45, 60, 90, 120 min for conditions B and C. Drying tests were performed in duplicate for each rice lot under each of the three drying conditions. The MC of samples removed from the drier was measured using an oven drying method (ASAE, 1995), in which 10 to 15 g of rough rice were dried in a convection oven for 24 h at 130°C.

Upon removal from the drier after a given duration of drying, the samples were immediately transferred to a conditioning chamber held at 21°C, 50% RH, which corresponds to a rice EMC of approximately 12.5%. After 2-5 days of conditioning, the samples were placed in sealed plastic bags and were held in cold storage at 4°C for three or four months prior to milling.

#### MILLING

To determine milling quality resulting from the drying treatments, two 150 g subsamples of each rough rice sample were hulled using a McGill sample huller (Rapsco, Brookshire, Tex.). The resultant brown rice was milled for

30 s using a McGill No. 2 laboratory mill (Rapsco, Brookshire, Tex.) with a 1.5 kg weight positioned on the mill lever arm 15 cm from the centerline of the milling chamber. The head rice was collected using a double tray shaker table, with both trays having 4.76-mm indented holes. The milling quality of the dried rice was evaluated in terms of HRY, which was defined as the percentage of head rice mass remaining from the original 150-g rough rice sample.

#### STATISTICAL ANALYSIS

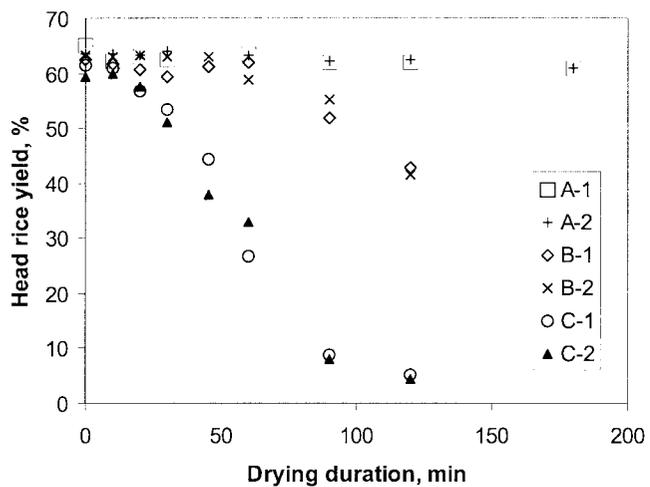
The experimental variables included variety (VAR), harvest MC (HMC), harvest location (LOC), drying condition (DC), and drying duration (DUR). The main effects and two-way interaction effects of all variables on HRYR were analyzed using the GLM procedure of SAS statistical software (SAS Institute, 1998). The HRYR for each dried rice sample was calculated by subtracting the HRY from the HRY of rice dried without drying treatments in the 21°C, 50% RH conditioning chamber. In the analysis, rice HMC was classified as high (> 24%), medium (19 to 24%), or low HMC (< 19%). There was a total of 324 HRY observations. Analysis of variance among variables and their interactions was performed at a significance level of 0.05 unless otherwise indicated.

## RESULTS AND DISCUSSION

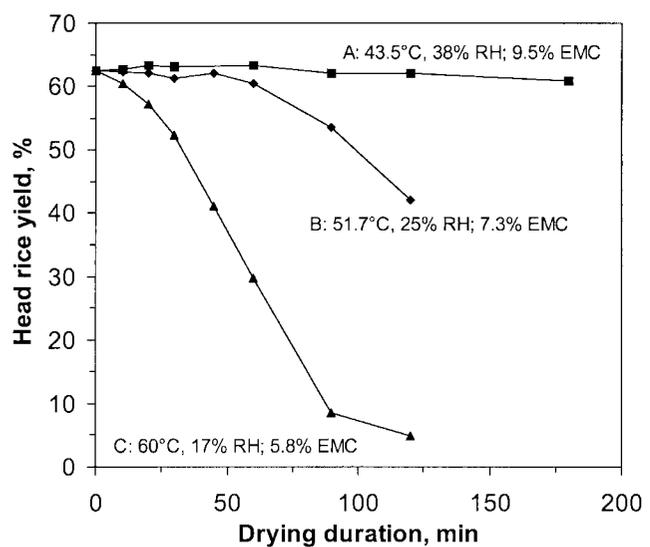
#### HEAD RICE YIELD DATA

Figure 1 shows the HRY of medium-grain Bengal (22.5% HMC) dried under the three drying air conditions. The rice dried under condition A showed no reduction in HRY, regardless of drying duration. The HRY for condition B did not change with drying duration until being dried for 50 min; with longer drying duration, a significant HRYR was observed. When the rice was dried under condition C, a severe drying condition with high air temperature and low relative humidity, the HRY decreased rapidly even in the early stages of drying. For example, 30-min drying under condition C resulted in approximately ten percentage points of HRYR. Since the HRY did not significantly change with drying duration under condition A, the following discussion focuses on the HRYR associated with drying conditions B and C.

Figure 2 illustrates the HRY data of the three varieties with a medium HMC (Bengal: 22.5%, Cypress: 19.8%, Kaybonnet: 19.1%) dried under conditions B and C. Drying under air condition B had little effect on the HRY of the two long-grain varieties (Cypress and Kaybonnet). However, the medium-grain Bengal showed a pronounced decrease in HRY when it was dried under the same condition for more than 40 min (fig. 2a). Under condition C, Cypress and Kaybonnet exhibited no HRYR for drying time less than 30 and 10 min, respectively (fig. 2b). After that, a significant HRYR was observed. However, Bengal showed HRYR after a very short drying duration. In general, Bengal showed more HRYR than did Cypress or Kaybonnet for a given drying duration (fig. 2b). The HRYR differences shown in figure 2 could be partially attributed to the difference in HMC. Variety difference may have also contributed to the HRYR differences due to the fact that different rice varieties have different kernel length, width, and thickness. Bengal, with a thick kernel shape, is



(a)

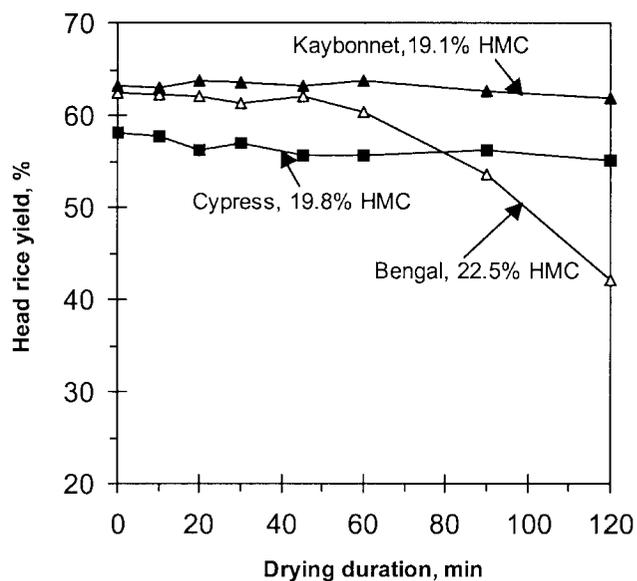


(b)

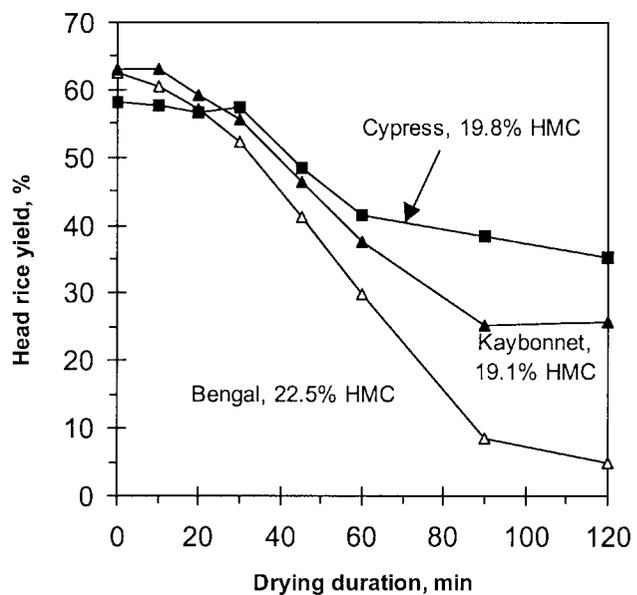
Figure 1—Experimental data for replicates (a) and for means of replicates (b) of the head rice yield of Bengal (harvested at 22.5% MC from Stuttgart) versus drying duration under the three indicated drying air conditions.

more vulnerable to fissure formation than slender kernels like Cypress and Kaybonnet.

Figure 3 shows the effect of HMC on HRY of three Bengal rice lots (HMCs of 17.4%, 22.5%, and 25.9%) dried under conditions B and C. The three rice lots showed a similar decrease in HRY after being dried for over 45 min under drying condition B even though they were different in HMC (fig. 3a). Unlike under drying condition B, HMC had a great effect on HRY with drying condition C (fig. 3b). For rice lots with HMCs of 17.4% and 22.5%, HRY significantly decreased after drying for 10 min (fig. 3b). The rice with high HMC (25.9%) could be dried for a longer duration (up to 20 min) at condition C without affecting the HRY. It appeared in this study that for a given drying duration, a lower HMC resulted in more HRYR, for example, for Bengal with HMCs of 25.9%, 22.5%, and 17.4%, the resulting HRY after 30 min of drying under



(a)

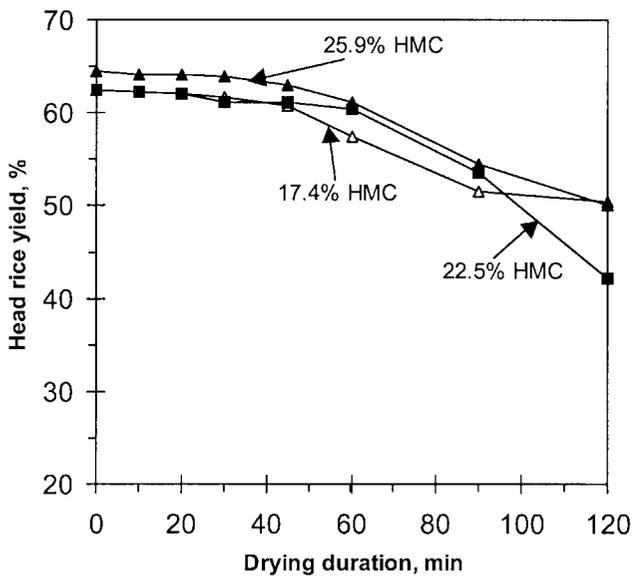


(b)

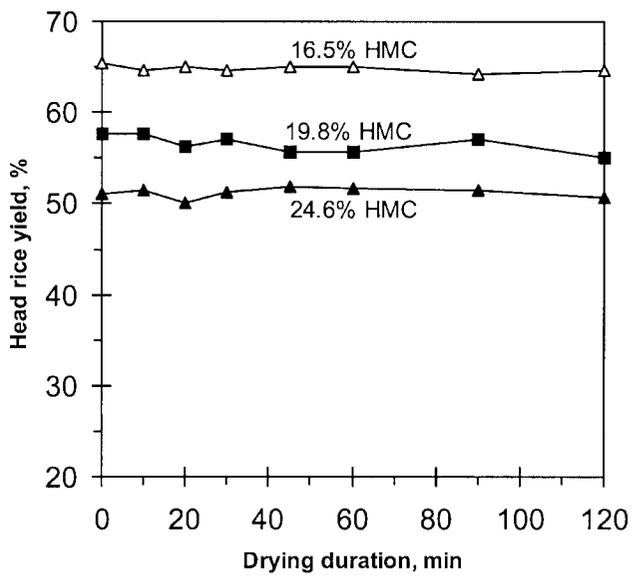
Figure 2—Head rice yield of three rice varieties versus drying duration when dried under air conditions B (51.7°C, 25% RH) (a), and C (60.0°C, 17% RH) (b).

condition C was 55.6%, 52.3%, and 38.5%, respectively (fig. 3b).

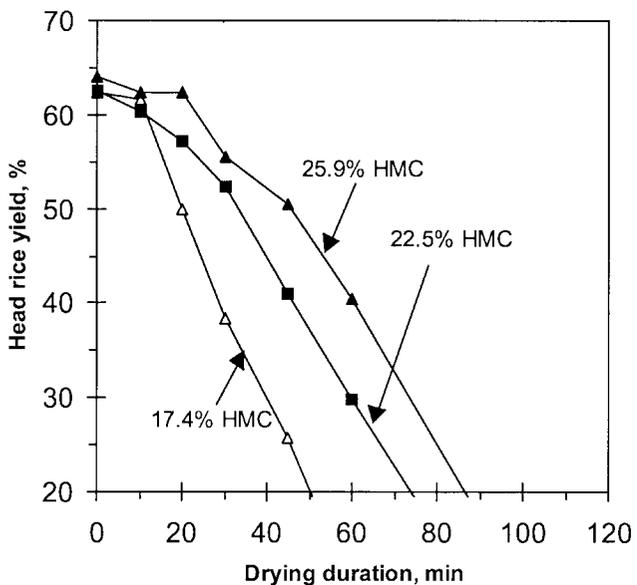
Figure 4 shows the HRY of three Cypress rice lots harvested at different MCs and dried under condition B (fig. 4a) and condition C (fig. 4b). An observation with Cypress was that the higher the HMC, the lower the overall level of HRY as can be seen in both figures 4a and 4b. The decreased HRY as HMC increased might be attributed to the increased number of weak, immature kernels that are often present with higher HMCs. As for HRYR pattern, when Cypress was dried under condition B, the HRY for a given rice lot showed little variation with drying duration (fig. 4a). Under drying condition C, the Cypress rice exhibited a significant HRYR after a certain period of



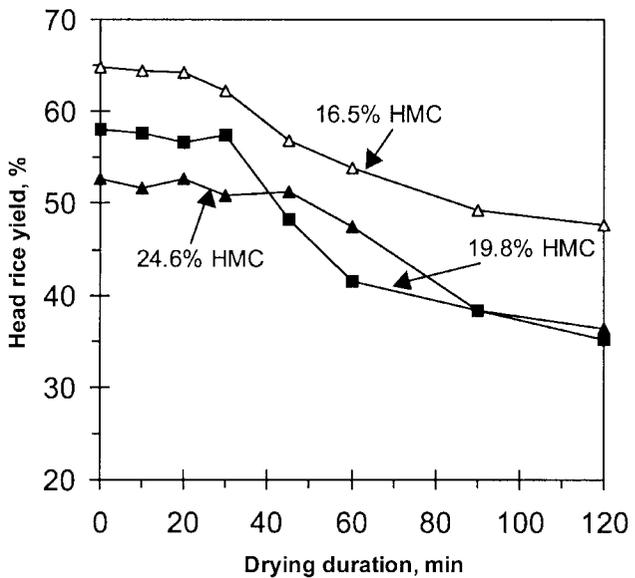
(a)



(a)



(b)



(b)

Figure 3—Effect of harvest moisture content (HMC) on head rice yield of Bengal when dried under air conditions B (51.7°C, 25% RH) (a), and C (60.0°C, 17% RH) (b).

Figure 4—Effect of harvest moisture content (HMC) on head rice yield of Cypress when dried under air conditions B (51.7°C, 25% RH) (a), and C (60.0°C, 17% RH) (b).

drying (fig. 4b). It appeared in this study that the period within which HRY was not affected increased with HMC.

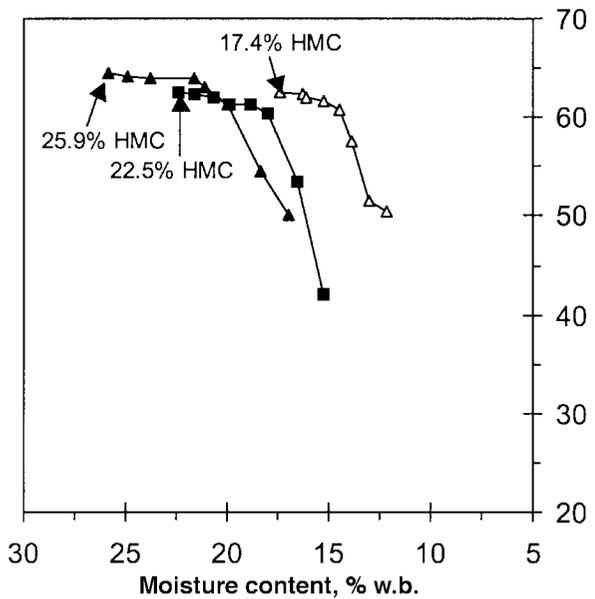
**STATISTICAL RESULTS**

HRYR data were analyzed using the SAS GLM procedure to illustrate the effects of all experimental variables on HRYR. Due to practical commercial drying considerations, only the HRYR data for drying durations of less than 60 min were used for the analysis. Initially, a model that consisted of all main effects and two-factor interactions was fit to the HRYR data. The results indicated that harvest location and drying replication were not significant variables affecting HRYR and were excluded from the model. All other variables in the model including

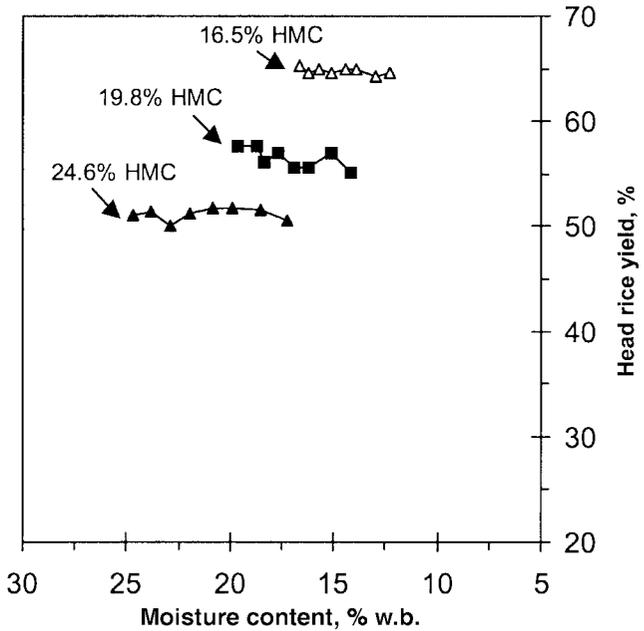
variety, HMC, drying condition, and drying duration had significant effects on HRYR. Additionally, there were significant interactions among these variables, i.e., VAR\*HMC, VAR\*DC, VAR\*DUR, HMC\*DC, HMC\*DUR, and DUR\*DC, at a level of  $p < 0.001$ .

**RELATING MC REDUCTION TO HMC**

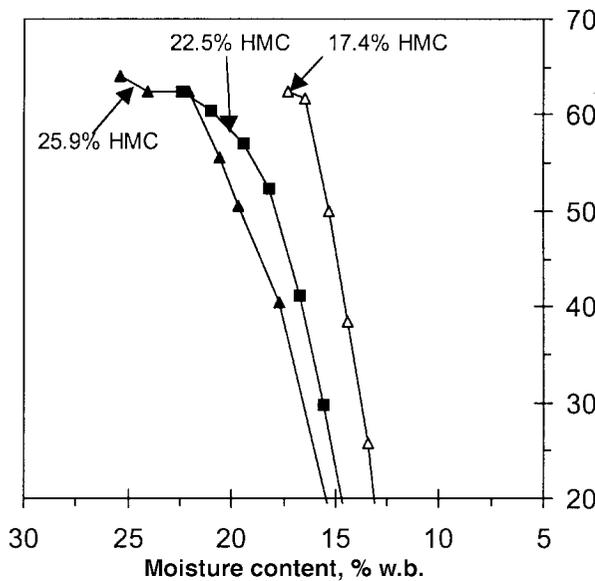
Figure 5 shows the HRY of Bengal with indicated HMCs in relation to the MC of rough rice achieved after drying for different durations. Drying of Bengal rice under condition B from its HMC of 25.9% to a MC of around 22% did not influence the resulting HRY (fig. 5a); however, further drying to a lower MC caused marked reduction in HRY. Similar trends were observed when



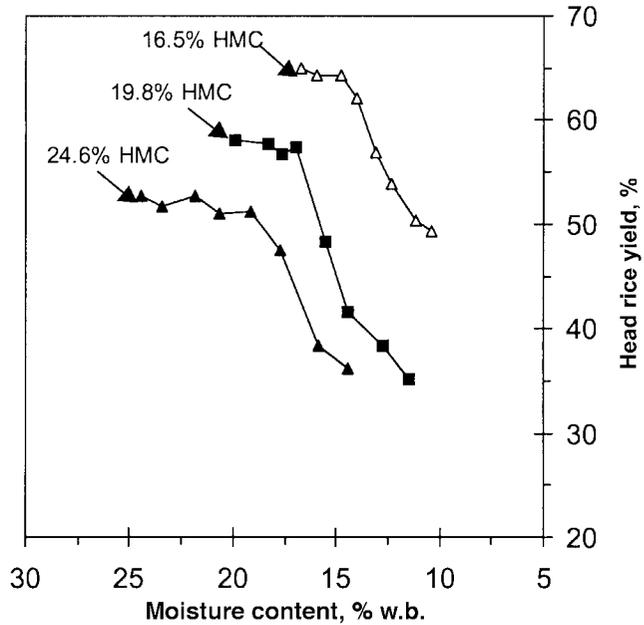
(a)



(a)



(b)



(b)

Figure 5—Head rice yield of Bengal versus the moisture content achieved by drying the indicated harvest moisture content (HMC) lots for various durations under air conditions B (51.7°C, 25% RH) (a), and C (60.0°C, 17% RH) (b).

Figure 6—Head rice yield of Cypress versus the moisture content achieved by drying the indicated harvest moisture content (HMC) lots for various durations under air conditions B (51.7°C, 25% RH) (a), and C (60.0°C, 17% RH) (b).

drying Bengal rice lots harvested at MCs of 22.5% and 17.4% under drying condition B (fig. 5a). For Bengal at drying condition C (fig. 5b), the amount of moisture removed without affecting its HRY was much less than at drying condition B (fig. 5a). In general, there exists a certain period in the early drying stages during which the MC of the rough rice decreased, whereas the HRY was not substantially affected. In this study, it was found the amount of moisture that could be removed before a certain HRYR occurred increased as HMC of the rice increased (fig. 5).

Figure 6 shows the trends between HRY and the MC of Cypress rough rice achieved by drying the indicated HMC lots for various drying durations under drying air conditions B and C. Drying the Cypress rice lots under condition B resulted in little change in HRY, although the rice MC was gradually decreased from the HMC as drying duration increased (fig. 6a). Similar to Bengal, Cypress dried at condition C showed a marked HRYR after the early stages of drying (fig. 6b). The results in figure 6 for Cypress were similar to those for Bengal in figure 5, in that

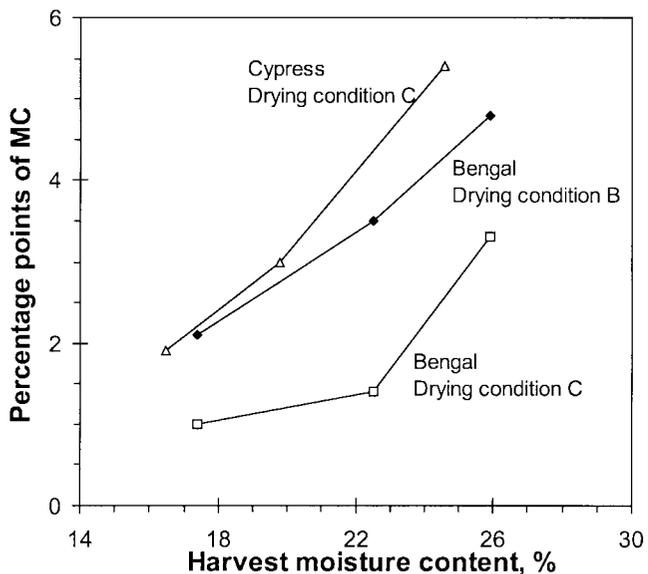


Figure 7—The percentage points of moisture content (MC) removed before head rice yield reduction (HRYR) occurred in relation to harvest moisture content.

the MC levels achieved for a given drying duration had a considerable effect on HRY of Cypress, particularly under condition C.

Figure 7 shows the percentage points of MC removed before HRYR occurred as a function of HMC. It should be noted the percentage points of MC were taken qualitatively from the previously discussed figures by visually identifying the turning points in the HRYR curves, and no quantitative statistical tests were performed to identify the percentage points of moisture removed before HRYR occurred. It appeared in this study that the amount of moisture that could be removed prior to HRYR reduction increased as the HMC of the rice increased. When the drying air condition was severe (e.g., condition C), the amount of moisture that could be removed before HRYR occurred decreased. For a given drying air condition, Cypress, a variety that has long, slender kernels, tolerated more percentage points of moisture removed before HRYR occurred than Bengal, a variety that has short, thick kernels.

## SUMMARY AND CONCLUSIONS

The variety, HMC, drying condition, and drying duration significantly affected the HRY of rough rice subjected to heated-air drying. There were also significant interactive effects among all these variables on HRYR. At a mild drying condition (condition A), drying did not significantly affect the HRY of any of the three varieties. At more severe drying conditions (condition B or C), HRY significantly decreased after a certain duration of early stage drying. For a given drying duration and condition,

medium-grain Bengal exhibited more HRYR than did long-grain Cypress or Kaybonnet. In this study, it was found that harvest location had no significant effect on HRYR during drying.

A decrease in MC of rice during early drying stages did not affect the HRY until a certain MC level was reached. The amount of moisture that could be removed before an occurrence of HRYR depended on variety, HMC, and drying air condition. It was found that the higher the HMC, the lower the overall level of HRY. It appeared in this study that the higher the HMC, the more moisture that could be removed before a HRYR occurred. Cypress and Kaybonnet rice were tolerant to more moisture removal for a given HMC than Bengal before HRYR occurred.

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