

# EFFECT OF WEATHER AND RICE MOISTURE AT HARVEST ON MILLING QUALITY OF CALIFORNIA MEDIUM-GRAIN RICE

J. F. Thompson, R. G. Mutters

**ABSTRACT.** California's medium-grain rice industry experiences a wide range of head rice yield (HRY). Average moisture of a representative paddy rice sample is the commercially used predictor of optimum harvest date to achieve high HRY. A two-year field study demonstrated that average rice moisture alone is not an adequate predictor of HRY. The history of rice moisture caused by varying meteorological conditions was needed to predict rice quality. Under typical calm conditions in California, daytime relative humidity is low and at night humidity increases, exposing rice to dew. During this meteorological pattern, HRY could be predicted by assuming that all kernels that dried below 15% moisture during the day would rehydrate at night and fissure, resulting in lost HRY. Harvest weather is also characterized by occasional episodes of dry north wind, lasting several days. These periods have insufficiently long rehydration periods to completely fissure kernels that dropped below 15% moisture, and actual HRY was much above predicted HRY. HRY dropped significantly during periods of dry north winds; however, rice value (government loan value minus drying costs) did not drop significantly during the windy period because the lower loan value was offset by lower drying costs. After the windy period ended, rice was again subject to nighttime dew and regained moisture, resulting in a large reduction in HRY and value. A combination of the range of individual kernel moisture at harvest and history of rice moisture influenced by weather conditions explained a great deal of the total HRY variation experienced by the California rice industry.

**Keywords.** Head rice yield, Humidity, Meteorology, Wind.

The unit value of rice is based primarily on its head rice yield (HRY, the proportion of kernels greater than 75% of intact length; USDA-FGIS, 1994). Improving HRY is an ongoing goal for rice growers. The average moisture content of the paddy rice at harvest (HMC, expressed on a wet weight basis) influences HRY. For medium-grain rice grown in Italy, dry conditions allowed HMC to drop below about 15%, and a subsequent rain caused a significant drop in HRY (Finassi et al., 2002). However, when repeated rain events kept HMC above 20%, HRY was not influenced by HMC. In Louisiana, where rain events are common during rice maturation, long and medium grain rice experienced a significant reduction in HRY when rice dropped below 15.0% to 19.8% HMC depending on variety and year of harvest (Jodari and Lindscombe, 1996). A warmer and drier harvest season caused fissuring to begin at higher HMC than a cooler and more humid season. In two harvest seasons in Arkansas with numerous rain events, HRY was not affected by harvest moistures between 15% and 22% (Siebenmorgen et al., 1992).

In California's rice production area, rain is rare and maximum HRY for medium-grain rice is obtained at high

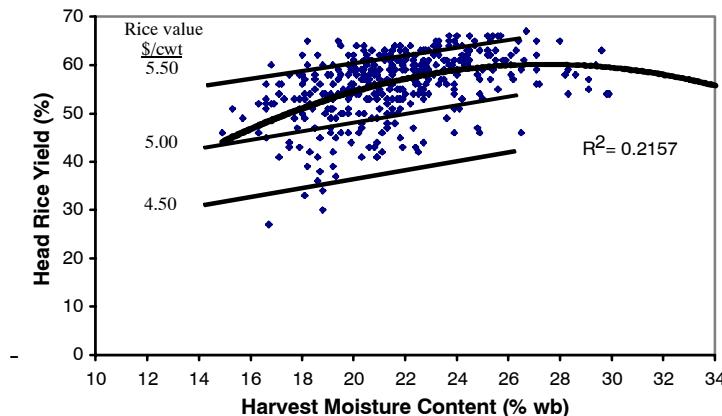
HMC. Kester et al. (1963) concluded that the highest HRY is obtained at 25% to 32% HMC. Morse et al. (1967) indicated that HRY peaks between 26% and 30% HMC. Geng et al. (1984) analyzed commercial data, and they concluded that high variability prevented them from finding a narrow range of HMC for high HRY and that HRY was maximum between  $25\% \pm 5\%$  HMC. Commercial quality data for California medium-grain rice (D. Jones, Farmers Rice Cooperative, Sacramento, Cal., personal communication, 1999) clearly showed that HMC explains only a small portion of the variability in HRY, as described by the low regression coefficient for a second-order polynomial regression line (fig. 1). While maximum HRY was obtained at HMCs above 20%, lots below 18% HMC had nearly the same quality, and lots above 22% moisture had HRY values of less than 50%. The data show that in commercial practice HMC was not a good predictor of HRY, and apparently there must be other variables influencing rice quality.

A great deal of research beginning the 1930s showed that paddy rice kernels fissure when dried below a critical moisture content and then rehydrate because of exposure to free moisture or high humidity, (Kunze, 1993; Siebenmorgen et al., 1998; Lan et al., 1999). The fissured kernels break during milling, causing low HRY in lots with high amounts of fissured kernels. At harvest, individual kernels vary widely in moisture (Siebenmorgen et al., 1992), and if the pattern of moisture distribution varies because of varying cultural practices or weather conditions, the proportion of kernels below the critical moisture may be a better indicator of HRY than average moisture. Geng et al. (1984) indicated that cycles of drying and moisture absorption may influence quality, but they did not describe a mechanism. Conventional wisdom in the California rice industry is that quality is lost

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Submitted for review in January 2005 as manuscript number FPE 5726; approved for publication by the Food & Process Engineering Institute Division of ASABE in January 2006.

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**Figure 1.** Typical relationship between moisture content of rice at harvest and head rice yield. Data are for 630 commercial lots of California medium-grain rice harvested in 1999.

during periods of dry north wind, and this supports the idea that weather is a factor in determining HRY. Steffe et al. (1980) indicated that north winds caused rapid drying and made it difficult to harvest at optimum moisture content. These observations suggest that the distribution of individual kernel moisture content and meteorological conditions influence HRY in addition to the average rice moisture on the day of harvest.

The objectives of this research were to describe the relationship between weather conditions at harvest and rice moisture variation, which contributes to the wide range of HRY typical of California medium-grain varieties, and to determine conditions at harvest that produce high-quality and high-value rice.

## MATERIALS AND METHODS

Variety M202 medium-grain rice was grown at the Rice Research Station in Biggs, California, and managed to produce a range of average rice moisture at harvest. In 2003, a field was divided into three basins, each drained on different dates to produce a range of HMC. Each plot was subjected to identical commercial cultural practices. The rice reached 50% heading on 29 August, 87 days after planting. Basin 1 was drained on 12 September, basin 2 on 18 September, and basin 3 on 26 September, and each basin was harvested on 30 September and 6, 13, and 16 October. In 2004, M202 rice was grown under three contrasting cultural systems. Basin 1 was a conventional water-seeded treatment, planted on 17 May; basin 2 was a spring- and fall-tilled, stale seedbed, water-seeded treatment, planted on 4 June; and basin 3 was a fall-tilled, no-till stale seedbed, water-seeded treatment, planted on 4 June. All basins were planted with M202 rice at a uniform 150 kg/ha seeding rate. Basin 1 was drained on 7 September, and basins 2 and 3 were drained on 15 September. Basins were harvested on 27 September and 4, 11, and 15 October. In both years, each replicate sample was harvested from a 1 m<sup>2</sup> area. Rice was cut by hand at approximately 10:00 to 12:00 h and threshed with a small-plot thresher. Air temperature and relative humidity at canopy height were measured at 15 min intervals during the entire harvest period each year (H08-032-08, Onset Computer Corp., Bourne, Mass.).

Rice moisture for each harvest replication was determined with a single-kernel moisture meter (PQ510, Kett Electric Laboratory, Japan) with a 0.15% moisture standard error of calibration based on oven-drying at 130°C for 24 h. Each moisture sample consisted of 200 kernels taken from the 1000 to 2000 g of rice from each harvest replication. On non-harvest days, rice moisture was measured at 10:00 and 17:00 h, the typical period when rice is free of dew and is suitable for commercial harvest. Six panicles were collected from each harvest area in each basin, and 200 of the hand-stripped kernels were measured in the single-kernel meter. In 2003, the harvest samples were dried with room-temperature air (20° to 25°C, with a relative humidity of 40% to 50%), and head rice yield was determined by the California Department of Food and Agriculture Grain Quality Inspection Lab using USDA-FGIS procedures (USDA-FGIS, 1994). In 2004, 500 g paddy samples were room air dried, husked (FC-2K, Yamamoto, Japan), and milled (VP-32T, Yamamoto, Japan). Whole-kernel determinations were made by the California Department of Food and Agriculture Grain Quality Inspection Lab using standard USDA-FGIS procedures for western production medium-grain rice (USDA-FGIS, 1994).

The effect of weather on HRY was evaluated on the basis of actual HRY compared with predicted head rice yield (PHRY). The PHRY was based on the assumption that all kernels that dry below 15% moisture and are rehydrated will fissure and result in broken kernels when milled. The 15% threshold moisture was based on laboratory tests (not reported) and is at the upper range of critical moistures reported by Siebenmorgen et al. (1998). PHRY was calculated using equation 1:

$$\text{PHRY} = \text{MHRY} \times (1 - \text{TMC}) \quad (1)$$

where

MHRY = average maximum HRY (%)

TMC = proportion of kernels  $\leq 15\%$  moisture content at harvest.

The MHRY was the average HRY of replicates harvested between 21% and 26% moisture. The MHRY averaged over both seasons was 63%. Single-kernel moisture measurements were used to determine TMC.

Rice value was calculated based on a typical U.S. medium-grain loan value of \$9.39/cwt for whole grain and

\$5.35/cwt for broken kernels (USDA-ASCS, 1999) minus drying cost. (Yield is expressed in units of hundredweight (cwt), a common industry trade unit equal to 100 pounds or 45.5 kg.) Rice drying cost was based on rice moisture and was equal to \$ 0.0319 \* HMC + 0.10/cwt (D. Jones, Farmers Rice Cooperative, Sacramento, Cal., personal communication, 2000). Rice value per hundredweight was calculated with equation 2:

$$V = HRY \times 0.097 + (TRY - HRY) \times 0.0535 \\ - (HMC \times 0.0319) - 0.1 \quad (2)$$

where

$V$  = rice value (\$/cwt)

HRY = head rice yield (%)

TRY = total rice yield (%)

HMC = rice moisture at harvest (% w.b.).

Equation 2 was rearranged to plot lines of equal rice value on a plot of HRY versus HMC (fig. 1).

## RESULTS AND DISCUSSION

In both years, a period of dry north wind occurred from 10 to 13 October, although in 2003 the nights of 11 and 12 October had prolonged periods of high relative humidity (table 1). In both years, during the 9 to 15 day period before the north wind, the average rice moisture remained nearly the same (tables 2 and 3). The north wind period had daytime minimum relative humidity of 14% in 2003 and 13% in 2004. Average wind speeds ranged from 19 to 40 km/h with gusts to 76 km/h in 2003, and from 23 to 47 km/h with gusts to 72 km/h in 2004. The highest wind speeds occurred during daylight hours. After several days of dry windy conditions, the rice moisture dropped by 6 to 10 percentage points. Before the windy period, the rice in all basins experienced wide diurnal swings in moisture (figs. 2 and 3). During the windy period, the rice had much less diurnal variation in moisture, and wetter rice experienced less variation in moisture than drier rice. After the windy period ended, the rice resumed a diurnal moisture fluctuation.

In both harvest seasons, before the windy period, HRY averaged across all basins remained relatively constant,

**Table 1. Daily period where relative humidity at canopy height exceeded 90%. Period begins the evening of the previous day and extends through morning of the date listed in the table.**

October	Daily Period with RH Exceeding 90% (h)	
	2003	2004
4	12.5	9.5 <sup>[a]</sup>
5	15.5	9.0
6	15.8 <sup>[a]</sup>	13.0
7	14.8	7.0
8	15.8	7.0
9	13.8	8.0
10	1.3	0
11	11.8	0 <sup>[a]</sup>
12	15.3	0
13	3.3 <sup>[a]</sup>	0
14	15.0	4.0
15	15.5	7.5 <sup>[a]</sup>
16	15.5 <sup>[a]</sup>	14.5

<sup>[a]</sup> Harvest date.

**Table 2. 2003 average harvest and quality data on each harvest date.<sup>[a]</sup>**

Harvest Date	HMC (% w.b.)	HRY (%)	Value (\$/cwt)
30 Sept.	25.9 a	63.2 a	5.48 a
6 Oct.	24.3 b	63.8 a	5.63 a
13 Oct. <sup>[b]</sup>	18.1 c	55.6 b	5.55 a
16 Oct.	19.6 c	45.8 c	5.01 b

<sup>[a]</sup> Means in the same column followed by the same letter are not significantly different by Duncan's multiple range test ( $\alpha = 0.05$ ):  
HMC = rice moisture at time of harvest.

HRY = head rice yield, milled white rice as a percent of rough rice.  
Value = USDA loan value minus typical drying costs based on harvest moisture.

<sup>[b]</sup> During windy period.

**Table 3. 2004 harvest and quality data for each basin on each harvest date.<sup>[a]</sup>**

Harvest Date	HMC (% w.b.)	HRY (%)	Value (\$/cwt)
27 Sept.	22.3 a	55.8 ab	5.27 a
4 Oct.	22.8 a	58.4 a	5.46 a
11 Oct. <sup>[b]</sup>	14.6 b	49.7 b	5.29 a
15 Oct.	14.3 b	25.3 c	4.04 b

<sup>[a]</sup> Means in the same column followed by the same letter are not significantly different by Duncan's multiple range test ( $\alpha = 0.05$ ):  
HMC = rice moisture at time of harvest.

HRY = head rice yield, milled white rice as a percent of rough rice.  
Value = USDA loan value minus typical drying costs based on harvest moisture.

<sup>[b]</sup> During windy period.

changing by less than 3 percentage points (tables 2 and 3). The HRY dropped during the windy conditions by 8.2 percentage points in 2003 and by 8.7 percentage points in 2004. After the wind stopped, the weather returned to typical calm and clear conditions in which dew formed on the rice each night. After the high humidity conditions returned, HRY decreased by 9.8 percentage points in 2003 and by 24.4 percentage points in 2004. These losses occurred in two days of high humidity conditions.

A more complete understanding of the effect of the windy period on HRY is obtained by comparing HRY versus HMC (fig. 4). Under California's typical weather at harvest, where rice dries during the day and rehydrates at night, HRY loss occurs at HMCs below a threshold of about 21%. The closed data points in figure 4 represent this condition, and they include replications harvested both before and after the wind events. Below the threshold moisture, HRY decreases linearly with decreasing HMC. The threshold moisture range at which HRY loss begins is much higher than that observed in the wetter harvest conditions of the southeastern U.S. (Siebenmorgen et al., 1992). This also fits the observation by Finassi et al. (2002) that, in Italy, rice is subject to HRY loss at higher HMC under dry meteorological conditions than under more humid conditions.

The HRY during the windy periods was significantly greater at given HMCs than the HRY during calm conditions (table 4 and fig. 4, open data points). Analysis was based on a linear regression technique using indicator variables to differentiate HRY under calm and windy conditions (Nutter et al., 1996). Data with HRY greater than 60% were excluded from the analysis to eliminate treatments whose HRY was not influenced by HMC. The effect of the wind on HRY was particularly great in 2004. Several replications harvested on 11 October had HRYs greater than 60% at HMCs near 16%. Under

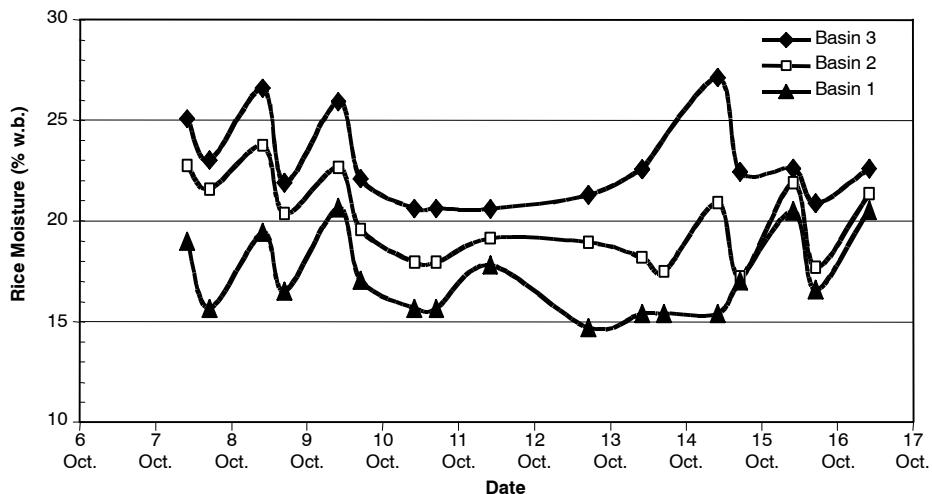


Figure 2. Rice moisture content near the time of the north wind event during the 2003 harvest season.

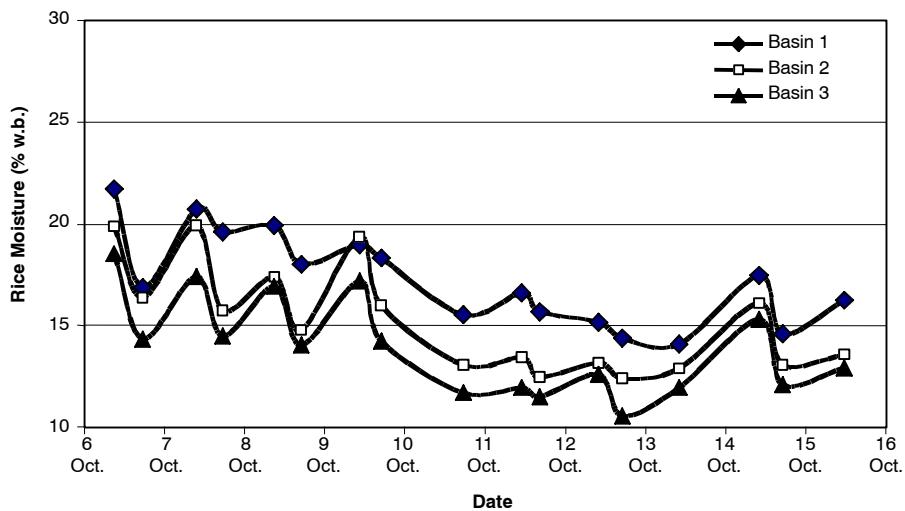


Figure 3. Rice moisture content near the time of the north wind event during the 2004 harvest season.

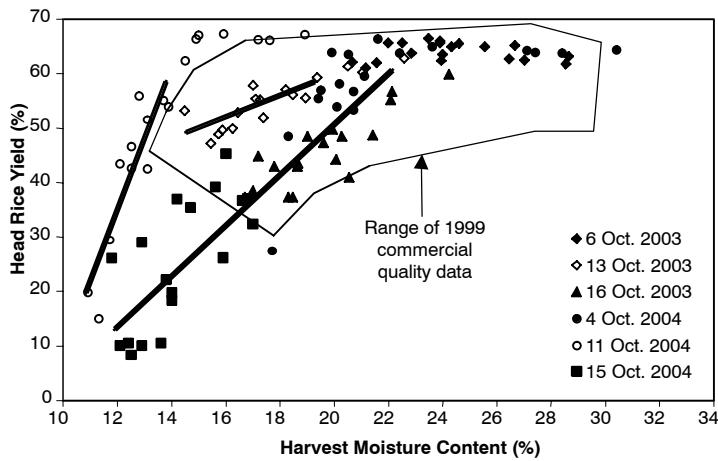


Figure 4. Head rice quality for each replication harvested on selected dates in 2003 and 2004 compared with the range of commercial quality typically seen in California medium-grain rice. Open data points are replications harvested during dry windy conditions.

calm conditions (fig. 4, closed data points), no replications were harvested at greater than 60% HRY with HMC less than 20%.

The PHRY reveals the mechanism for high HRY during the dry windy periods. During calm conditions before the

windy period, the actual HRY was nearly equal to the PHRY (table 4). Each night, kernels that dried below 15% moisture during the previous day were rehydrated and fissured. During the windy periods, the actual HRY was significantly higher

**Table 4. Head rice yield and potential head rice yield for each harvest location averaged over all basins.**

Harvest Date	Predicted Head Rice Yield	Actual Head Rice Yield	Standard Error (predicted – actual)
2003			
30 Sept.	62.8	63.2	-0.5
6 Oct.	65.1	63.8	1.3
13 Oct. <sup>[a]</sup>	29.7	55.6	-25.9
16 Oct.	49.6	45.8	3.8
2004			
27 Sept.	57.8	55.8	2.0
4 Oct.	61.4	58.2	3.1
11 Oct. <sup>[a]</sup>	15.7	49.7	-34.0
15 Oct.	12.9	25.3	-12.1

<sup>[a]</sup> During windy period.

than the PHRY. For example, rice harvested on 13 October 2003 had an actual HRY that was 24.4 points higher than the PHRY, and on 11 October 2004, the HRY was 34.0 points higher than the PHRY. During the windy conditions, there was only a slight potential for rehydration at night and HRY remained high during this period. After the wind stopped, nighttime dew conditions returned and rehydration caused the HRY to be much closer to the PHRY.

The weather data suggest that more than 12 h of rehydration conditions were required to completely fissure rough rice. The HRY in 2003 after the wind stopped was within 3.8 percentage points of the PHRY (table 4). The harvest was preceded by three days with a total of 45 h of relative humidity greater than 90% (table 1). In 2004, the harvest after the windy period was preceded by two days of high humidity, with a total of only 11.5 h of relative humidity greater than 90%. Under these rehydration conditions, the HRY was 12.1 points higher than the PHRY. Although this difference was not statistically significant based on the regression analysis, it suggests that more than 11.5 h of hours are required for complete rehydration. Banaszek and Siebenmorgen (1990) demonstrated that rehydration at 20°C is 70% complete in 24 h.

Rice value combines the financial effects of HRY and HMC. During windy conditions, the value dropped because of reduced HRY, but the effect was countered by lower drying costs because harvest moisture also dropped (tables 2 and 3). Across both seasons, rice lost less than \$0.17/cwt in value during the windy period, which is small compared to the typical value of rice of \$4.00 to \$5.60 per cwt. However, after the wind stopped and dew conditions returned, the HRY dropped significantly and the HMC increased slightly in 2003 but remained low the following year. In 2004, with a prolonged north wind period, the rice value after two days of calm conditions decreased by \$1.25/cwt compared with the value at the beginning of the windy period. However, after two days of rehydration conditions, the PHRY after the wind stopped was still lower than the actual HRY. After several more days of high humidity at night, the value would have likely dropped even more. In the 2003 season, the windy period had only two nights of low relative humidity, compared with four in the following year, and the loss in rice value was slightly more than \$0.50/cwt.

The combined effects of weather and rice moisture can explain a great deal of the variation in head rice quality experienced by the California medium-grain rice industry.

High commercial quality is obtained before and during dry windy periods. Under calm conditions with daily rehydration (fig. 4, solid data points), high quality is obtained when rice is harvested above about 21% moisture. These data points fall near the top of the right half of the commercial quality envelope in figure 4. Under windy conditions (fig. 4, open data points), high quality can be obtained at harvest moisture as low as 15%. These data points fall near the top left of the envelope of commercial rice quality in figure 4. Low quality is associated with rice that was harvested below 21% moisture under calm conditions, which is represented by the data points near the bottom left of the envelope. Conditions that cause low HRY at high moisture were not experienced in the two years of testing. This condition may be associated with rice that has dried to just below 21% moisture and then rehydrated by rain or long periods of dew.

The commercial implications of these results are that, contrary to industry wisdom, dry windy conditions cause only small amounts of HRY loss and rice value can remain quite high because reduced drying costs offset the effect of the lower HRY. In fact, the estimated value of some replications harvested during the windy conditions was nearly \$6.00 per cwt, the highest of any harvested in the two seasons.

Under calm conditions with high nighttime relative humidity, rice should be harvested before grain moisture drops below about 21%. Under windy conditions with little rehydration at night, high rice value can be obtained at average harvest moisture as low as 15%. Rice harvest should proceed at maximum capacity during and immediately after periods of drying winds in order to complete harvest of all fields that have dried below about 21% moisture. After the windy period ends, HRY and rice value will drop appreciably because of kernel rehydration.

Under weather conditions in California, rice moisture varies diurnally corresponding to the wide range of relative humidity and is affected by weather patterns. This means that it is possible to harvest rice at high moisture and have low HRY. For example, basin 2 on 7 October 2003 dropped to 22% moisture, but eight days later it was again at 22% moisture in spite of having dropped to 17% moisture in the intervening period (fig. 2). Rice harvested on 8 October had a 65% HRY, and eight days later it was below 50% (data not shown). This further demonstrates that quality is related to the history of rice moisture, not just its value at a particular time.

## CONCLUSIONS

Harvesting medium-grain rice under California's dry climate conditions produced a wide range of head rice quality. Rice moisture at harvest was not, by itself, a good predictor of head rice yield. Moisture history was also needed to predict the effects of meteorological conditions on quality. Under typical calm conditions, with low relative humidity during the day and dew-forming conditions at night, reductions in HRY occurred when rice moisture, measured at noon, dropped below about 21%. Dry windy conditions during harvest caused rapid reductions in rice moisture, predisposing rice to significant HRY loss, but most of the loss occurred only after rehydration conditions returned.

The proportion of kernels below 15% moisture was a good predictor of HRY yield after enough time had passed for complete rehydration of the rice. Complete HRY loss took more than 11.5 h of exposure to greater than 90% relative humidity. Meteorological conditions that caused rice drying but did not allow complete rehydration of kernels that dried below 15% moisture caused some loss in HRY, but the reduced HMC decreased drying costs, thus reducing the rice value loss caused by the reduced HRY. Under dry windy conditions, commercial harvest should proceed rapidly, harvesting maximum amounts of rice below about 21% moisture before rehydration conditions return. Harvesting rice under a combination of dry meteorological conditions and conditions of diurnal rehydration explains a great deal of the commercial variation in California medium-grain rice quality.

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