

INDIVIDUAL RICE KERNEL MOISTURE CONTENT VARIABILITY TRENDS

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ABSTRACT. Variation in individual kernel moisture content (MC) distributions in rice panicles were measured for rice cultivars Bengal, Cypress, and Drew. Rice panicles were harvested at different stages of maturity from foundation seed fields at two locations with widely varying soils in Arkansas during the autumns of 1998, 1999, and 2000. The objective was to quantify variability of individual rice kernel MCs as affected by maturity, planting location, and year. Individual kernel MC distributions were multi-modal until the average harvest MC (HMC) reached about 16%, at which point the distributions tended to be primarily single-modal. For all cultivars, HMC significantly affected kernel MC standard deviation (SD). For Cypress and Drew, individual kernel MC SD was also significantly affected by year and location with significant interactions between HMC and year and HMC and location. Regression equations that accounted for the variation in individual kernel MC at varying kernel maturity stages were generated for each cultivar.

Keywords. Individual kernel moisture content, Moisture content distributions, Harvest moisture content, Rice.

Physical properties of individual rice kernels at harvest influence post-harvest processing and quality. Of particular interest are kernel MC and thickness, both of which have been shown to directly impact processing performance. Previous work by Lu et al. (1995) and Lu and Siebenmorgen (1995) have shown that significant losses in head rice yield (HRY) can be incurred when long-grain rice is harvested at HMCs lower than 15% or higher than 22% wet basis (w.b.) and that kernel breaking force was highly correlated to kernel thickness and HMC. Kocher et al. (1990) showed that at high HMCs a significant percentage of kernels in a bulk have much higher MCs than the bulk average MC. Notably, these high MC kernels are typically thinner, weaker kernels than the bulk average thereby having a depressing effect on milling quality (Sun and Siebenmorgen, 1993; Lu and Siebenmorgen, 1995).

Functional properties of rice are affected by kernel maturity. Kester et al. (1963) studied changes in rice chemical and physical properties of three short-grain rice cultivars across HMC. They reported that HRY, peak viscosity (PV), water absorption, and milled rice kernel color were highly affected by rice maturity levels. Recently, Wang et al. (2004) reported that rice cultivar, growing location, and HMC of rough rice affected PV. PV consistently increased as HMC decreased, although the rate of increase varied with variety and location. This variation in slope is speculated to be due to varying distributions of kernel MCs and corresponding maturities.

Large variations in individual kernel MCs can exist among kernels on a panicle, plant, and among plants at harvest (Holloway et al., 1995; Siebenmorgen et al., 1992; Kocher et al., 1990; Chau and Kunze, 1982; McDonald, 1967). Chau and Kunze (1982) measured variation among harvested rice kernels of medium-grain rice (cv. Brazos). They found that rice with an average MC of 22% at harvest had less than 10 percentage points MC difference within the most mature panicles and greater than 10 percentage points MC difference on the most immature panicles. Chau and Kunze (1982) also showed MC variations of up to 46 percentage points between kernels from the bottom of the least mature panicle to the top of the most mature panicles. In 1967, McDonald reported that rice kernel MCs on panicles varied by as much as 10 percentage points.

Kernel MC distributions have been previously quantified at different HMCs. Kocher et al. (1990) measured such distributions across a range of HMCs and concluded that rice kernel MC variance decreased as the average MC decreased. Individual kernel MC frequency distributions exhibited a tri-modal pattern on early harvest dates, which was later corroborated by Siebenmorgen et al. (1992). As the rice matured, the multi-modal distributions transitioned into a single mode distribution and the MC at which the lowest MC mode was centered decreased. According to Kocher et al. (1990), the kernel MC distributions later in the harvest season were single modal, but were skewed towards lower MCs. Kocher et al. (1990) found that a direct linear function relating kernel MC variation to average HMC explained 72% of the variance in individual kernel MCs.

Holloway et al. (1995) investigated possible causes of the multimodal MC distribution among rice kernels at harvest as reported by Kocher et al. (1990). In a greenhouse experiment using a long-grain rice cultivar Alan, it was found that the different MC distribution modes could not be explained by differences in kernel MC patterns among main stems or primary, secondary, or tertiary tillers. Instead, it was proposed that the multi-modal MC distributions were the result of individual kernel MC plateaus during kernel

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development. This postulation was based on a study conducted by Yoshida (1981), which showed the MC change of individual kernels of rice on a single panicle from flowering through maturation. Holloway et al. (1995) described MC plateaus as periods during growth and maturation when the kernel MC remained relatively constant. When the MCs of all individual kernels were tallied to obtain the MC frequency distribution at a given overall MC, modes would tend to form around the plateau MCs. This is because, at any given time, a greater number of kernels would exist at the plateau MCs than at other MC levels.

The past research described above has shown the existence and importance of variability in individual rice kernel MCs at harvest. However, while kernel MC variability has been measured under specific conditions, research has not addressed this topic to quantify the variation in individual kernel MC as rice is harvested gradually at receding average HMC. Therefore, the objective of this study was to assess trends in individual kernel MC distributions among rice cultivars as affected by average HMC, planting location, and year. The ultimate intent of this work was to explain the variability in processing performance of rice lots.

MATERIALS AND METHODS

Panicles of three rice cultivars: Bengal (medium-grain), Cypress, and Drew (long-grains) were collected from foundation seed fields at the University of Arkansas research and extension centers at Stuttgart, Arkansas (Rice Research and Extension Center or RREC) and Keiser, Arkansas (Northeast Research and Extension Center or NEREC), at HMCs that ranged from approximately 12% to 24% during the autumns of 1998, 1999, and 2000. The extension center at Stuttgart, Arkansas has Dewitt silt loam soil and Keiser, Arkansas has Sharkey silt loam soil. The annual average rainfall in Stuttgart, Arkansas (91° 28' 00") is approximately 1232 mm and Keiser, Arkansas (90° 04' 00") has 1214 mm. The average high temperature during cropping season in Stuttgart, Arkansas is 28°C and the annual average low is 16.3°C during cropping season from April to October. For Keiser, Arkansas the average high temperature during cropping season is 27.8°C and average low temperature of 15°C. Arkansas is in the southwestern United States. Due to frost damage to Cypress in 2000, only Bengal and Drew samples were collected that year. Rice panicles were collected by hand at various maturities, as indicated by the overall bulk HMC. At each harvest, 10 panicles were picked randomly from marked plots within the foundation seed fields. The size of each sampling plot was approximately 60 m². Each panicle was placed in a separate plastic bag for MC measurements. Immediately after harvest, the kernels were stripped by hand from the panicles and empty kernels and chaff separated. Individual kernel MCs, as well as the average and SD of kernel MCs, from each panicle were measured using a single kernel moisture meter (Shizuoka Seiki CTR 800E, Shizuoka, Japan). The moisture meter was calibrated before each harvest season and showed good agreement with rough rice bulk MCs determined by an oven method (130°C and 24 h, Jindal and Siebenmorgen, 1987). Rice panicle individual kernel MCs were pooled across panicles harvested at a given MC for SD analyses. SD

analyses were done using the pooled kernels from ten panicles for each HMC.

The experimental design consisted of HMC, location and year as sources of variation and the dependent variables are MCSD and MC range. Population normality tests for MC distributions were conducted using Shapiro-Wilk tests in JMP®, Sall et al. (2002). JMP is a statistical discovery, window-based software, developed by SAS Institute. Analysis of variance and correlation analyses were performed in SAS using the PROC GLM.

RESULTS AND DISCUSSION

KERNEL MC RANGES FROM PANICLES

The average HMCs and ranges in kernel MCs among individual kernels from rice panicles for the three cultivars harvested in 1998, 1999, and 2000 are shown in figure 1. The range is simply calculated by subtracting the minimum individual kernel MC recorded from the maximum kernel MC recorded. The individual kernel MC ranges indicate the spread between maximum and minimum kernel MCs from individual panicles harvested at a certain average HMC. There was a high correlation ($R > 0.89$, $P < 0.001$) between kernel MC range and HMC for all cultivars. For all cultivars, the range decreased as HMC decreased, indicating that kernel MC range is directly related to the overall, average maturity level of the kernels. Chau and Kunze (1982) reported similar findings regarding rice kernel MC ranges for mature and immature panicles for rice cultivar Brazos. They indicated that less than a 10 percentage point range in kernel MCs existed on the most mature panicles and more than 10 percentage points for the most immature panicles. Figure 1 supports these findings in that the kernel MC range was generally at or below 10 percentage points when the average HMC reached 12% to 14%.

Figure 1 also shows that the kernel MC range was affected by location, particularly for 1998 results. For all cultivars, MC ranges were greater in Stuttgart than in Keiser for 1998 at all HMC levels ($P = 0.05$). It is speculated that the different environment, particularly the soil type, contributed to the greater kernel MCs range for Stuttgart. Similar results were obtained for Bengal in 1999 and Drew in 2000; in both cases, MC ranges were greater in Stuttgart than Keiser at HMCs lower than 18%. There was no significant effect of location and year on kernel MC range for Cypress and Drew in 1999 and for Bengal in 2000.

INDIVIDUAL KERNEL MC DISTRIBUTIONS FROM PANICLES

Figure 2 shows selected frequency distributions of individual rice kernel MCs from panicles of Bengal, Cypress, and Drew harvested from Stuttgart and Keiser at low (12% to 14%) and high (20% to 24%) HMCs in 1998. There were similar trends in individual kernel MC distributions across the three cultivars over the two HMC levels, which were multi-modal, particularly at average HMCs greater than 16%. As the average HMCs decreased to the low HMC levels, the low MC mode (primary mode, fig. 2) increased drastically in magnitude and the frequency distribution tended to develop into a single modal distribution. This observation corroborated the findings of Kocher et al. (1990) and Holloway et al. (1995) in that the individual kernel MC distributions in a panicle were multi-modal at high HMCs,

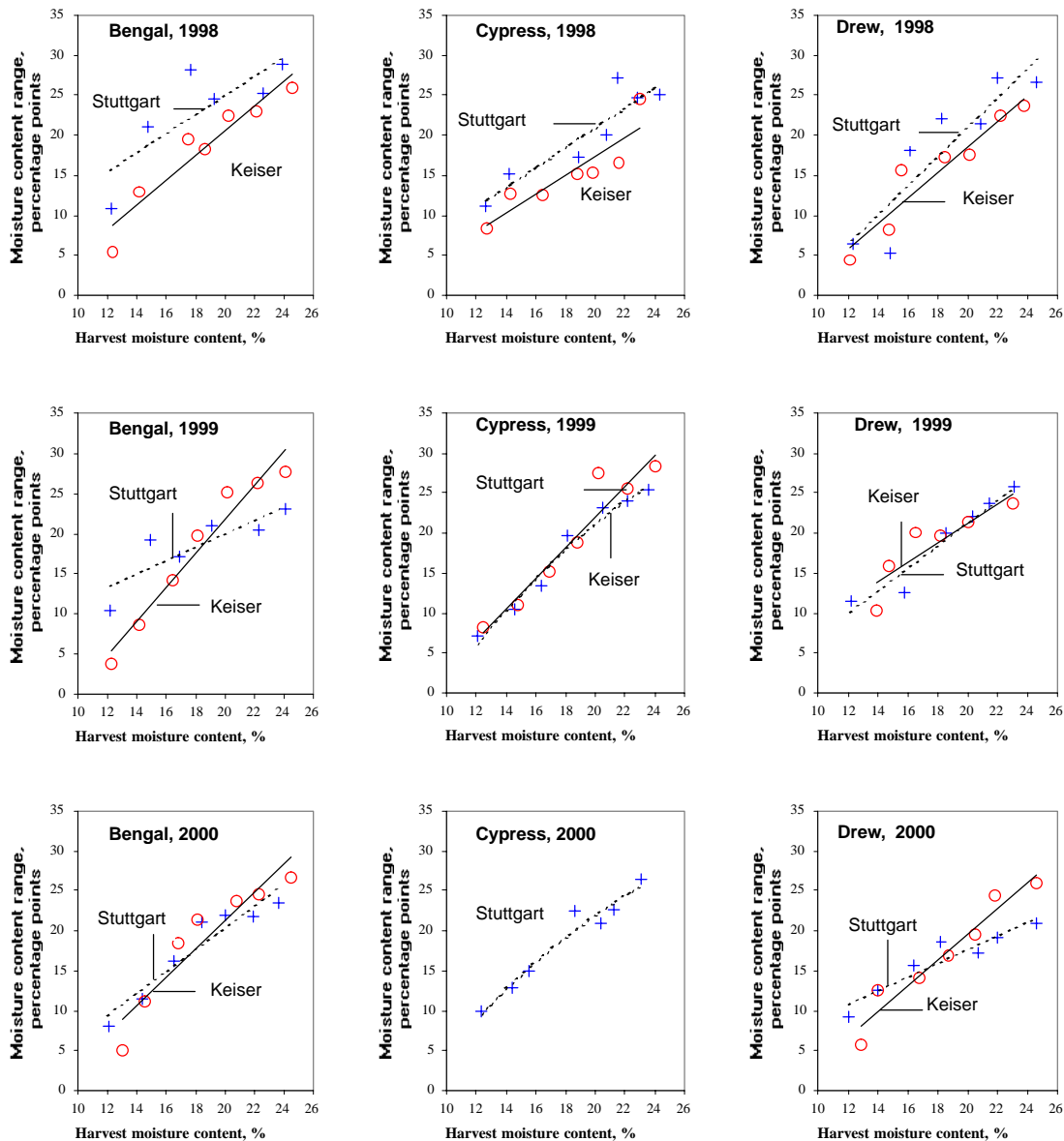


Figure 1. Ranges of individual kernel moisture content from panicles of three rice cultivars at different average harvest moisture contents from Stuttgart and Keiser, Arkansas in 1998, 1999, and 2000. Each data point is the average of the moisture content ranges from pooling 10 panicles harvested at each moisture content level.

became essentially single modal and skewed toward the lower individual kernel MC at lower HMC. This indicates a decrease in the number of high MC, immature kernels as HMC decreases. For all HMC levels, however, normality tests using the Shapiro-Wilk tests (JMP version 5) showed that the distributions were not statistically normal, even at low HMC distributions. This finding is in agreement with the results of Kasahara and Inohara (1988) and Kocher et al. (1990), wherein they found non-normality in kernel MC distributions. Consequently, at lower HMCs, the kernel MC distributions tended toward a narrow MC spread, the mean of which approaches the rice equilibrium MC at the prevailing average ambient air conditions.

STANDARD DEVIATION OF KERNEL MC FROM PANICLES

While the SD does not completely characterize the shape of an individual kernel MC distribution, it does provide a

measure of the deviation of individual kernel MCs from the mean at a given HMC. To test whether factors such as HMC, year, and location affected the SD of individual kernel MCs of the three cultivars, an analysis of variance was performed. The results indicated that for Bengal, only the HMC significantly affected SD ($P < 0.0001$). For Cypress, HMC ($P < 0.0001$), year ($P = 0.001$), HMC*year interaction ($P < 0.001$), location, and HMC*location interaction ($P = 0.002$) had significant effects on SD. For Drew, HMC ($P < 0.001$), HMC*year interaction ($P = 0.002$), location ($P = 0.011$), and HMC*location interaction ($P = 0.006$) had significant effects on kernel MC SD. At higher HMC, there are some kernels that developed early but there are also kernels that are in the dough or milky stages. Results obtained by Chau and Kunze (1982) support this finding who have shown that MC variations of up to 46 percentage points between kernels from the bottom of the least mature panicle to the top of the most

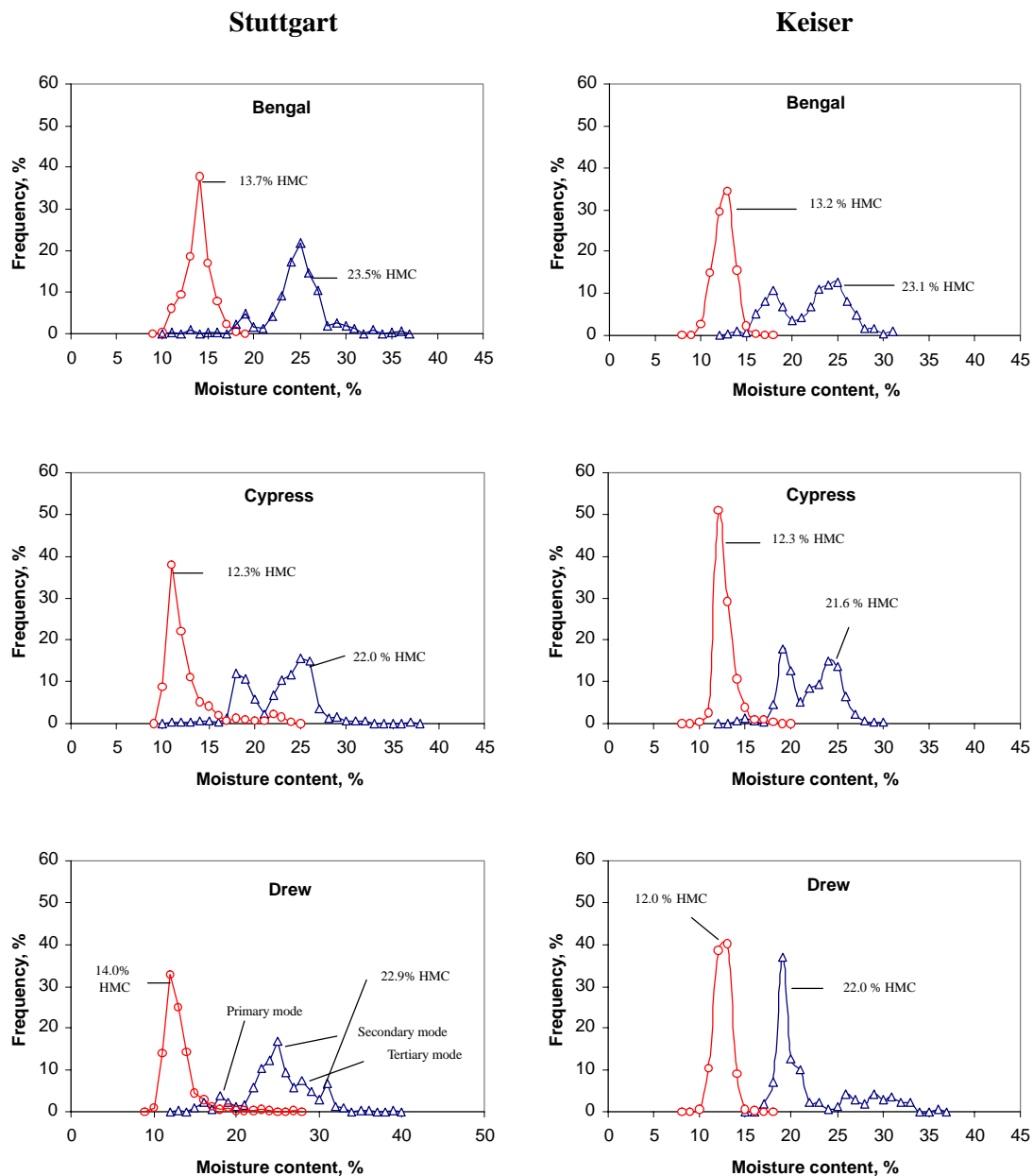


Figure 2. Individual kernel moisture content frequency distributions at selected average harvest moisture contents (HMCs) for rice cultivars Bengal, Cypress, and Drew harvested in 1998 at Stuttgart (left column) and Keiser (right column), Arkansas. Each curve represents the pooling of kernel MCs from 10 panicles at each HMC level.

mature panicles were incurred at 22% HMC. Possible reasons for the significant effects of HMC, year, and location and their interactions on MC variability can be tied to the physiological growth of rice. Holloway et al. (1995) discussed the causes of variation in kernel MC within the panicle and among tillers. One of the reasons cited that rice do not flower at the same time. Even panicle initiation and flowering varies among tillers and among plants. Consequently, at critical growth stage, environmental conditions could affect kernel filling when the endosperm is being formed. Counce et. al. (2001) have shown in a controlled environment studies that high nighttime temperature affects grain filling.

Figure 3 shows a comparison of the individual kernel MC SDs for 1998, 1999, and 2000 for each cultivar at each

location. For all years and both cultivars and locations, the SD in individual kernel MCs from rice panicles increased with an increase in HMC; however in 1998 at Stuttgart, SD increased to a certain point and decreased after reaching a peak for all the three cultivars. This quadratic trend was evident in other crop years, but most dramatic in the 1998 samples from Stuttgart. The large variation in kernel MCs at higher HMCs is due to large differences in the timing of kernel maturity wherein some kernels matured much earlier than others; this was also reflected in the kernel MC ranges shown in figure 1. Regression curves relating the SD to average HMC were generated for each cultivar for each year of harvest and planting location. A second-degree polynomial and linear models were used to describe individual kernel MC SD trends across average HMCs. The resulting

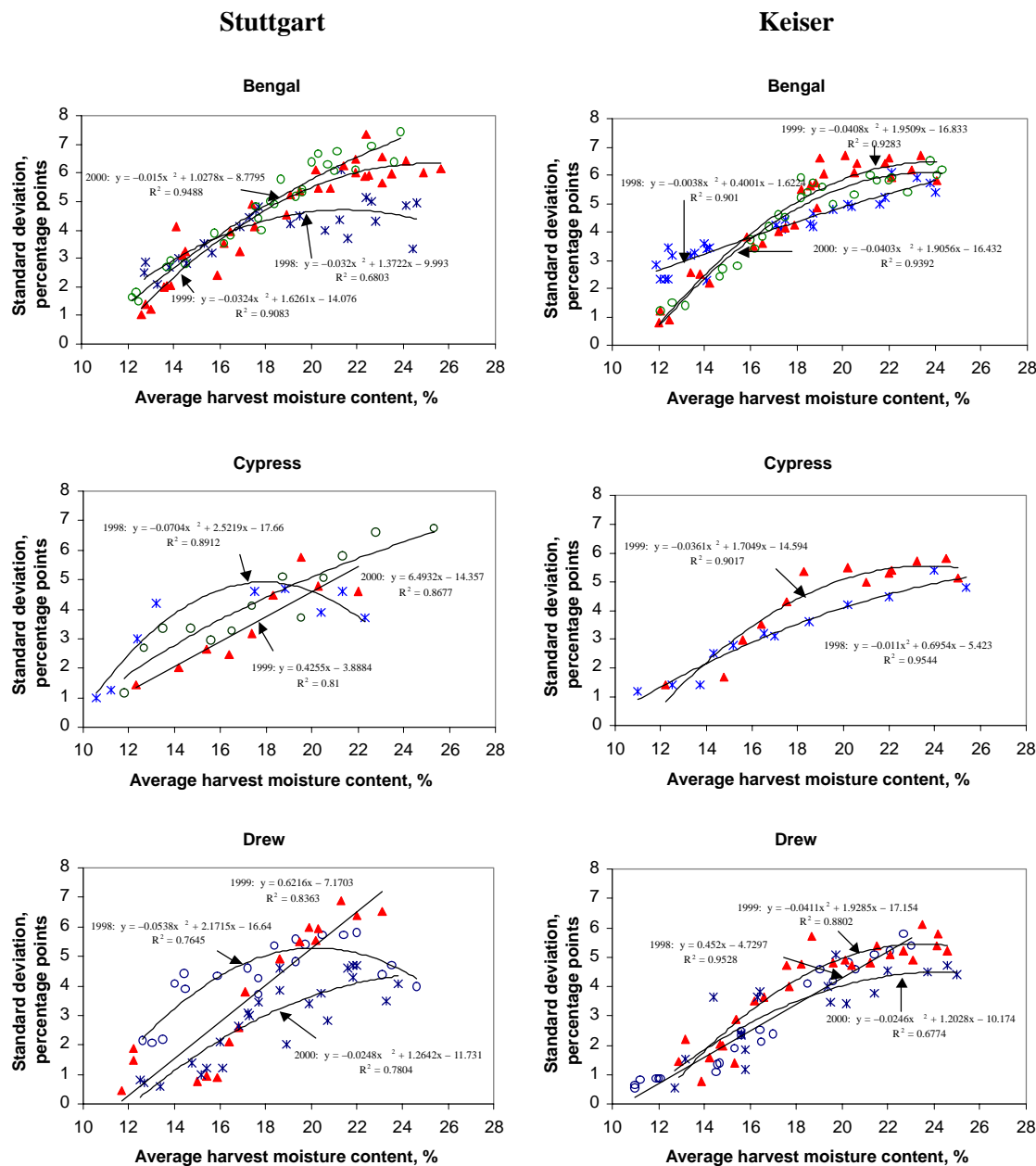


Figure 3. Standard deviations of individual kernel moisture contents from panicles of rice (cv. Bengal, Cypress, and Drew) harvested at different average harvest moisture contents from Stuttgart, Arkansas (left column) and Keiser, Arkansas (right column) in 1998, 1999, and 2000. Each data point represents the average of the individual kernel moisture content standard deviations from 10 panicles of rice representing each harvest moisture content level.

relationships produced coefficients of determination (R^2) ranging from 68% to 95% (fig. 3).

Kernel MC SD trends for Bengal at both Stuttgart and Keiser were similar in 1999 and 2000. However, the Bengal kernel MC SD regression functions in 1998 followed different patterns between Stuttgart and Keiser and were different than the Bengal curves in 1999 and 2000. The 1998 Bengal SDs were lower than the 1999 and 2000 SDs at HMCs greater than 16%. Regression curves for Cypress indicated that HMC explained most (>80%) of the change in SD. In general, the SD versus HMC relationships for Cypress were similar across location and years with the noted exception of the Stuttgart samples harvested in 1998. As with Bengal and Drew, some undetermined environmental and/or production

factors caused a strong parabolic relationship to exist between SD and HMC in 1998 at Stuttgart. The kernel SD versus HMC relationships for Drew were similar to the trends for Bengal and Cypress.

INDIVIDUAL KERNEL MC FREQUENCY MODES

The frequency distributions in figure 2 indicate that SD is not an optimal approach to characterize the variation in kernel MC variation. In an effort to more adequately represent this variation, the modes of each MC frequency distribution were identified. In figure 2, the primary, secondary, and tertiary modes of the 22.9% HMC frequency distribution for Drew from Stuttgart are illustrated.

To analyze the percentages of the total kernels in the primary and secondary modes for the three cultivars at Stuttgart and Keiser at different HMCs, figure 4 was plotted. Generally for all cultivars, there was a linear increase in the percentage of kernels at the primary mode and a linear decrease at the secondary mode as HMC decreased; the rates of increase and decrease were similar across cultivars. At high HMCs, a relatively low percentage of kernels at the primary mode and large percentage in the secondary mode indicates a large percentage of kernels with high MCs or immature kernels. At 16% HMC, the percentage of kernels at the secondary modes were below 5% of the total kernels for all cultivars. At HMCs below 13%, the percentage of

kernels at the secondary modes were practically negligible. Figure 4 shows that for Bengal, trends in primary and secondary mode percentages were similar for 1998, 1999, and 2000 for the two locations. The uniformity in trends across years and locations for Bengal is corroborated by the earlier observation that Bengal SDs depended only on HMC. For Cypress and Drew there were large differences across years in the percentage of total kernels at the primary mode at low HMCs for samples taken from Stuttgart. Additionally, there were differences for Cypress across years in the secondary mode trends. The foregoing analysis indicates some consistent trends in individual kernel MC distribution trends for the three cultivars grown in Stuttgart and Keiser

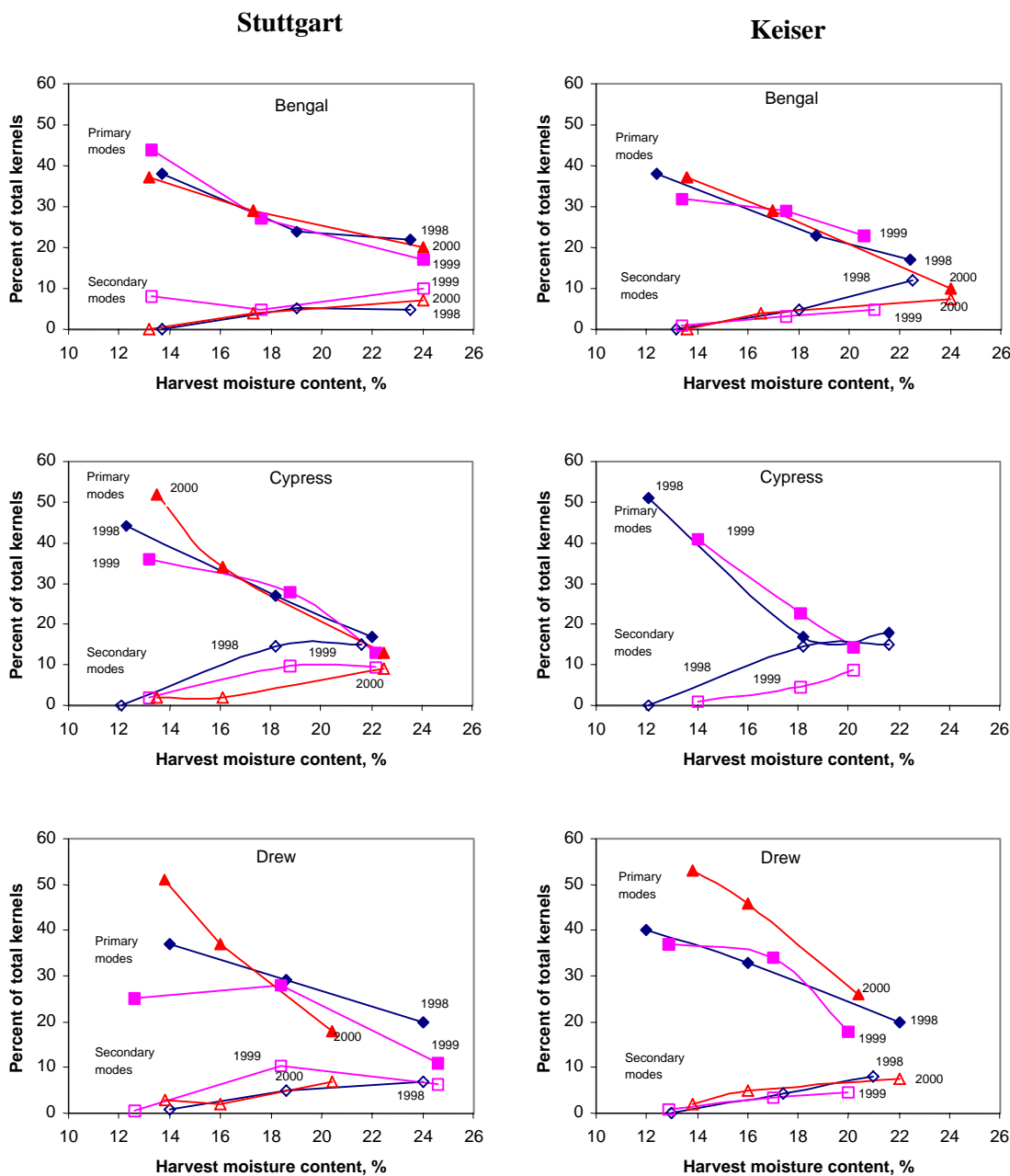


Figure 4. Percentage of total kernels existing at the primary and secondary modes for Bengal, Cypress, and Drew harvested at different harvest moisture contents from Stuttgart, Arkansas (left column) and Keiser, Arkansas (right column) in 1998, 1999, and 2000. Each data point is taken from the frequency distribution representing the pooled kernel moisture contents from 10 rice panicles at each harvest moisture content level.

across all three seasons. However, the distribution trends observed in 1998 were an apparent anomaly.

There are varying factors that can be attributed to the variability in individual kernel MC. Physiologically, the rice caryopsis (the dehulled or brown rice kernel) becomes structurally mature 14 days after fertilization (DAF); it attains full length first, then full width, and finally full thickness, Luh and Luh (1991). It is during this stage that rice kernel development is affected by different factors. These factors could be affected by the genetic or inherent property of the cultivar, planting location, which include soil properties, cultural and management practices, and environmental factors such as air temperature and humidity or interactions of these factors. Further investigation to quantify the effect of these factors on kernel MC variations would be very important.

SUMMARY AND CONCLUSIONS

This study generated the following conclusions:

- For all cultivars, individual kernel MC ranges from rice panicles were affected by growing location.
- The individual kernel MC distributions for the three cultivars were multi-modal until the average HMC reached approximately 16% at which point MCs tended to have single modal distributions. The MC variability can be tied to the physiological growth in that panicle initiation and flowering varies with tillers and among plants. Kernel filling, or endosperm formation, can also be affected by environmental and genetic characteristics of rice.
- Variation in individual kernel MCs from panicles of rice was determined for the three rice cultivars using the SD. For all cultivars, HMC significantly affected kernel MC SD. For Cypress and Drew, kernel MC SD was also affected by planting location, year and the interactions of HMC*year, and HMC*location. Regression curves for SD were generated and showed high coefficient of determination to account for the variation in individual kernel MC at varying average HMCs. These regression curves adequately represented kernel MC SD that were specific for each variety, planting location, and harvest season.
- There was a linear rate of increase in the percentage of total kernels at the primary mode and a linear rate of decrease in the percentage of total kernels at the secondary mode as HMC decreased. This result further indicated the increase in number of low MC kernels as HMC decreased.

Applications derived from this study further supports drying of paddy, and other grains for that matter, to MC 15% and lower. The results could be the basis for developing guidelines on the sampling of panicles for the evaluation of crop maturity as indicated by MC. The information discovered from this study would also help breeders in evaluating and selecting new breeding lines.

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