Chapter

15

Production Factors Impacting Rice Milling Yield

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A previous chapter addressed the general procedure for conducting a laboratory milling analysis and factors that impact the measurement of milling yield, specifically milled rice yield (MRY) and head rice yield (HRY). These factors include the rice sample moisture content, temperature and milling ease, as well as laboratory mill settings and the duration for which the rice is milled. The impact of these factors is primarily manifested through variation in the degree to which rice kernels comprising a sample are milled; in turn, the "degree of milling," or DOM, is inversely related to both MRY and HRY.

There are many factors during rice production that can affect milling yield and quality. One such factor is the nighttime air temperature levels during grain filling, which have been correlated to milling yields and to chalkiness, a rice quality index that has received tremendous notoriety in recent years. Chalkiness, illustrated in Photo 15-1, refers to a portion(s) of the kernel endosperm in which starch granules are loosely packed. Air spaces between the starch granules of chalky portions alter how light is refracted through the kernel, thus giving a "chalky" vs. "translucent" appearance. High nighttime air temperatures have also been shown to impact many other functional-quality attributes. Another production factor that is strongly associated with rice milling yields is the moisture content (MC) at which rice is harvested. The MC of rice at harvest is an indicator of the prevalence of immature kernels at high harvest MCs and the percentage of fissured kernels at low harvest MCs.

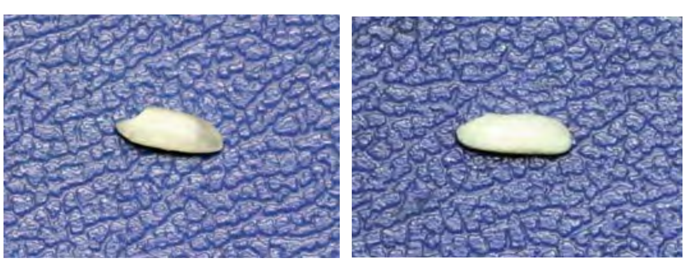

Photo 15-1. Illustrations of chalky kernels. Chalk appears opaque white and may affect a particular region of a kernel (left) or the entire kernel (right).

The physical strength of a kernel ultimately determines its ability to withstand the rigors of postharvest processing without breaking apart. Kernels that are chalky, fissured, immature or otherwise physically damaged generally have reduced mechanical strength relative to nondamaged kernels. These damaged kernels are less likely to withstand the aggressive actions of dehulling and milling, resulting in a greater percentage of broken kernels produced in the milling process. Head rice yield, the mass percentage of kernels that remain intact (head rice) relative to the initial quantity of rough rice, is a primary driver of the economic value of a rice lot; please also see Chapter 14.

Nighttime Air Temperature

The physiological processes leading to deleterious nighttime air temperature impacts are not completely understood. However, the general premise is that abnormally high nighttime air temperatures during kernel formation (reproductive stages R5-R8) disrupt the starch formation process within the developing kernel. Thus, starch structure is altered and the general packing density of starch granules is reduced, creating chalky portions of kernels with associated changes in physicochemical properties.

Previous research conducted in controlled-air chambers has shown that increasing nighttime air temperatures (defined as those occurring between 8 p.m. and 6 a.m.) during certain kernel reproductive stages was strongly correlated to increasing levels of chalkiness and reduced HRYs, but the degree of susceptibility was cultivar-dependent. To test these findings in commercial practice, field data were collected from six cultivars grown in 2007 through 2010 at locations from northern to southern Arkansas. The 95th percentile of nighttime air temperatures was used to represent the temperature below which 95 percent of nighttime air temperatures occurred during a reproductive stage. It is noted that the data from 2010 generally represented extreme nighttime air temperatures for the U.S. Mid-South, with historically high chalk levels and low HRYs. Figure 15-1, from this study, illustrates that, in general, as nighttime air temperatures during the R-8 reproductive stage increased, chalk values increased and HRYs correspondingly decreased dramatically, particularly in some cultivars. This appears to be partially related to the fact that earlier kernels fill first and have completed filling by the early R8 crop growth stage. The later kernels fill over a longer period and are smaller, lighter and produce lower HRYs than the first kernels to fill. These later filling kernels are subject to all stresses including high night temperatures over this longer period and are more subject to variation than earlier kernels (see discussion of MC distribution in the “Harvest Moisture Content” section).

The most dramatic impact on milling yield is that peak HRYs, associated with harvest MC levels corresponding to maximum milling yield (see below), can be reduced substantially when high nighttime air temperatures occur during grain filling. This effect can help explain previously inexplicable differences in milling yield. Figure 15-2 provides such an example, in which peak HRYs of the same cultivar, grown during 2008 at two Arkansas locations (Pine Tree in the northern and Stuttgart in the southern parts of the state), were as much as four percentage points different; this difference was attributed to the effect of higher nighttime air temperatures during R8 at Stuttgart.

Of additional note, strong correlations between many compositional/functional properties and nighttime air temperatures during kernel development were noted as part of the above study. Of particular relevance to milling characteristics, brown rice total lipid content, reasoned to be an indicator of the thickness of overall rice kernel bran layers, was shown to linearly increase with increasing nighttime air temperatures, thus impacting the duration required to mill kernels to a specified DOM level. This not only

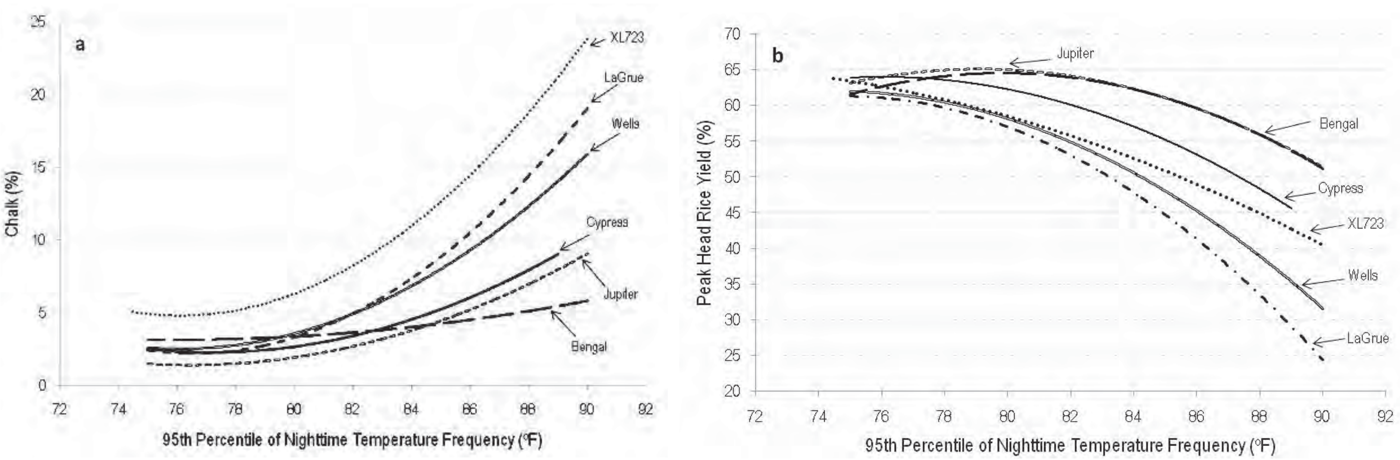

Figure 15-1. **Relationships of chalk (a) and peak head rice yields (b) and the 95th percentiles of nighttime air temperature frequencies during the R8 stages of the indicated cultivars grown during 2007, 2008, 2009 and 2010. Source: Lanning et al., 2011.**

affects the throughput of commercial mills, but also impacts laboratory assessment of milling yield and the equitable comparison of HRYs among samples; please see Chapter 14.

This recent research has shown, at both laboratory and field levels, that HRY is inversely affected by nighttime air temperatures during the grain filling stages of reproductive growth. The research has also shown that the effects of nighttime air temperatures reach beyond milling yields and may be responsible for inexplicable processing variability sometimes purported in Mid-South rice.

Harvest Moisture Content

Head rice yield typically varies with the MC at which rice is harvested. Research in Arkansas has reported that the peak HRY, under Arkansas weather conditions, is attained at a harvest MC of approximately 19 to 21 percent for long-grain cultivars and 22 to 24 percent for medium-grains. Reports from Texas indicate that HRY peaked shortly after "maturity" and declined sharply thereafter. Harvesting at MCs greater than or less than optimal can result in decreased HRY, as illustrated in Figure 15-3; the causes are explained as follows.

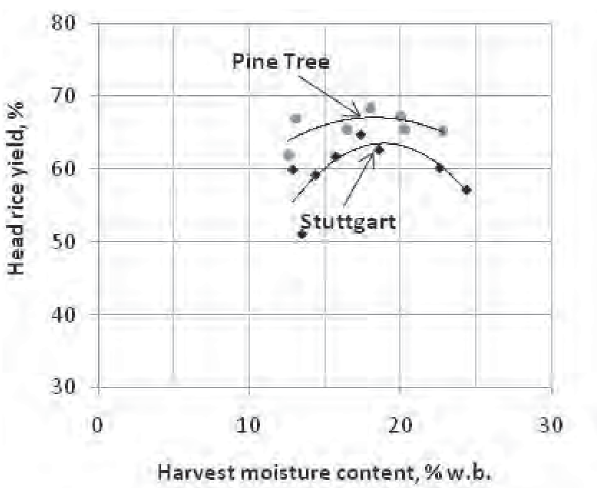

Figure 15-2. Difference in head rice yields of long-grain cultivar Wells harvested over a range of moisture contents at northern (Pine Tree) and southern (Stuttgart) locations in Arkansas during 2008. The difference in peak head rice yields between the two lots is attributed to elevated nighttime air temperatures that were observed in Stuttgart during the grain-filling stages compared to Pine Tree.

As rice matures, kernels on a panicle exist at very different MCs, representing various maturity and kernel strength levels. An example of this is illustrated in Figure 15-4, which shows that a large spread in individual kernel MCs existed when the average, bulk MC was 22.7 percent. Additionally, the distribution of individual kernel MCs on panicles changes as the bulk MC of a sample changes. For example, individual kernel MC distributions usually have multiple "peaks" when rice is harvested at 16 percent MC or greater, but generally have a single peak at lesser MCs.

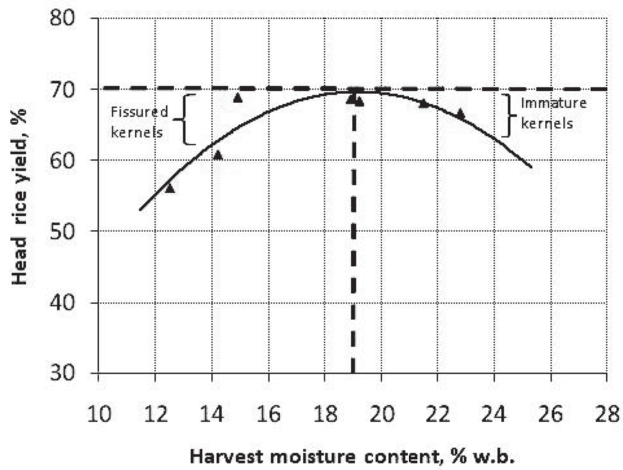

Figure 15-3. Parabolic relationship between head rice yield and harvest moisture content of long-grain cultivar Cypress sampled over a range of harvest moisture contents from Keiser, Arkansas.

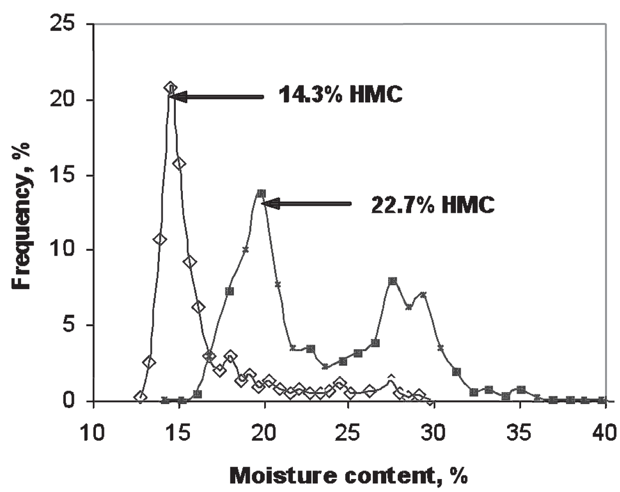

Figure 15-4. Individual kernel moisture content distributions within panicles (composite of kernels from five panicles) of Bengal rice at average harvest moisture contents (HMCs) of 22.7% and 14.3% from Stuttgart, Arkansas.

Source: Bautista and Siebenmorgen, 2005.

At lower bulk MCs, there is usually only a single peak, yet there is typically still a large range in kernel-to-kernel MCs, as is shown in Figure 15-4, for rice at a bulk MC of 14.3 percent. Thus, at any given point in time during the harvest season, some kernels on a panicle may be at much different MC than others and thus will respond differently to ambient air changes.

Individual kernel MC distributions can be used to explain milling yield changes throughout a harvest season by indicating the percentage of "immature" kernels, often considered as those kernels with MCs greater than 22 percent, as well as the percentage of "dry" kernels, often taken as those kernels with MCs less than 14 percent. Immature kernels, illustrated in Photo 15-2, can be a source of milling yield reduction due to the fact that these kernels are typically weak in structure and often break during milling. Rapid rewetting of low-MC kernels, such as would occur through exposure to rain or ambient air relative humidities greater than approximately 80 to 85 percent, typically cause dry kernels to expand rapidly at the kernel surface. However, because an extended duration is required for the moisture to migrate inward, the kernel center cannot immediately expand, creating stress differentials from the kernel surface to the core that ultimately result in material failure and fissures. Fissured kernels, as illustrated in Photo 15-3, typically break apart during milling, drastically reducing HRY.

Photo 15-2. **Illustration of immature kernels, on the panicle (left) and after harvest and hulling (right), which are generally weak in structure and prone to breaking.**

Photo 15-3. **Illustration of a kernel fissured due to rapid moisture adsorption.**

Figure 15-5 shows that the percentage of fissured kernels in samples increases approximately exponentially as the MC at which rice is harvested decreases. As rice dries in the field, the percentage of kernels with MCs less than 14 percent increases dramatically (Figure 15-6), thus exposing increasing numbers of dry kernels to rapid moisture adsorption conditions. The propensity for kernels to fissure due to moisture adsorption increases as the kernel MC decreases. It is to be noted that the rate of fissured kernel percentage increase (Figure 15-5) is not always perfectly correlated to the percentage of low MC kernels, since fissuring by moisture adsorption is dependent on moisture being supplied by the environment in some manner, such as precipitation or high relative humidity air.

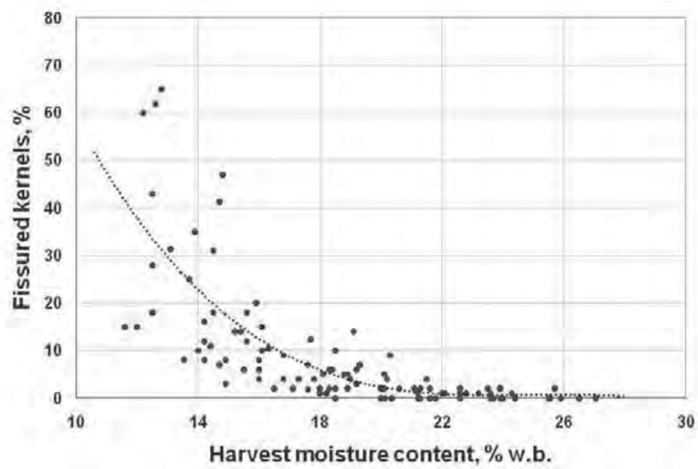

Figure 15-5. **Fissured kernel percentages as a function of harvest moisture content.**
Source: Bautista et al., 2009.

An example of the relationship between HRY and individual kernel MC distributions is given in Figure 15-6. The HRY versus harvest-MC curve of Figure 15-6 indicates a peak HRY at approximately 20 percent harvest MC. The decline in HRY at low harvest MCs corresponds to the increasing percentage of kernels with MCs less than 14 percent; such kernels would likely be fissured due to rapid moisture adsorption.

It is noted that in some cases, very good HRYs have been reported even when rice was harvested at relatively low MCs. Though this is sometimes possible, due to lack of precipitation and low relative humidities during the harvest season, it is not the long-term rule. If rice is allowed to dry in the field to MCs less than 14 to 15 percent, a short period of aggressive moisture adsorption conditions prior to harvest can rapidly and dramatically decrease HRYs.

Figure 15-6 also shows that HRYs of long-grain rice decline at harvest MCs greater than the peak of 20 percent. This is likely due to the increasing presence of thin, immature kernels, illustrated in Figure 15-6 by the curve depicting the percentage of kernels with MCs greater than 22 percent. Research has shown that these thin kernels often break during milling.

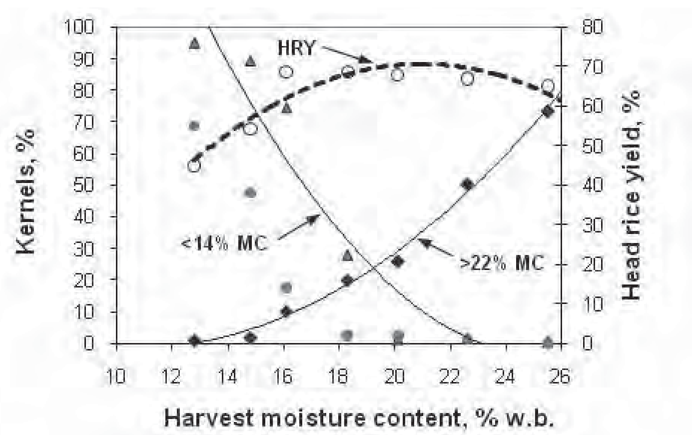

Figure 15-6. Relationships of percentages of kernels at moisture contents (MCs) >22% or <14% and head rice yields (HRYs) to harvest MCs for long-grain cultivar Drew harvested at Keiser, Arkansas. Source: Bautista et al., 2009.

Trends in HRY across harvest MCs were studied over a five-year period for multiple cultivars and locations in Arkansas. Most of these trends were parabolic in form, similar to that indicated in Figure 15-6. Such trends allowed the harvest MC at which HRY peaked to be estimated. It is from this study that the optimum harvest MC for maximizing HRY was reported to be 19 to 21 percent for long-grain cultivars and 22 to 24 percent for medium-grains, under Arkansas weather conditions. Of confirming note is that for California conditions, recommendations call for harvesting medium-grain cultivars at MCs greater than 21 percent.

Based strictly on maximizing HRY, it is generally recommended to harvest rice at these optimal MCs. However, when considering that drying costs generally increase dramatically with harvest MC, the economic optimum harvest MC may be slightly less than the optimal MC for maximizing HRY, depending on drying charges and the relative value of head rice to brokens. Please see the relevant article in the References.

Other Production Factors

Other production factors can also impact milling yield and quality. For example, diseases such as rice blast can cause milling yield reductions. For example, blast was reported to have significantly reduced HRYs by 7 and 12 percentage points in a long-grain and medium-grain cultivar, respectively, grown in Arkansas. Kernel smut disease anecdotally reduces milling yield and can sufficiently discolor rough rice to create quality reductions during parboiling. Field insects can also have detrimental effects on rice quality. Most notable is the stink bug, which bores into the kernel during development, resulting in a black spot on the kernel known as "peck." Such kernels are typically removed after milling using color sorters.

The amount and timing of nitrogen fertilizer applied to rice during growth can impact milling yields. Greater nitrogen application rates at the beginning of kernel development are generally considered to increase HRY. One researcher surmises that a decline in HRY associated with reduced nitrogen application was a result of either decreased integrity of protein structural components of the rice kernel or of faster maturation and drying. Other data shows that top-dressing nitrogen fertilizer at heading resulted in increased protein content for all cultivars tested and increased HRY for four of five cultivars evaluated, with the outlier being a cultivar with known high HRY potential.

Summary

In summary, any factor that causes a reduction in the strength of kernels, and consequently the ability of kernels to withstand the forces imparted during hulling and milling, will impact milling yield. In this chapter, high nighttime air temperatures during grain filling and the moisture content at which rice is harvested are detailed in terms of impact on milling yield. Other production factors, including diseases and nitrogen application rates, can also have significant impacts on milling yields and quality. All of these factors can have milling yield implications, with their mode of impact being different. For example, nighttime air temperatures during grain filling can produce kernel chalkiness, which reduces kernel strength. Additionally, harvesting at very high MCs can produce large percentages of thin, immature kernels, whereas at low MCs, large percentages of fissured kernels can result from rapid moisture adsorption; both factors dramatically reduce kernel strength. Because of the importance of milling yields in the rice industry, these production factors can have significant economic implications in terms of economic value.

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