Chapter

15

Production Factors Impacting Rice Milling Yield

Terry Siebenmorgen, Brandon Grigg, Paul Counce and Jarrod Hardke

Chapter 14 addressed the general procedure for conducting a laboratory milling analysis and factors that impact the measurement of milling yields, 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. Minute 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.

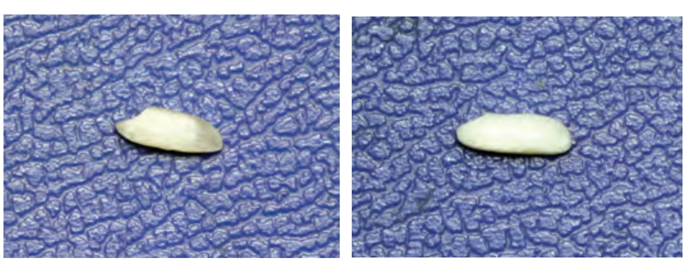

Photo 15-1. Illustrations of chalky kernels. Chalk appears opaque white and may affect a particular region of a kernel (left) or the entire kernel (right).

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.

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 ambient 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.

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 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.

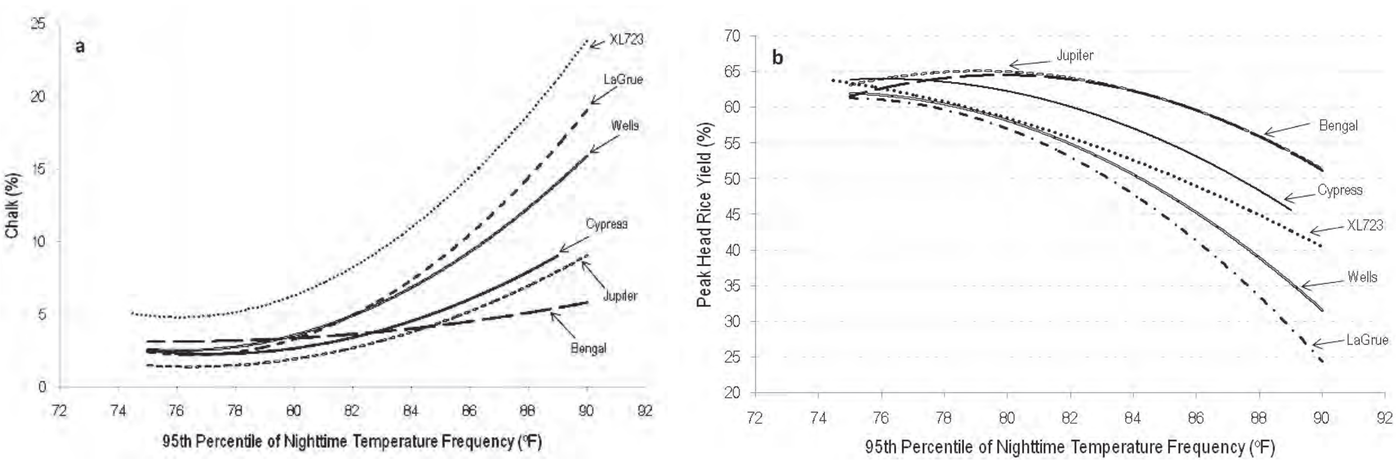

Figure 15-1. Relationships of chalk (a) and peak head rice yields (b) and the 95th percentiles of nighttime air temperature frequencies during the R8 stages of the indicated cultivars grown during 2007, 2008, 2009 and 2010. Source: Lanning et al., 2011.

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.

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 of 'Bengal' medium-grain rice 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. 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

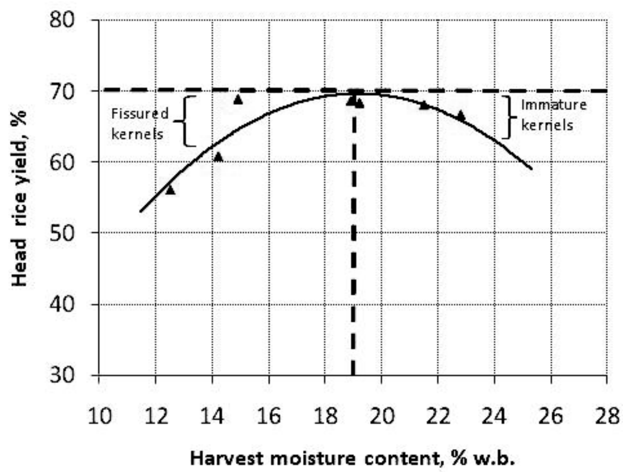

Figure 15-3. Parabolic relationship between head rice yield and harvest moisture content of long-grain cultivar Cypress sampled over a range of harvest moisture contents from Keiser, Arkansas.

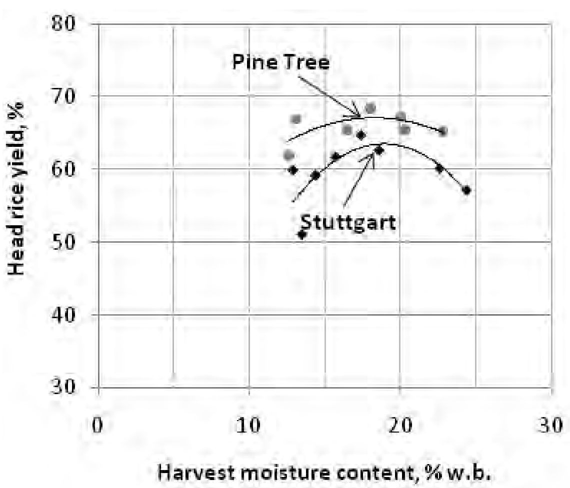

Figure 15-2. Difference in head rice yields of long-grain cultivar Wells harvested over a range of moisture contents at northern (Pine Tree) and southern (Stuttgart) locations in Arkansas during 2008. The difference in peak head rice yields between the two lots is attributed to elevated nighttime air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

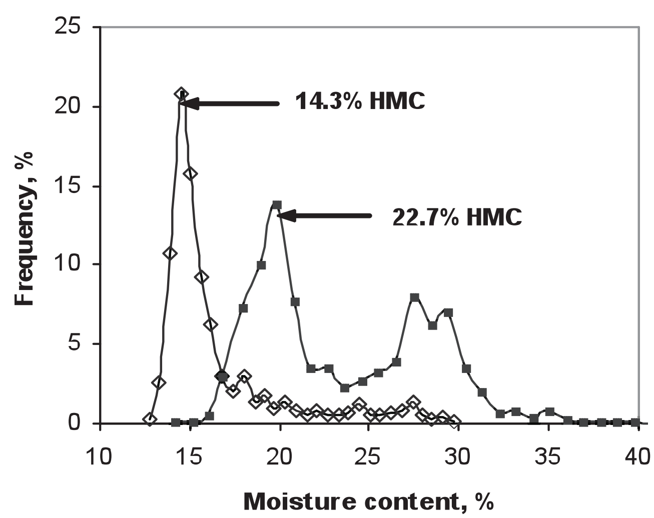

Figure 15-4. Individual kernel moisture content distributions within panicles (composite of kernels from five panicles) of Bengal rice at average harvest moisture contents (HMCs) of 22.7% and 14.3% from Stuttgart, Arkansas.

Source: Bautista and Siebenmorgen, 2005.

"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.

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.

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.

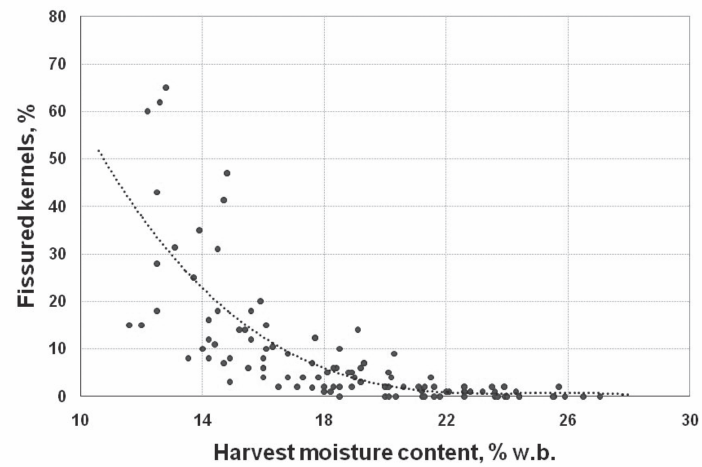

Figure 15-5. **Fissured kernel percentages as a function of harvest moisture content.**

Source: Bautista et al., 2009.

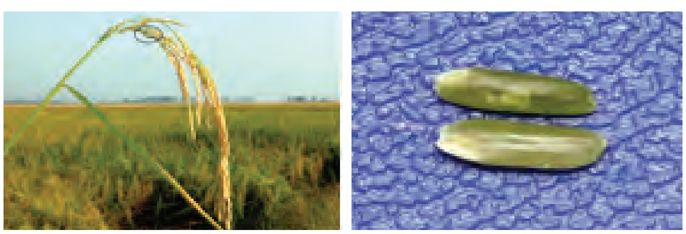

Photo 15-2. **Illustration of immature kernels, on the panicle (left) and after harvest and hulling (right), which are generally weak in structure and prone to breaking.**

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

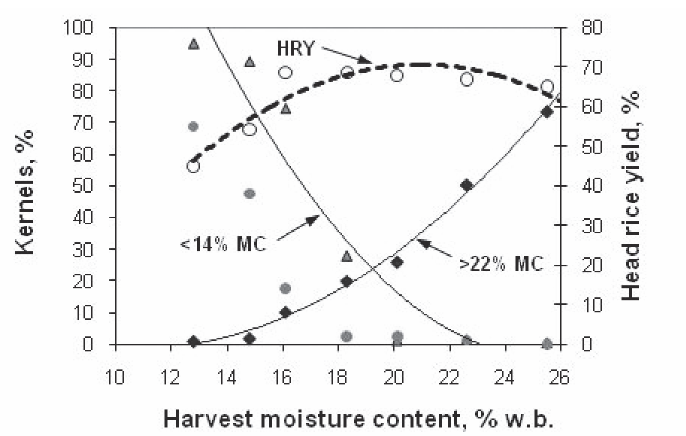

Figure 15-6. **Relationships of percentages of kernels at moisture contents (MCs) >22% or <14% and head rice yields (HRYs) to harvest MCs for long-grain cultivar Drew harvested at Keiser, Arkansas.**

Source: Bautista et al., 2009.

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.

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. Candole et al. 2000 reported that blast 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 surmised 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 implications in terms of economic value.

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Chapter

16

Fundamentals of On-Farm Rice Drying and Storage

Sammy Sadaka and Jarrod Hardke

Arkansas rice producers are increasingly adopting the use of on-farm drying and storage facilities. Quality is the major factor affecting the market value of rice, and proper management of rice dried and stored on-farm is essential to maintaining high quality rice. Immediately following harvest, rice quality is typically at its peak. The final quality of rice ready to market is sensitive to all post-harvest processes, such as drying, handling, storage and milling. On-farm rice drying and storage has the potential to increase harvest efficiency, reduce harvesting delays and provide more control over grain quality, all of which contribute to overall market/delivery time flexibility.

Management Key

Follow the "50-50 Rule" and do not attempt to dry grain when the temperature is below 50 degrees or when the humidity is above 50 percent.

Tips for Rice Drying

The goal of rice drying is to reduce grain moisture content to meet the recommended levels for safe, long-term storage. When placed in storage, rice should be dried quickly to a moisture level of about 12 percent to minimize any quality deterioration. Rice drying can be accomplished in bins by blowing large volumes of dry air through the grain (Photo 16-1).

The flow rate and the quality of this air determine the drying duration and the final moisture content of the rice kernels. Air quality typically refers to the equilibrium moisture content (EMC) achievable under the conditions of the air. (Table 16-1). If the EMC of air is 12 percent, then rice moisture will eventually reach 12 percent. It is important to know that a given volume of air has the capability of holding a given amount of moisture. The amount of moisture a volume of air can hold depends on its quality.

Photo 16-1. Grain drying facility.

Therefore, it is possible to increase the drying rate, or force the grains to reach equilibrium with air sooner, by passing larger amounts of air over the grain. High volumes of air are needed to carry the moisture away

Table 16-1. **Long-grain rice equilibrium moisture content.**

		Relative Humidity (%)													
		25	30	35	40	45	50	55	60	65	70	75	80	85	
Temperature	35	9.2	10.1	10.9	11.7	12.5	13.3	14.1	14.9	15.7	16.6	17.6	18.6	19.8	21.3
	40	9.0	9.9	10.7	11.5	12.3	13.0	13.8	14.6	15.4	16.3	17.2	18.2	19.4	20.9
	45	8.8	9.7	10.5	11.2	12.0	12.8	13.5	14.3	15.1	15.9	16.9	17.9	19.0	20.5
	50	8.6	9.5	10.3	11.0	11.8	12.5	13.3	14.0	14.8	15.7	16.5	17.5	18.7	20.1
	55	8.5	9.3	10.1	10.8	11.5	12.3	13.0	13.8	14.5	15.4	16.3	17.2	18.4	19.8
	60	8.3	9.1	9.9	10.6	11.3	12.1	12.8	13.5	14.3	15.1	16.0	16.9	18.1	19.5
	65	8.2	8.9	9.7	10.4	11.1	11.9	12.6	13.3	14.1	14.9	15.7	16.7	17.8	19.2
	70	8.0	8.8	9.5	10.3	11.0	11.7	12.4	13.1	13.8	14.6	15.5	16.4	17.5	18.9
	75	7.9	8.7	9.4	10.1	10.8	11.5	12.2	12.9	13.6	14.4	15.2	16.2	17.2	18.6
	80	7.8	8.5	9.2	9.9	10.6	1.3	12.0	12.7	13.4	14.2	15.0	15.9	17.0	18.3
	85	7.6	8.4	9.1	9.8	10.5	11.1	11.8	12.5	13.2	14.0	14.8	15.7	16.8	18.1
	90	7.5	8.3	9.0	9.6	10.3	11.0	11.6	12.3	13.0	13.8	14.6	15.5	16.5	17.8
	95	7.4	8.1	8.8	9.5	10.2	10.8	11.5	12.2	12.9	13.6	14.4	15.3	16.3	17.6
	100	7.3	8.0	8.7	9.4	10.0	10.7	11.3	12.0	12.7	13.4	14.2	15.1	16.1	17.4

in a timely fashion when rice is at high moisture levels. Doubling the airflow will typically cut the drying time to about half. It is also possible to add heat to condition the air to a desirable EMC – or to maintain the same level available during the daylight hours. If the EMC of air is greater than 12 percent, then it will not be possible to reduce rice moisture to 12 percent. In this situation, the air can be heated to reduce the EMC to 12 percent. While heating the air typically reduces its EMC and increases its moisture-holding capacity, it is important to consider the added cost to the drying process. Airflow rates for drying vary from a low of 1 cubic foot per minute (CFM) per hundredweight (cwt) to a high of 100 or more CFM per cwt. The recommended minimum airflow rates for different moisture contents levels are shown in Table 16-2.

Management Key

One way to reduce drying time is to increase airflow, but this may not be the most energy efficient manner of drying.

Air may be delivered to the drying bin by a centrifugal fan or an axial flow fan. Manufacturers provide several models of these fans to meet the needs of field applications. The two critical characteristics of fans are flow rate (CFM) and static pressure expressed in inches of water.

Table 16-2. **Recommended minimum airflow rates for different moisture content levels.**

Moisture Content	Airflow Rate
%	CFM†
13-15	1-2
15-18	4
18-20	6
20-22	8
> 22	12

† Cubic foot per minute per cwt.

The axial fan (Photo 16-2) utilizes a propeller wheel mounted directly to the motor shaft; thus, it develops a very high tip speed and is often noisy. Axial fans are cheaper and are most often used where high airflow rates, at low static pressures, are needed.

Centrifugal fans (Photo 16-3) provide a relatively constant air volume over a wide range of static pressures. Centrifugal fans are more expensive than axial fans and can be purchased as a direct-driven or a belt-driven unit. Belt-driven units are more expensive but have a greater life expectancy. Centrifugal fans are highly recommended where high static pressures and less noise are needed.

Practically, most on-farm bins have limited available air capacity. As grain bins are filled and the grain depth increases, it becomes more difficult to move air up through the grain. Additionally, less air will be

Photo 16-2. Axial fan.

Photo 16-3. Centrifugal fan.

available for each bushel of grain in the bin as it becomes full. This is why, initially, bins should not be completely filled with high moisture content grain. Once grain moisture reaches 15 percent or less throughout the bin, the bin filling process may be completed. However, care should be taken not to mix dry grain (less than 15 percent moisture) with moist grain (greater than 18 percent moisture). The reason is that any rewetting after the rice kernel is dried to a level below 15 percent may cause excessive fissuring

Management Key

Dry high moisture rice in shallow depths until 15 percent moisture or less, then deeper depths can be dried.

and reductions in head rice yield (HRY). Rewetting may also occur if moist air is pumped through the grain.

The EMC can be determined by measuring the air temperature and relative humidity. Thermometers, or temperature sensors, are typically used to determine the temperature, while the relative humidity is usually determined by using a sling psychrometer. Sling psychrometers (Figure 16-1) are relatively inexpensive, and they work by first measuring the air temperature with a wet and dry bulb thermometer and then determine relative humidity using a table. One should strive to maintain a steady EMC that is very close to the storage moisture content. There are typically numerous days during the harvest season when the EMC is at, or below, the desired level without adding any heat.

Figure 16-1. Sling psychrometer.

As mentioned earlier, it may be necessary to add some heat to condition the air to a desirable EMC during night or damp weather conditions. If heat is not available, it may be better to turn the fans off at night instead of pumping in moist air. Pumping in air at night may actually add moisture to the bin that will have to be removed later. This increases drying costs and may result in significant HRY reductions. Fans should be turned off almost any time the EMC of the air is greater than that of the grain. The exception might be for very damp rice – to avoid heat buildup.

Management Key

Exercise extreme caution when drying air temperature exceeds 100°F.

As the bin is being filled, grain should not be allowed to cone. If coning occurs, the large particles will migrate to the outside and small particles (flour and trash) will remain at the center of the cone

(Figure 16-2). This results in a non-uniform distribution of voids among the grains, which leads to uneven air flow distribution through the grain. Most of the air will pass up the outside of the bin through the larger and cleaner grain. A level height should be maintained throughout the filling process. Once the separation occurs, it is hard to remedy later – even if the bin is later shoveled level.

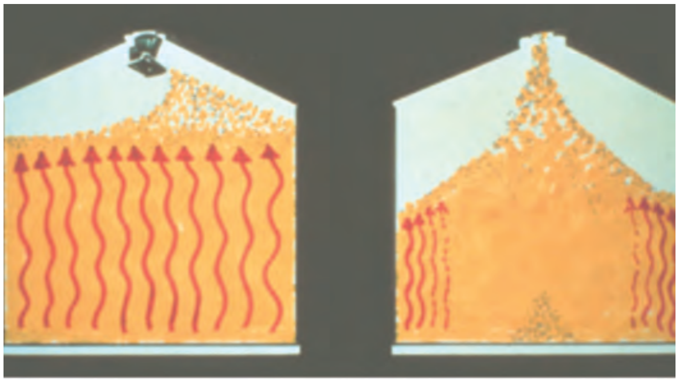

Figure 16-2. Grain bin filling and coning.

A stirring method is needed in grain drying as well. Stirring facilitates the drying process by lifting grain from the bottom to the top. It also facilitates aeration and removes hot spots; therefore, it helps maintain grain in store and speeds the drying process. Stirring also makes the grain flow extremely well which improves grain handling. This loosens the grain so that additional air may be moved up through the grain. On the other hand, there is a concern among some producers that the stirring may grind away the rice if left on. There is no research evidence to support this concern. There will usually be a small amount of flour-like substance formed around the auger's top.

Tips for Rice Storage

Once rice has been successfully dried to about 12.5 percent moisture throughout the storage container, the bin can be filled and the surface leveled. After this has been accomplished, aeration is needed to limit the amount of heat generated by bulk stored rice. Aeration with ambient (outside) air may be needed for the next few weeks, but only when humidity is below 60 percent and the air temperature is 50 to 60°F. Do not operate fans when air temperatures are below 32°F.

Bulk rice stored in bins should be monitored at least once a week for variation in temperature or moisture. Moisture migration can occur in bins with improper temperature control and can result in deterioration or spoilage of kernels. Periodic aeration may be necessary to counter extreme temperature changes during storage.

Additional information on rice drying and storage can be found here: https://www.uaex.edu/farm-ranch/crops-commercial-horticulture/Grain_drying_and_storage/rice_drying_and_storage.aspx.