Chapter

14

Laboratory Measurement of Rice Milling Yield

Terry Siebenmorgen

Laboratory milling systems are used throughout the rice industry to 1) estimate the milling yield that may be expected of rice lots when milled in large-scale milling systems and 2) produce milled rice samples from which visual, functional, sensory and nutritional assessments of the rice lot can be made. This chapter presents factors that can affect the laboratory measurement of rice milling yield, focusing on the use of the McGill #2 rice mill, a popular laboratory-scale mill used in the United States. Factors that affect the performance of this mill are detailed, as are properties of the rice that impact milling yield measurement. In particular, the degree of milling (DOM), the degree to which bran is removed from kernels during milling, is discussed in terms of its measurement and its effect on milling yield parameters.

Definitions

Definitions are provided to clarify terms commonly used in reference to milling yield measurement.

Rough rice is unprocessed rice with hulls intact; also often referred to as "paddy."

Brown rice is rice that remains once hulls have been removed from rough rice.

Milled rice is rice that remains once brown rice has been milled to remove the germ and a specified amount of the bran; this fraction includes both broken and intact kernels (head rice).

Milled rice yield (MRY) is the mass percentage of rough rice that remains as milled rice; often referred to as the "total" yield. Milled rice yield is calculated as:

$$MRY = \frac{\text{Milled rice mass}}{\text{Rough rice mass}} \times 100$$

Head rice comprises milled rice kernels that are at least three-fourths the original length of the kernel; often referred to as "whole" kernels or "fancy."

Head rice yield (HRY) is the mass percentage of rough rice that remains as head rice, calculated as:

$$HRY = \frac{\text{Head rice mass}}{\text{Rough rice mass}} \times 100$$

Milling yield is a term that is often referred to as "milling quality"; this term is often used in reference to HRY but also is routinely expressed as a ratio, with the numerator being the head rice yield and the denominator the milled rice yield. For example, a milling yield of 55/70 would indicate a HRY of 55 percent, a MRY of 70 percent and a brokens yield of 15 percent (the difference between MRY and HRY).

Degree of milling (DOM) is the extent of bran removal from brown rice.

Moisture content (MC[1]) is the mass percentage of a rice sample that is water (this is the definition of "wet basis" moisture content, which is predominantly used in the rice and grain industry), calculated as:

$$MC = \frac{\text{Mass of "wet" rice - Mass of completely dry rice (0\% MC)}}{\text{Mass of "wet" rice}} \times 100$$

[1] All moisture contents in this chapter are expressed on a wet basis.

Equilibrium moisture content (EMC) is the moisture content to which rice will equilibrate after an extended period of exposure to air at set temperature and relative humidity conditions; this is the state of the rice in which there is no moisture transfer between the rice and surrounding air.

Introduction

Laboratory-scale milling systems have long been used to estimate the milling performance that can be expected of a rice lot when milled in large, industrial-scale systems. Laboratory systems comprise equipment that first removes the hull from the rough rice kernel, producing brown rice. Brown rice is typically milled to remove the germ and bran layers, leaving milled rice. The predominant measurements of rice milling yield are made using the endosperm, or milled rice kernel. The degree to which the bran layers are removed from brown rice, the DOM, plays a significant role in determining overall milling yield and functional quality of milled rice.

Milling yield is quantified using two parameters, the milled rice yield (MRY) and head rice yield (HRY). Milled rice is the component of rough rice produced by removing the hulls, germ and desired amount of bran; milled rice includes intact and broken kernels. Milled rice yield is calculated as the mass fraction of rough rice remaining as milled rice. Broken kernels, defined by the USDA as kernels that are "less than three-fourths of whole kernels," are typically removed from milled rice. The remaining "whole" kernels are generally known in the milling industry as "head rice" and are those milled kernels at least three-fourths the original length of the kernel. Head rice yield is the mass fraction of rough rice that remains as head rice.

Both MRY and HRY are highly dependent upon the physical integrity of rough rice kernels, as well as the extent to which bran is removed during milling. In most markets, broken kernels are valued at only 50 to 60 percent that of head rice, thus underpinning the tremendous impact that HRY has on the economic value of a rice lot, and also justifying the need for laboratory milling systems to accurately determine this important parameter.

Laboratory Assessment of Milling Yield

The Federal Grain Inspection Service (FGIS) provides a methodology for conducting a milling yield analysis, which calls for using specified equipment/settings and a representative 1-kg sample of rough rice to be processed. It is common for practitioners to deviate from the FGIS procedure in terms of the equipment used and the amount of rough rice processed.

A typical laboratory huller is illustrated in Photo 14-1. The FGIS methodology specifies roller clearances for a McGill huller that prevent all rough rice kernels from being hulled in a single pass; setting the rollers to hull all kernels, particularly thin kernels, in a single pass will cause undue breakage. The *FGIS Rice Inspection Handbook* states that "after shelling, the sample contains 2 to 3 percent paddy kernels in long-grain rice or 3 to 4 percent paddy kernels in medium- or short-grain rice." Typically, roller clearances are set to allow at least 4 to 5 percent of long-grain rough rice kernels to be unhulled; this percentage varies slightly with the cultivar or cultivar mix being analyzed. In commercial mills, unhulled kernels from a huller are separated from brown rice and conveyed to another huller for a second hulling pass. In laboratory practices, the resulting brown rice kernels

Photo 14-1. A laboratory-scale rice huller (THU35B, Satake, Hiroshima, Japan).

and unhulled kernels from a huller are typically left mixed and subsequently milled together.

The resulting brown rice is milled, which for FGIS procedures constitutes using a McGill #3 mill (Rapsco, Brookshire, Texas, USA). The McGill #3 is designed to mill the brown rice produced by a 1-kg rough-rice sample. However, this amount of rice is often greater than is available, especially in research settings. Thus, smaller-scale mills are often substituted for laboratory use. Several companies have developed laboratory mills capable of milling lesser quantities of rice. Perhaps the most commonly used laboratory-scale mill in the U.S. rice industry is the McGill #2 mill (Rapsco, Brookshire, Texas, USA), illustrated in Photo 14-2. This batch-type mill has gained popularity over the McGill #3 because of its lower initial cost, as well as its lower electrical-power and sample-size requirements. Andrews et al. 1992 reported that the McGill #2 mill may be used with rough rice sample quantities as small as 125 g (yielding a resultant brown rice mass of approximately 100 g) and that settings could be adjusted to produce results equivalent to the McGill #3.

Photo 14-2. **A laboratory-scale rice mill (McGill #2, Rapsco, Brookshire, Texas, USA).**

After milling, broken kernels are then separated from head rice by some means. A common laboratory method for separating broken kernels from head rice employs a “sizing device,” often referred to as a “shaker table.” Such a device, illustrated in Photo 14-3, comprises two oscillating, inclined, indented plates with indentions sized according to the type of rice (short-, medium- or long-grain) to be sorted. The plate oscillation causes the greater-mass head rice to be conveyed ahead of the lesser-mass broken kernels. Head rice falls into a collection pan after passing over the second plate. The operator will terminate the sizing device operation when all head rice is collected and before brokens enter the collection pan.

Recent advances in imaging technology have allowed the introduction of laboratory instruments that estimate the percentage of head rice and broken kernels in a milled-rice sample based on kernel dimensional analysis rather than physical separation. While these imaging systems are effective in rapidly estimating HRY, separation of broken kernels is often necessary in laboratory settings in order to isolate head rice required for other quality and functionality assessments. Additionally, the cost of such imaging systems may necessitate the traditional sizing-device approach.

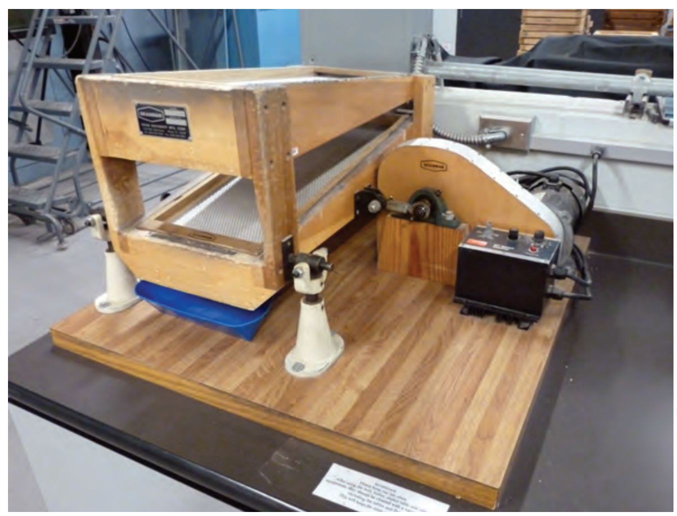

Photo 14-3. **A laboratory-scale rice sizing device (Model 61, Grain Machinery Manufacturing Corp., Miami, Florida, USA).**

It should be noted that milled rice is very susceptible to fissuring due to rapid moisture gain or loss, which is determined by the gradient in moisture content between that of the kernels and the rice EMC associated with the surrounding air temperature and relative humidity. Fissured kernels may break upon handling and thus artificially reduce the number of head rice kernels. As reported by Siebenmorgen et al. 2009, milled rice kernels may fissure after very short periods of exposure to air with low relative humidities (less than 30 percent) and/or high temperatures; these conditions would cause rapid moisture loss from kernels. Conversely, fissures can also be created by conditions that cause rapid moisture addition to kernels and are thus associated with high relative humidities (greater than 75 percent) and/or low temperatures. The MC of the rice also plays a role in this moisture gain or loss. While milling is typically conducted at rough rice MCs of approximately 12.5 percent (see below), sometimes samples are supplied at MCs significantly different than this level. In these cases, it is particularly important to be cognizant of the air conditions to which milled rice is exposed. The greater the gradient between the rice MC and the EMC associated with the air, the greater the rate and the extent of kernel fissuring. For example, rice samples with greater MCs will be more susceptible to fissuring in dry-air environments than samples with lesser MCs. The reverse holds true regarding lesser-MC rice samples in very humid environments. Ideally, milled rice fissuring will be minimized or totally prevented if laboratory air relative humidity is maintained between 30 and 75 percent under laboratory temperatures of 70°F. If very low or high laboratory air relative humidities are experienced, milled rice exposure to the air should be minimized. A more complete treatment of this topic, detailing the fissuring rates and extents under a wide range of air temperatures and relative humidities, is provided by Siebenmorgen et al. 2009.

As mentioned previously, a sample's DOM reflects the degree to which bran layers are removed from the brown rice kernel or, conversely, the amount of bran remaining on the milled kernel after milling. This is an important concept, because DOM is known to affect the rice milling yield indices of MRY and HRY, as well as processing characteristics, including cooked rice texture and viscosity parameters. Establishing a target DOM varies with end-use application. For example, ready-to-eat cereal manufacturers typically specify more lightly-milled rice than that used for household cooking applications.

The current FGIS approach to establishing a DOM level of milled rice is to use a classification scale. Based on visual grading, primarily of milled rice kernel color, a sample's DOM is classified as either reasonably well-milled (darkest in color), well-milled, or hard-milled (lightest in color). This classification system is rather subjective and may be skewed by other factors, such as preharvest and postharvest environmental conditions, which can affect kernel color. Instrumental optical or color measurements, such as those obtained by the Satake Milling Meter (Satake Corporation, Hiroshima, Japan), the Kett Whiteness Meter (Kett Laboratory, Tokyo, Japan) or the Hunter Colorflex System (Hunterlab, Reston, Virginia, USA) can minimize subjectivity in color assessment, but to date, instrumental readings have not been standardized to the FGIS DOM categories, nor do they address environmental effects on color.

Surface Lipid Content as a Measure of Degree of Milling

A more objective assessment of DOM can be made by quantifying the surface lipid content (SLC), which is an indication of the amount of bran remaining on milled rice kernels. Because rice bran is approximately 20 percent oil or lipid, measuring the mass of lipid remaining on the surface of kernels after milling indicates the amount of remaining bran. Surface lipid content is the mass percentage of the milled head rice sample that is lipid remaining on the surface of milled rice kernels. As milling progresses and DOM is said to increase, SLC decreases, corresponding to decreasing bran on milled rice kernels. Correspondingly, as SLC decreases, not only bran but also some endosperm is removed and conveyed away in the bran stream, thereby decreasing the mass of milled rice and head rice, which will decrease MRY and HRY.

Surface lipid content may be measured by conventional lipid extraction procedures, such as those using Goldfisch or Soxhlet methods. However, these methods are costly, requiring labor-intensive sample preparation and chemical reagents and do not lend well to online use in a production or high-throughput lab environment. Therefore, much of the rice industry is moving toward more rapid, indirect methods for estimating SLC, the most common of which is near-infrared (NIR) spectroscopy (Saleh, et al. 2008).

During the milling process, there are several factors that influence the degree to which individual kernels, which collectively represent the bulk population of kernels, are milled. Among these are kernel shape characteristics and the MC and temperature of the rice at the time of milling. Additionally, laboratory mill settings can play a large role in determining the

DOM. These factors are discussed in greater detail in the following paragraphs.

Factors That Impact Degree of Milling

There are many factors that impact the rate at which the SLC of a sample decreases as milling progresses, and the consequent effect on MRY and HRY. The **duration that rice is milled** in a laboratory mill is one such factor. Figure 14-1 shows that as milling duration increases, SLC of the head rice decreases, as do MRY and HRY. This is logical because as milling progresses, more of the surface of both head rice and broken kernels is removed, which would decrease the mass of both fractions. The same trend holds true for increasing **pressure within the milling chamber** by increasing the mass attached to the milling lever arm of the mill. Andrews et al. 1992 showed that more pressure applied to the rice in the milling chamber results in more thorough milling, reducing the remaining mass of whole and broken kernels. This study also showed that **initial ample mass**, while having a significant effect on milled rice yields, was not a major factor influencing HRY. It is to be noted, however, that physical limitations of the McGill #2 milling chamber require a rough rice sample size of at least 125 g. Andrews et al. showed that starting with a sample size of only 100 g of rough rice, and thus feeding a brown rice mass of approximately 80 g into the McGill #2 mill, caused a "bottoming out" of the mill lever arm during milling, thus providing insufficient milling action.

The rice MC at the time of milling plays a significant role in the bran removal rate. Several studies have shown that for a set milling duration, as milling MC increases, DOM increases and HRY decreases, since bran is removed at a greater rate as MC increases. An example of this important effect is shown in Figure 14-2, which shows that increasing the MC of rice samples from 9.5 to 14 percent resulted in a HRY reduction ranging from 13 to 17 percentage points, depending on the milling duration. It is to be noted, however, that much of this HRY difference was the result of greater DOM of the greater-MC samples. Reid et al. 1998 and Lanning and Siebenmorgen 2011 also showed that milling MC significantly influenced the rate at which HRY changed with respect to SLC.

Brown rice temperature at the time of milling also impacts bran removal rate. Archer and Siebenmorgen 1995 found that when milling in a McGill #2 mill for set durations, as the initial rice temperature decreased, MRY and HRY increased, indicating greater bran removal resistance, greater SLC levels and correspondingly greater milled rice and head rice masses.

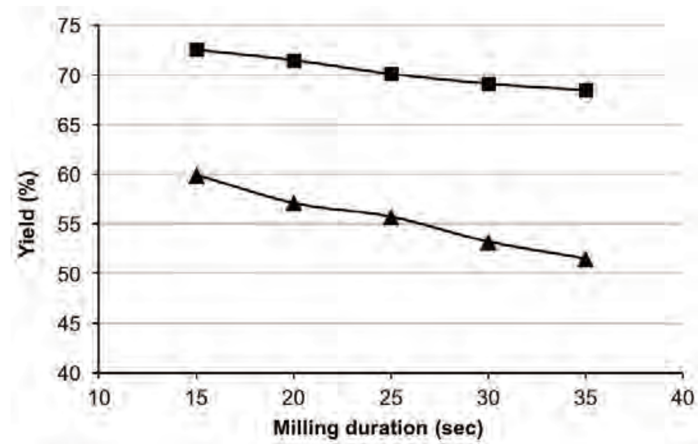

Figure 14-1. Milled rice yields and head rice yields for CL153 rice milled for the indicated durations in a laboratory mill. Also shown are the surface lipid concentrations (SLCs) of each head rice sample.

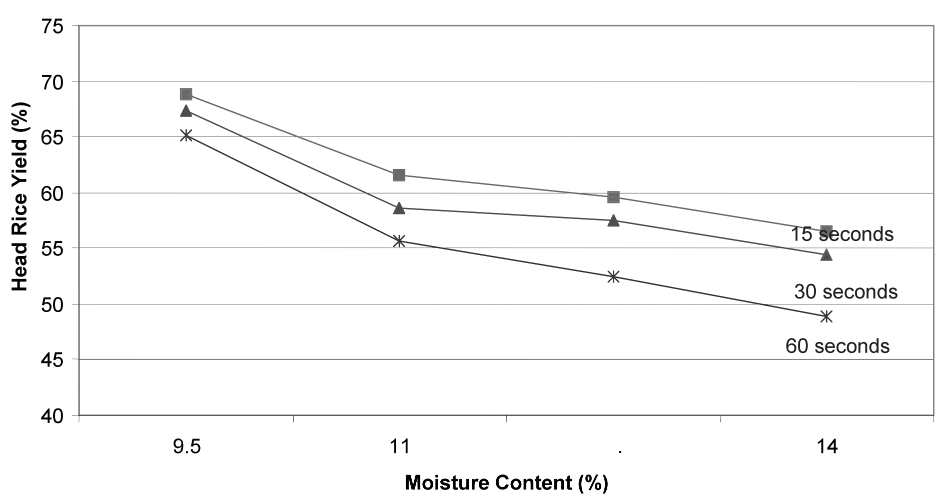

Figure 14-2. Head rice yields attained by milling Newbonnet rice at the indicated moisture contents for the indicated durations. (Source: Andrews et al. 1992)

The differences in milling yield values appeared to be mostly attributable to changes in SLC, since the differences in yields were negated when the milling yield values were adjusted to a constant SLC. Thus, it is recommended to allow laboratory samples to equilibrate to similar temperatures prior to milling.

Additionally, the **rice cultivar or cultivar mix** also affects milling behavior. Rice cultivars inherently differ in physical attributes, including the bran thickness and kernel shape, size and surface topography. These characteristics impact the relative ease with which bran is removed during milling and thus affect the milling duration required to reach a specified DOM/SLC (see relevant articles in the Reference section). For example, cultivars with deep grooves on the kernel surface are likely to have bran remaining in the grooves after milling and, therefore, require more milling pressure or longer milling durations than kernels with smooth surfaces in order to achieve a desired DOM. Milling for longer durations results in greater removal of bran, as well as endosperm, thereby reducing milling yields.

In addition to kernel-surface topography, other cultivar differences can impact milling behavior. It has been reported that hybrid cultivars generally reach a target SLC in a shorter duration than pureline cultivars. "Millability" curves showing first the SLC attained when milled for various durations for the indicated cultivars (Figure 14-3) and secondly the HRYs attained for the various surface lipid contents (Figure 14-4) illustrate differences in milling behavior of cultivars. These differences were attributed to lesser brown rice total lipid content, a presumed indication of a thinner bran layer, as well as greater bran removal rates, in hybrid vs. pureline cultivars.

Figure 14-3 indicates that if milling to a desired SLC of, say, 0.5 percent, Wells required 31 s of milling, whereas XL 723 required only 16 s. Or, alternatively, if a set milling duration of 30 s is used, Wells would be milled to only a SLC of 0.52 percent, whereas XL 723 would be milled to a SLC of 0.29 percent; this difference in milling degree could account for at least

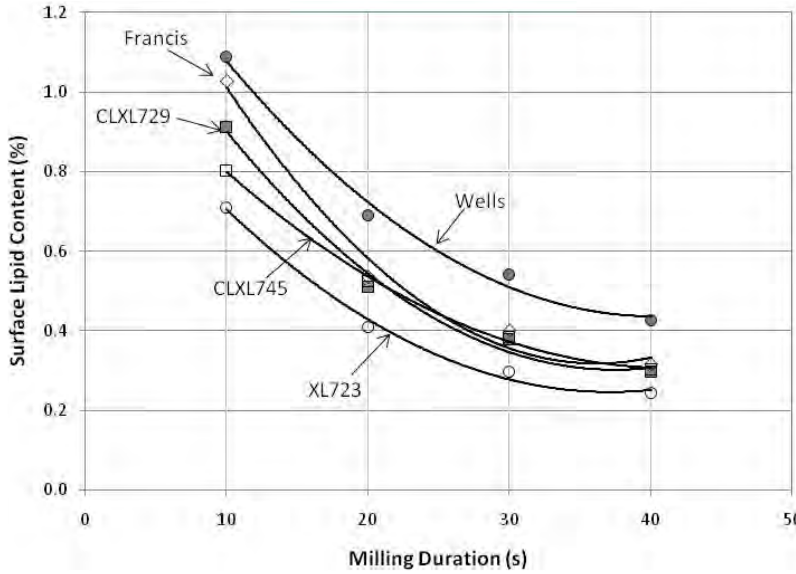

Figure 14-3. **Head rice surface lipid contents of Wells, Francis, XL723, CL XL729 and CL XL745 cultivars after milling at rough rice moisture contents of approximately 12.5% (w.b.) for 10, 20, 30 and 40 s using a laboratory mill. Each data point represents the average surface lipid content measured from three replications of each milling duration.**

(Source: Lanning and Siebenmorgen, 2011).

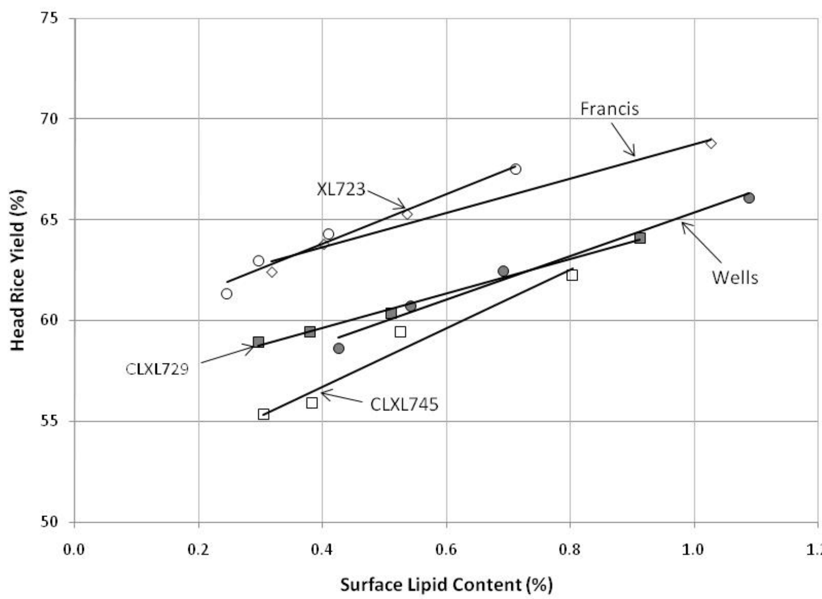

Figure 14-4. **Head rice yield vs. head rice surface lipid content of Wells, Francis, XL723, CL XL729 and CL XL745 cultivars milled at rough rice moisture contents of approximately 12.5% (w.b.) for 10, 20, 30 and 40 s using a McGill #2 laboratory mill. Each data point represents the average of three milling replications.**

(Source: Lanning and Siebenmorgen, 2011).

2.5 percentage points lower HRY in XL 723 than Wells, just due to having milled XL 723 to a greater extent (see below).

Total lipid content of the brown rice of a cultivar can be impacted by nighttime air temperatures during kernel formation; the greater the nighttime air temperatures during kernel formation, the greater the total lipid content was found to be (Lanning et al. 2012). Thus, year-to-year and location-to-location differences within cultivars can be expected.

Accounting for Degree of Milling When Determining Milling Yield

In assessing milling yield, it is important to have an understanding of how the above variables impact milled rice SLC and, in turn, milling yield. As such, SLC should be measured when conducting laboratory milling analyses in order to equitably compare MRY, HRY, and subsequent milled rice functional properties.

To determine the effect that milling to various degrees has on milling yield of a rice lot, subsamples of the lots can be milled for various durations and the SLC, MRY and HRY measured, providing curves as illustrated in Figures 14-3 and 14-4. Figure 14-3 illustrates the rate at which SLC can change with milling duration and shows that SLC of head rice decreases at an exponential rate with milling duration. In turn, Figure 14-4 shows that HRY is directly and linearly correlated with SLC. The slope of the regression curve can vary among cultivars and lots, depending on the aforementioned variables.

Cooper and Siebenmorgen, 2007, evaluated the millability curves (HRY vs. SLC) of 17 rice lots comprising multiple cultivars, harvest years, harvest locations and storage conditions in an attempt to develop a method for adjusting HRY to account for variation in SLC. Across all lots, the average HRY vs. SLC slope was 9.4; i.e., HRY changed by 9.4 percentage points for every 1.0 percentage point change in SLC. In more practical terms, a decrease of 0.1 percentage points in SLC resulted in a decrease in HRY of 0.94, or nearly 1.0 percentage point. A followup study by Pereira et al. 2008 refined this adjustment method by calculating separate slopes for medium- and long-grain cultivars as 8.5 and 11.3, respectively. That is, for long-grain cultivars, prolonging milling to change the SLC from, say, 0.5 to 0.4 percent would reduce HRY by 1.13 percentage points.

It is typically impractical to produce millability curves for samples from every milling lot being considered. However, it is recommended that the SLC of head rice be measured, and realize that when comparing HRYs of milled samples, SLC levels should be similar and that SLC differences account for HRY differences in the amount of generally 1.1 percentage points of HRY for every 0.1 percentage points of SLC in long-grain cultivars.

Impact of Degree of Milling on End-Use Functionality

Laboratory milling systems are often used to produce representative samples of milled and/or head rice from which functional, sensory and nutritional tests can be performed. As with MRY and HRY, most postmilling properties and processes are impacted by the degree to which rice is milled. Since rice protein and lipid contents are greater in the bran than the endosperm, milling effectively alters the relative proximate composition of the milled kernel by increasing starch content and decreasing protein and lipid contents; the degree to which the composition is altered depends on the DOM. While beyond the scope of this chapter, the reader is referred to articles listed in the Reference section that address DOM impact on rice functional, textural and nutritional properties.

Summary

There are many factors inherent to the rice sample being milled, as well as the laboratory rice mill settings used, that impact the resultant milled rice product. This chapter addresses the effects of many of these factors in determining milling yields. The importance of measuring the DOM of laboratory-milled rice cannot be overstated for allowing equitable comparison of milling yields. The impact of milling to various extents, as measured by SLC, on HRY is detailed.

A considerable advancement in laboratory milling systems could be made by incorporating the means to measure DOM during milling in laboratory mills such that samples could be milled for varying durations to achieve a desired SLC level. This would thus account for varying milling rates produced by rice factors known to impact the rate of bran removal.

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