

EVALUATION OF LABORATORY MILLS FOR MILLING SMALL SAMPLES OF RICE

R. C. Bautista, T. J. Siebenmorgen

ABSTRACT. *The International Rice Research Institute (IRRI) Test Tube Mill and the Kett "Pearlest" Polisher were evaluated in terms of milling performance in comparison with a McGill No. 2 Mill. Degree of milling (DOM), evaluated in terms of percent bran removal (the percentage of weight lost during milling) from brown rice, and whole kernel yield (WKY) were compared using sample lots of medium- and long-grain rice at 12 and 15% m.c. (wet basis). The milling effect of each mill on the shape and size of kernels was compared and analyzed using a Satake image analysis system and a video microscope. Degree of milling and WKY versus milling duration curves were determined for the three mills. The removal of bran as the milling duration increased resulted in a linear reduction of WKY for each mill, although the relationship varied for each mill. The type of mill, moisture content of the samples, and milling duration affected WKY. The type of mill and milling duration affected the shape and dimensions of the milled rice kernels. Overall, the IRRI Test Tube Mill performed better than the Kett Polisher and was comparable to the McGill No. 2 Mill.*

Keywords. *IRRI Test Tube Mill, Kett Polisher, McGill No. 2 Mill, Rice bran removal, Head rice yield, Whole kernel yield, Kernel size reduction, Video microscopy system.*

The goals of rice milling are to remove the bran layers and the germ with minimum kernel breakage and to preserve each kernel in its original shape (Webb, 1985). Milling small rice samples for quality analyses has presented problems because of the lack of appropriate laboratory rice mills. Rice samples from breeding lines, ranging from approximately 2.5 to 10.0 g, or even smaller samples obtained from single or multiple panicles are examples of "small" samples. Existing laboratory mills for rice have limited capability to mill small samples; e. g., the McGill No. 2 laboratory mill requires about 120 g of brown rice to properly remove bran from all kernels (table 1). Due to the enormous number of "small" samples being generated from experimental test plots and breeding lines, a laboratory mill that would adequately provide an indication of milling quality would be extremely beneficial to rice breeders, cereal chemists, and physiologists.

IRRI TEST TUBE MILL

The International Rice Research Institute (IRRI) Test Tube Mill was developed to mill very small samples of rice. It emerged from a concept proposed by a rice breeder and was developed by the Agricultural Engineering Department of the IRRI in the early 1970s. This mill is an abrasive type that utilizes an abrasive compound and milling is accomplished by vigorously oscillating tubes containing small samples of rice. It was tested and modified in the mid-1980s to accommodate a higher number of tubes containing smaller mass of samples and milled for shorter durations. Bautista (IRRI, 1987) reported that milling was influenced by the frequency and length of tube oscillation. Using a dye to test the milling degree for a long-grain variety at approximately 13% m.c., a speed of 1750 cycles/min was sufficient to mill a 3-g brown rice sample per tube in 20 min using 12-mm tube oscillation.

Table 1. Milling specifications of the three laboratory rice mills evaluated.

Mill	Sample Size Requirement	Milling Duration	Mode of Milling
IRRI Test Tube Mill	3-g brown rice for each test tube, total of 70 tubes	About 30 min ^[a]	Abrasion (with aluminum oxide) created by oscillating motion
McGill No. 2	120-g brown rice	30 s ^[b]	Friction between kernels
Kett "Pearlest" Polisher	10-g brown rice	30 s ^[b]	Friction by centrifugal action (spinning disc and rubber walls)

^[a] Milling duration is dependent on moisture content, variety, and stroke length and frequency of the mill.

^[b] McGill No. 2 and Kett Polisher are also dependent on moisture content and variety.

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The current IRRI mill uses an abrasive compound (aluminum oxide) that is mixed directly with the rice to provide additional abrasive action for bran removal. The mill essentially comprises two boxes shaken vigorously in opposite directions, with each box holding as many as 70 test tubes (7 mL). Each test tube typically contains approximately 3 g of brown rice and about 4 g of aluminum oxide. The milling duration required to remove bran varies with variety and moisture content (m.c.). Milled rice is separated from the bran and aluminum oxide by using a sieving screen (No. 20). The mill was developed with the intention of milling rice from green house or breeding studies in which very small amounts of rice are produced, yet an indication of milling quality is desired.

KETT POLISHER

The Kett “Pearlest” Polisher is a mill designed for small sample sizes that utilizes centrifugal action to force kernels against a rubber surface to cause removal of bran layers. Centrifugal mills such as the Kett polisher provide a more aggressive means of milling small samples. Manufacturer claims are that sufficient milling of 10 g of brown rice can be attained in 30 s in the Kett Polisher. This mill is indeed capable of milling very small samples of rice, but it has been criticized for damaging kernels during the milling process.

MCGILL No. 2 MILL

The McGill No. 2 Mill is a batch type friction mill. It consists of a milling chamber consisting of a rotating shaft with two lobes, a perforated concave and cover, a lever with a counter weight for adjusting pressure in the milling chamber, and a pressure cover. Laboratory milling evaluation of rice samples is commonly performed with the McGill No. 2 Mill. This evaluation typically starts with 150 to 162 g of dried (12% m.c.) rough rice, which is typically dehulled before milling. Brown rice is milled in the McGill No. 2 Mill to a certain degree of milling (DOM). Attempted milling of smaller samples of rice (less than 120 g of brown rice) has presented problems because the design of the McGill No. 2 Mill does not provide sufficient milling action for these small samples (Andrews et al., 1992).

Evaluation of performance and factors affecting milling using McGill mills have been reported (Reid et al., 1998; Archer and Siebenmorgen, 1995; Sun and Siebenmorgen, 1992; Andrews et al., 1992; Banaszek et al., 1989; Velupillai and Pandey, 1987; Takai and Barredo, 1981). Based on these studies, factors that affect milling include sample moisture content, milling duration, initial temperature of the brown rice, pressure on the sample inside the milling chamber, and sample mass. Several researchers have documented the effect of moisture content at milling on head rice yield (HRY) and DOM (Banaszek et al., 1989; Webb and Calderwood, 1977; Wasserman, 1961; Pominski et al., 1961). Head rice yield includes those kernels that are three-fourths or greater of the original kernel length remaining after broken are removed (USDA, 1995). Head rice yield is the mass percentage of rough rice remaining as head rice. Reid et al. (1998) showed that the bran layers are more easily removed during milling as moisture content increases. They also indicated that sample moisture content has an inverse relationship with HRY when all other milling factors are held constant. According to Kohlwey’s (1992) speculations, the

relationship between moisture content and ease of milling could be related to the depression of the starch gelatinization temperature as moisture content increases. Kohlwey (1992) mentioned that because starch–melting temperature is lower at high moisture contents, it would be expected that more endosperm would be removed, along with bran, per unit of milling at higher moisture contents.

Andrews et al. (1992) have shown that the removal of bran layers as milling duration increased resulted in a reduction of milled rice yield (MRY) and HRY. Sun and Siebenmorgen (1992) also established a linear relationship between HRY and DOM for samples milled with a McGill No. 2 Mill. Velupillai and Pandey (1987) showed dependence of the DOM on milling duration by milling samples for periods of 0 to 60 s in 5-s increments. Milling duration is also very important as prolonged continuous milling increases the degree of polishing and kernel breakage. Takai and Barredo (1981) milled samples with a McGill mill intermittently and thereby obtained a feasible solution to prevent over milling and increasing the level of broken milled kernels.

Archer and Siebenmorgen (1995) showed that the initial temperature of the brown rice affects the MRY and HRY. They found that bran was more readily removed at higher temperatures. They speculated that bran started to be removed after a sufficiently high temperature was reached during milling.

OBJECTIVES

The following objectives were pursued: 1) to evaluate the performance of the IRRI Test Tube Mill and the Kett “Pearlest” Polisher in relation to the McGill No. 2 Mill and 2) to characterize the effect of each mill on the shape and integrity of the milled rice.

MATERIALS AND METHODS

Table 1 shows the specifications of the three lab mills evaluated. Milling tests were conducted to determine each mill’s performance. Each of the three mills was operated according to separate experimental procedures (as per operating specifications for each mill) as indicated in figure 1. Two rice varieties, ‘Bengal’ (medium–grain) and ‘Drew’ (long–grain), were harvested with a plot combine from the University of Arkansas Rice Research and Extension Center at Stuttgart, Arkansas at approximately 18% m.c. (wet basis). Immediately after harvest, samples were placed in double–lined plastic bags. Two lots of each variety were dried gently in an environmental chamber; one to 12% and the other to 15% m.c. Each lot was cleaned using a dockage tester (Precision Size Tester, Model XT4 Carter Day Co., Minneapolis, Minn.). After cleaning, samples were sealed in Ziploc bags and stored at 4°C.

Brown rice was prepared for each milling run by taking enough rough rice samples from the 4°C cooler, allowing the samples to equilibrate at lab temperature of approximately 21°C for 24 h, and hulling. A laboratory huller (Satake Rice Machine, Type THU, Satake Co., Hiroshima, Japan) with 0.48–mm clearance between rollers was used for hulling of all samples to obtain brown rice.

Milling with the IRRI Test Tube Mill was performed by filling each tube (12 mm in diameter and 75 mm long) with 3 g of brown rice mixed with 4 g of aluminum oxide and

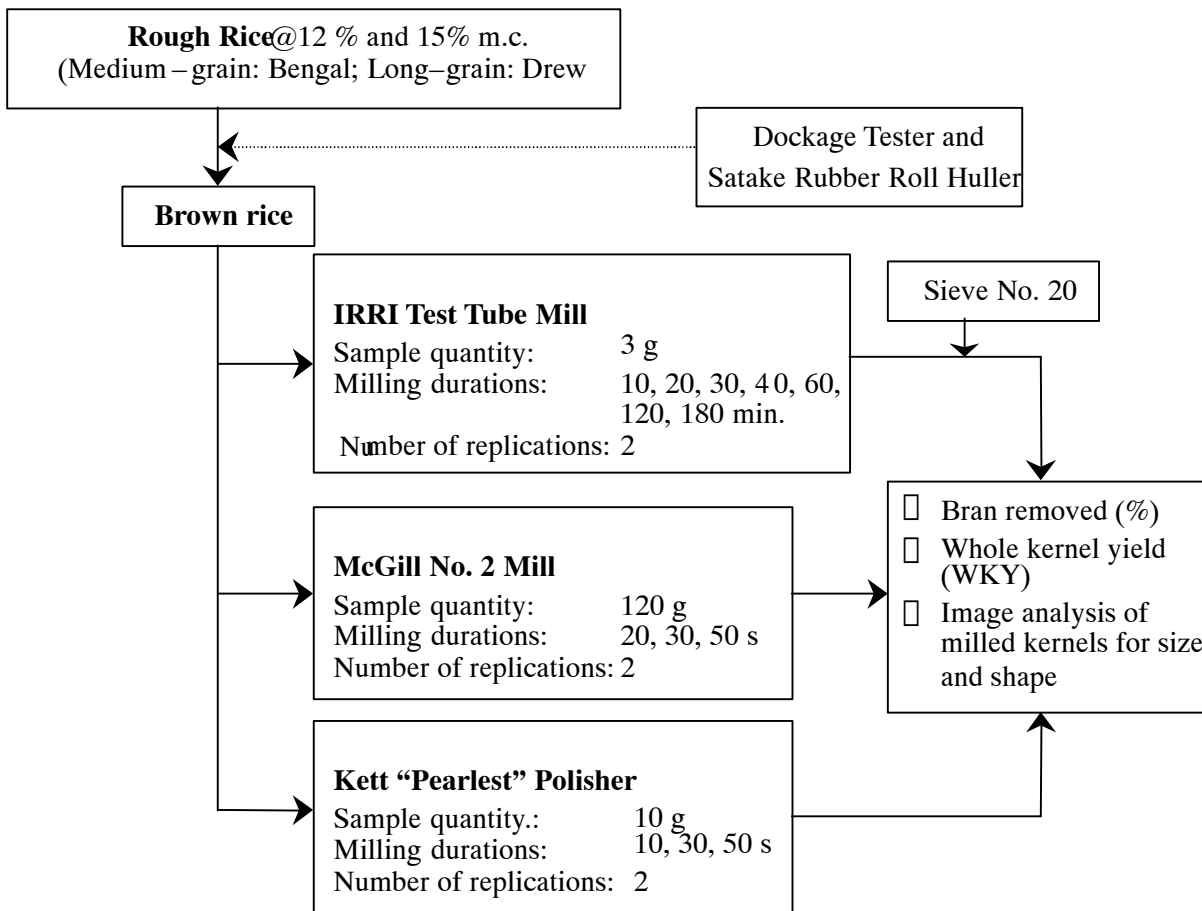


Figure 1. Flow chart of experimental procedures used in the evaluation of the three laboratory rice mills.

placing it on the tube holder. The two tube holders were then secured in the oscillating arm of the mill. The samples were run on the mill at durations of 10, 20, 30, 40, 60, 120, and 180 min. After milling, samples were cleaned using screen size No. 20 (Central Scientific Co., Chicago, Ill.) to separate the bran from the milled rice.

Milling with the Kett Polisher was performed by filling the milling chamber with 10-g brown rice for milling durations of 10, 30, and 50 s. Milled rice was removed from the collecting pan at the end of each milling run. Cleaning the milled rice samples using a sieve was not necessary because the Kett Polisher is equipped with a vacuum device for separating the bran from the milled rice.

The McGill No. 2 Mill was warmed up before running each experiment. This task was accomplished by milling two loads of 120 g of brown rice that were discarded. Milling durations were 10, 30, and 50 s. A 1500-g mass was placed on the mill lever arm, 150 mm from the center of the milling chamber. It was not necessary to use the sieve to separate the bran from the milled rice because the McGill mill has a perforated screen that separates the bran during milling.

The milling evaluation was primarily based on the percentage weight of bran removed and the percentage whole kernel yield (WKY). In this study, the bran removed refers to the weight of bran layers and germ removed from the brown rice after milling for a certain duration. The following equation was utilized:

Bran removal =

$$\frac{\text{Mass of brown rice} - \text{Mass of milled rice (head rice \& brokens)}}{\text{Mass of brown rice}} \quad (1)$$

Based on the recent work by the Standards Committee of the American Association of Cereal Chemists (AACC, 2000), a 12% brown rice weight reduction is the target to be attained in milling.

Whole kernel yield was determined using a sizing device (Grainman Model 61-115-60, Grain Machinery Mfg. Corp). Whole kernel yield is defined as the ratio of the mass of kernels with length at least 3/4 of the original kernel length (head rice) after milling, to the original mass of brown rice. The whole kernels may be well milled or could be below the required degree of milling depending on the experimental milling treatment. The following equation applies:

$$\text{Whole kernel yield} = \frac{\text{Mass of head rice}}{\text{Mass of brown rice}} \quad (2)$$

Images of milled rice obtained from each sample (10 kernels for each replication, picked randomly from the HRYs) were taken using a video microscope with 50X magnification. An image analysis system (Satake RIA-1A, Satake Co., Japan) was used to evaluate the brown and milled rice kernel dimensions (length, width, and thickness) of 200 randomly selected kernels per sample.

STATISTICAL ANALYSIS

Comparison of the mean percentage bran removed and percentage WKY for each moisture content level, milling duration, and variety was analyzed using a statistical package (JMP® version 4, SAS Institute, Sall et al., 2001). Analysis of variance among variables was performed at a significance level of 0.05.

RESULTS AND DISCUSSION

BRAN REMOVAL

Figure 2 shows the weight percentage of bran removed from brown rice at various milling durations for Bengal and Drew at 12 and 15% m.c. for each mill. Sample moisture content, variety of rice, and milling duration affected the percentage of bran removed for all lab mills tested. Generally, the percentage of bran removed increased with milling duration, and bran removal was greater at the higher moisture content.

Using the McGill No. 2 Mill, about 30 s was required to attain the 12% acceptable bran removal level for Bengal and Drew. The 12% acceptable bran removal is referred to the minimum level of bran removed. There was a higher percentage of bran removed for the 10- and 30-s milling durations using the McGill No. 2 Mill than the Kett Polisher. Generally, it took shorter milling duration for the McGill No. 2 Mill than for the Kett Polisher to attain similar percentages of weight removed. However, after 50 s of milling, the bran removal was comparable for the McGill and Kett mills.

The IRRI Test Tube Mill needed much longer milling durations to achieve similar bran removal percentages. Relative to the McGill No. 2 Mill and Kett Polisher, which generally required approximately 30 s to attain 12% bran removal, the IRRI mill required 60 to 180 min, depending on the moisture content of the rice, to attain comparable levels. Specifically, the IRRI Test Tube Mill required more than 130 min to obtain a 12% bran removal for Drew at 12% m.c., but only 80 min for samples at 15% m.c. For Bengal at 12% m.c., the IRRI mill needed 180 min, while at 15% m.c., it needed only 60 min to attain 12% bran removal.

Sample moisture content affected the required milling duration. It took more time to remove a certain percentage of bran at 12% m.c. than at 15% m.c. for the IRRI Test Tube Mill and the McGill No. 2 Mill. A similar trend was observed for the Kett Polisher with Bengal, but little difference was observed due to sample moisture content with Drew. This lack of difference due to sample moisture content when milling Drew with the Kett Polisher can be explained in terms of the relative brittleness of kernels at lower moisture contents as well as the milling action of the Kett Polisher. The presence of chipped ends of rice kernels in the bran after milling was an indication that the Kett Polisher not only removed bran but also some fragments of the kernel endosperm. It was observed that most milled kernels obtained from the Kett Polisher were damaged visibly as indicated by chipped ends. Thus, in the case of the Kett Polisher, the weight of material removed from the brown rice

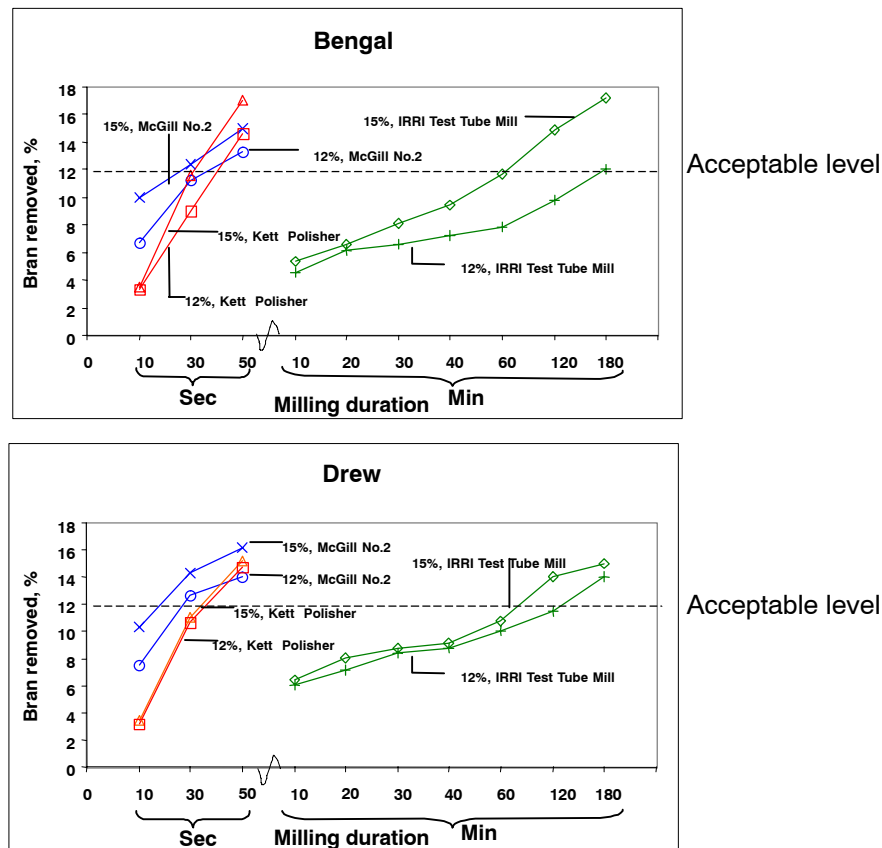


Figure 2. Percentage of bran removed (eq. 1) when using the IRRI Test Tube Mill, McGill No. 2 Mill, and Kett Polisher at various milling durations for two varieties of rice (cv. Bengal and Drew) at 12 and 15% m.c. Each data point is an average of two replications. ‘Acceptable level’ line at 12% is the target bran removal rate to be obtained (AACC, 2000).

does not necessarily represent only the weight of bran and germ removed, but also parts of the endosperm that were removed from kernels. Generally, there was more bran removed for Bengal than Drew at both moisture contents using the IRRI Test Tube Mill, Kett Polisher, and McGill No. 2 Mill at a given milling duration and moisture content.

WHOLE KERNEL YIELDS

The type of mill, moisture content of samples, and milling duration affected WKY. Figure 3 shows the WKY changes with milling duration for Bengal and Drew at 12 and 15% m.c. for the three mills tested. For all mills, WKY decreased with an increase in milling duration, primarily due to the increasing removal of bran layers and resultant decrease in head rice weight as milling duration increased. For the McGill No. 2 Mill, the decrease in WKY was generally linear from 10- to 50-s milling duration. A similar observation was reported by Reid et al. (1998). Other factors that influenced WKY were moisture content and variety. WKYs tended to be inversely related to sample moisture content, in that higher WKYs were obtained at 12% than at 15% m.c. Andrews et al. (1992) obtained similar findings using a McGill No. 2 Mill.

Whole kernel yields were higher for Drew than Bengal at a given moisture content. This result implied that kernel type affected milling behavior. The IRRI Test Tube Mill had higher WKYs than the Kett Polisher and the McGill No. 2 Mill at any given milling duration for both varieties at 12% m.c. The gentle milling action of the IRRI mill required more time to cause sufficient removal of the bran layers. This gentle milling action resulted in very high WKYs using the IRRI Test Tube Mill. Because of the associated low bran removal levels, milling for short durations in the IRRI mill may not represent the true milling response of a rice sample.

Visual inspection of kernels from the IRRI mill showed that most of the kernels were undermilled. For this reason, the percentage of bran removed must be considered when obtaining WKYs with the IRRI mill. A 12% bran removal could be used as a milling degree to compare equivalent WKYs.

The Kett Polisher had a sharp decrease in WKY, particularly for Bengal and Drew at 12 and 15% m.c. with an increase in milling duration. A significant difference ($p = 0.05$) in WKY was found between Bengal and Drew for the Kett Polisher, where Bengal had lower WKY than Drew across milling duration. Between the Kett Polisher and McGill No. 2 Mill, WKY was lower for the Kett Polisher than the McGill No.2 Mill, specifically, at 30- and 50-s milling duration. It was also noted that some of the kernels obtained from the Kett Polisher were visually undermilled, especially at shorter milling durations. However, at longer milling durations in the Kett Polisher, it was observed that the number of kernels with chipped ends tended to increase.

KERNEL DIMENSIONAL SIZE REDUCTION

Reduction in kernel size was affected by the sample moisture content, milling duration, mill type, and, to a lesser degree, variety. Figures 4 and 5 show the average percentage reduction in kernel dimensions (length, width, and thickness) for each rice variety using the IRRI Mill, the Kett Polisher, and the McGill No. 2 Mill. For kernels that appear roughly cylindrical in shape, width refers to the distance between the dorsal and ventral sides of the kernel. Thickness refers to the distance between the lateral sides of the kernel.

For all mills, the reduction in kernel dimensions was generally higher at higher sample moisture content (figs. 4 and 5). For 15 and 12% m.c., the kernel length reduction was greatest, followed by width and then thickness. Given the conical shape of the rice kernel, length is a function of width and thickness. Based on speculations by Kohlwey (1992), the starch melting temperature is lower at high moisture contents, thus more endosperm would be removed, along with the bran, per unit milling duration at higher moisture contents.

Kernel size reduction increased with milling duration (figs. 4 and 5). Findings by Andrews et al. (1992) showed that when milling time applied was increased, HRY decreased. Reduction in kernel size is related to a decrease in head rice yield.

Statistical analysis showed significant effects ($p = 0.05$) due to mill type on the reduction in kernel size. Among mills, the Kett Polisher produced the highest reduction in kernel length for both Bengal and Drew. This result was due mostly to the aggressive impact incurred by kernels in the mill's chamber that chipped off the ends of the kernels. The IRRI Test Tube Mill produced the highest reduction in kernel width.

The type of mill affected the size and shape of the milled rice kernels. From the images taken using the video microscopy system, the McGill No. 2 and IRRI Test Tube mills produced kernels that maintained the original shape of the kernel (fig. 6). The Kett polisher produced a greater reduction in length than the IRRI Test Tube Mill and the McGill No. 2 Mill.

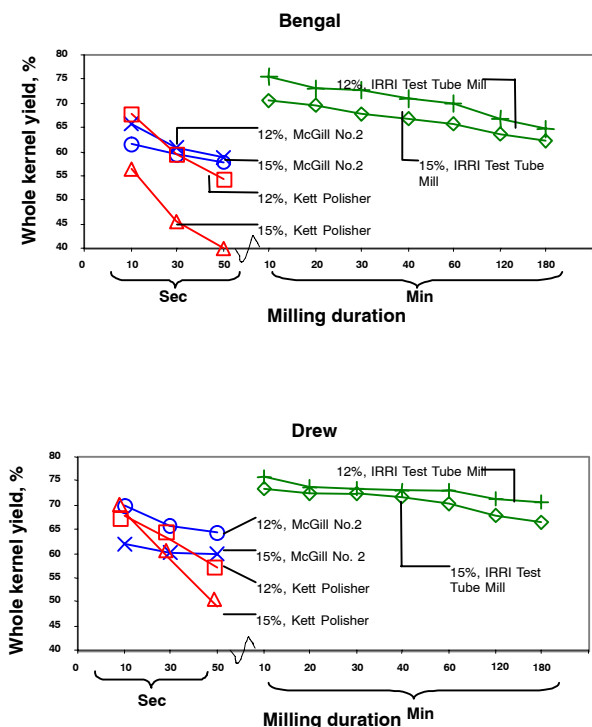


Figure 3. Whole kernel yields (eq. 2) for the IRRI Test Tube Mill, McGill No. 2 Mill, and Kett Polisher as a function of milling duration for two varieties of rice (cv. Bengal and Drew) at 12 and 15% m.c. Each data point is the average of two replications.

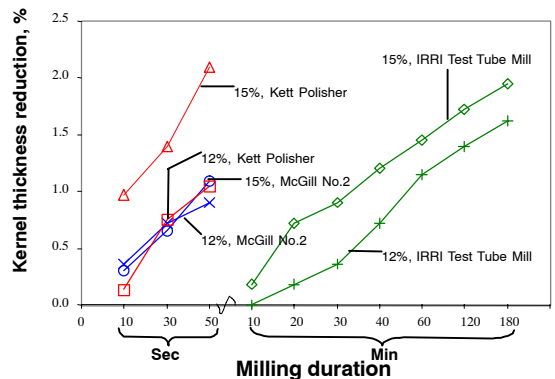
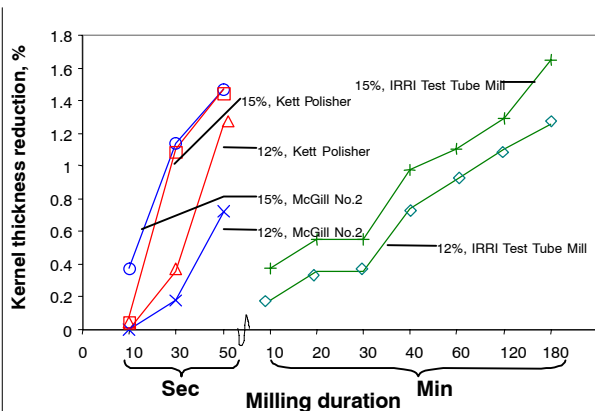
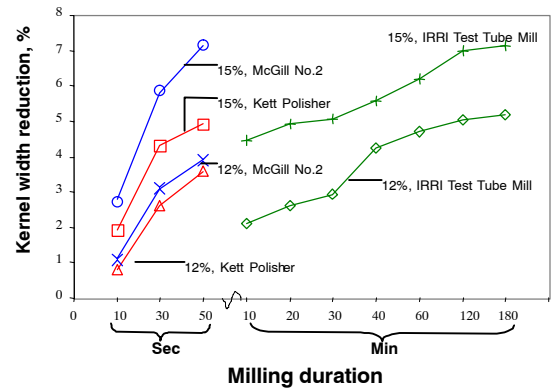
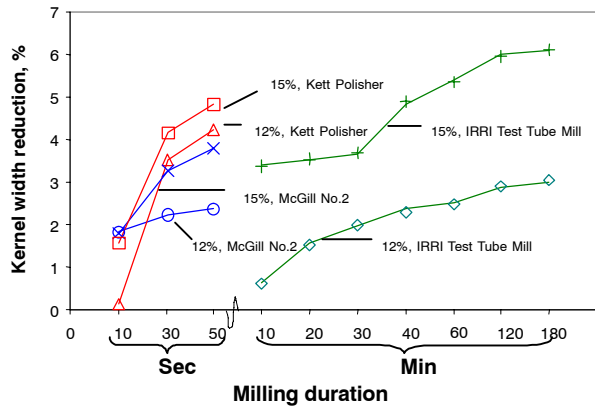
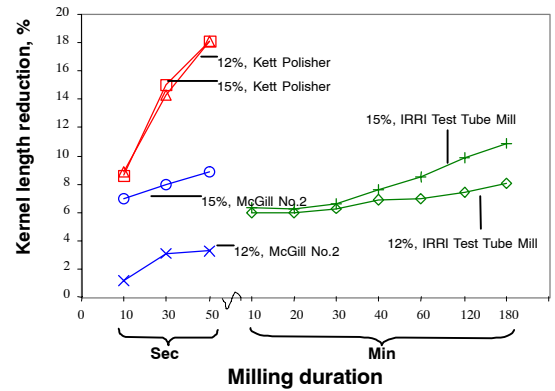
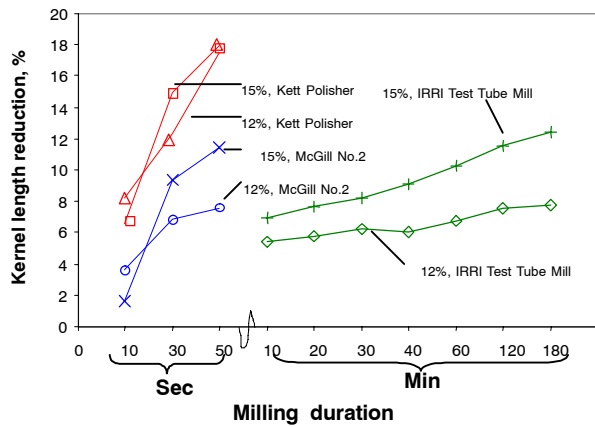


Figure 4. Average percentage reduction in kernel dimensions (length, width, and thickness) after milling brown rice at 12 and 15% m.c. using an IRRI Test Tube Mill, a McGill No. 2 Mill, and a Kett Polisher for variety Bengal. Each data point is the average of two replications.

Figure 5. Average percentage reduction in kernel dimensions (length, width, and thickness) after milling brown rice at 12 and 15% m.c. using an IRRI Test Tube Mill, a McGill No. 2 Mill, and a Kett Polisher for variety Drew. Each data point is the average of two replications.

CONCLUSIONS

This study evaluated three lab mills (IRRI Test Tube Mill, Kett “Pearlest” Polisher, and McGill No. 2 Mill) in terms of bran removal and WKY as affected by milling duration, sample moisture content, and the variety of rice. The percentage of bran removed and the WKY was affected by sample moisture content, variety, and milling duration for the three mills tested. For all mills, the percentage of bran removed increased with milling duration and sample moisture content. Whole kernel yield generally decreased with milling duration. Also, WKY decreased with an increase in

sample moisture content. The reduction in kernel dimensions was affected by mill type, milling duration, sample moisture content, and, to a lesser degree, variety. The Kett Polisher tended to chip off kernel ends, which caused a higher reduction in length and adversely affected the integrity of the kernel.

Longer milling durations were required with the IRRI Test Tube Mill to attain desired bran removal. Although this mill produced an extremely high WKY, it may not represent the samples’ true HRY due to the very gentle milling action employed. However, it could give indications of the HRY potential of a small sample. Because they use a gentle milling actions the IRRI Test Tube and McGill mills maintained the integrity of the kernel endosperm, which made them highly suitable for milling samples for subsequent analysis.

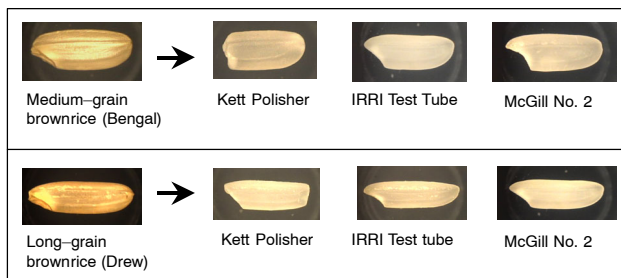


Figure 6. Images of rice kernels milled with the three indicated laboratory mills showing the effect of each machine on the shape and size of milled rice kernels.

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