INFLUENCE OF RICE SAMPLE PREPARATION AND MILLING PROCEDURES ON MILLING QUALITY APPRAISALS

R. Khir, Z. Pan, J. F. Thompson

ABSTRACT. *The objective of this research was to investigate the effect of sample preparation and milling procedure on milling quality appraisals of rough rice. Samples of freshly harvested medium-grain rice (M202) with different initial moisture contents (MCs) ranging from 20.2% to 25.1% (w.b.) were used for this study. To create rough rice with varying quality, the samples were dried from their initial MC to a moisture content of 13.1% ±0.3% (w.b.) using air at different temperatures. Before milling, the MC of the samples was measured using three different methods: standard oven method, Dickey-John GAC 2100 (DKJ), and single-kernel moisture meter (SKM). The samples were milled using a McGill No. 3 mill. Three milling procedures were used: the standard western milling procedure, referred to as normal milling (NM), the southern milling procedure (SMP), and low-temperature milling (LM). The effect of storage after drying on quality appraisals was evaluated. Milling quality was compared based on total rice yield (TRY), head rice yield (HRY), whiteness index (WI), and lipid content (LC). HRY was found to be significantly affected by variation in initial MC, drying temperature, storage time after drying, and milling procedure. WI and LC were not significantly affected by these parameters. HRY decreased significantly with increased initial MC and drying temperature. The LM and SMP procedures significantly improved HRY up to 4.8% and 2.8%, respectively. HRY significantly increased with increase in storage time of dried rice up to four days, after which HRY was not affected by storage time. Regression models were successfully developed to predict HRY under tested rice conditions and milling procedures. The DKJ and SKM instruments, which are widely used in the rice industry, need to be calibrated at the full moisture range to ensure accurate results in MC measurement. The obtained results provide valuable information to achieve consistent, accurate, and reliable milling quality appraisals.*

Keywords. *Appraisal, Drying, Milling quality, Rice, Sample preparation, Storage, Tempering.*

Improving the consistency and accuracy of rice milling appraisals is an increasingly important goal in the rice industry, as the monetary value of a rice lot is appraised based on its milling quality. Milling quality is determined by milling small samples using standard procedures and appraised based on indexes called total rice yield (TRY) and head rice yield (HRY) (Bhattacharya, 2011). HRY is the amount of whole kernels in the milled sample, and TRY is the amount of whole and broken kernels in the milled sample expressed as percent of the unmilled sample. The quality indexes are closely related to the true quality of rough rice, sample preparation, and milling procedures, including drying, tempering, storage time after drying, and milling conditions (Mutters and Thompson, 2009). The samples are normally collected from freshly harvested rice lots and dried from their initial MCs to moisture content of about 14% (w.b.) using specific drying procedures, followed by storage and milling of dried samples (USDA-FGIS, 1980). In the U.S., the milling process is typically conducted according to the official procedures of the USDA Federal Grain Inspection Service (USDA-FGIS, 2005). These standards mainly specify procedures for milling dried rice. There is no documented information on the procedures for preparing rice samples nor for the time required to store dried rice samples that are to be used in milling quality appraisal (Thompson et al., 1990; Pan and Thompson, 2007).

Medium-grain rice is typically harvested at high moisture content, ranging from 23% to 25%, to minimize HRY losses (Mutters and Thompson, 2009). Consequently, samples taken from rice lots with high MC for milling analysis may be sensitive to preparation procedures. The samples may not be a true reflection of the quality of the rice lots if improper preparation procedures, such as drying temperature, tempering treatment, and storage time after drying, are applied. Therefore, there is a need to develop a standard methodology for sample preparation in order to

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achieve consistent and reliable milling quality appraisals.

It has been observed in the rice industry that variations in handling, moisture history, drying procedure, and storage period after drying cause differences in milling quality appraisals among samples taken from the same lot of rough rice (Webb and Calderwood, 1977; Bautista and Siebenmorgen, 2002). Variability in HRY caused by sample MC at time of appraisal, drying method, and collection method were 2.2, 2.4, and 3.8 percentage points for appraisal samples taken from medium-grain rice lots (Mutters and Thompson, 2009). Pominski et al. (1961) reported that the appraisal quality of long-grain rice increased by 0.7 and 3.0 percentage points of TRY and HRY per percentage point of moisture drop for MC between 10% and 14%. Similarly, Wasserman (1960) found that the milling appraisal of short-grain rice increased by 1.2 and 1.8 percentage points of TRY and HRY per percentage point of moisture drop between 10% and 14% moisture. Mossman (1986) stated that rapid sample drying using high air temperatures and prolonged exposure to drying air resulted in loss of rice milling quality.

Additionally, the general practice in the rice industry has been that, after drying rough rice, storage for appreciable periods of times is necessary to obtain increased HRY. However, the effect of storage time on appraisal quality is not clear from the literature. Wasserman et al. (1958) and Pominski et al. (1965) found that the HRY of short-grain rice did not change significantly over a storage period of nine weeks after drying. Thompson et al. (1990) reported that rice milling quality appraisals of short, medium, and long grain rice were found to be unaffected by storage times of 10 to 118 days prior to milling. However, the appraisals were affected by the MC of the sample at the time of milling, particularly for long and medium grain rice. Thompson et al. (1990) also stated that the normal sample handling, preparation, and milling quality analysis system results in a variation in appraisal results.

Moreover, the FGIS specifies different official procedures for appraisal sample milling of rice produced in the western and southern regions of U.S. Our previous research has demonstrated that differences in appraised milling quality (TRY and HRY) are caused by the milling procedure. The highest temperatures (57°C and 74°C) of the mill and milled rice using the western milling procedure (WMP) resulted in significant reduction in the appraised TRY and HRY of milled rice compared to the southern milling procedure (SMP) (Pan and Thompson, 2002; Pan et al., 2005, 2013). In addition, the combination of high milling temperature and high milling weight (pressure) produced lower appraised TRY and HRY but higher WI with the western milling procedure compared to the southern milling procedure (Pan et al., 2007). The milling procedures have been updated several times (USDA-FGIS, 1979, 1982, 1994, 2005).

Our elaborate review of pervious research revealed that there is limited availability of scientific information regarding the effect of rice sample preparation, storage period after drying, and milling procedures on quality appraisals (Pominski et al., 1965; Thompson et al., 1990; Pan and Thompson, 2002; Pan et al., 2005, 2007). Therefore, there is a need to standardize the related procedures for improving the consistency and accuracy of rice sample quality appraisals. The objectives of this study were to: (1) determine the effect of initial MC, drying temperature, and milling procedure on milling quality appraisals; (2) investigate the effect of storage time after drying on quality appraisals; and (3) develop regression models to predict HRY changes for tested rice sample conditions and milling procedures.

Materials and Methods

Samples with Different Initial MCs and Drying Temperatures

Freshly harvested medium-grain rice, variety M202, obtained from Farmers' Rice Cooperative (West Sacramento, Cal.), was used in this study. The initial MC of the rough rice sample was 24.8% ±0.1% (high MC) at harvest. To create rough rice with different initial MCs, the rice sample was split into three large portions. Two portions were separately spread on a concrete floor and gradually dried to 22.7% ±0.1% and 20.2% ±0.2% (low MC) with ambient air at temperature of 19°C ±2°C at the Food Processing Laboratory in the Department of Biological and Agricultural Engineering, University of California, Davis. The thickness of the rice bed on the floor was less than 5 cm. During the slow drying process, the rough rice was commingled frequently to ensure uniform drying. It took about 36 and 60 h to reach 22.7% and 20.2% MC, respectively. The three rice samples were then dried from their initial MCs of 24.8%, 22.7%, and 20.2% to MC of 17% using air at temperatures of 23°C, 36°C, 43°C, and 53°C and air velocity of 0.1 m s^{-1}, which is typically used in commercial rice drying operations. Air velocity was measured using a hot-wire anemometer (Solomat MPM 500, Devon, U.K.) with an accuracy of 0.01 m s^{-1}. A second drying process was carried out on the 17% moisture content samples by further drying them to 14% MC using the ambient air at temperature of 22°C ±1°C and air velocity of 0.1 m s^{-1}. The samples were stored in ziplock bags at room temperature for about one month before milling. All reported MCs in this section are averages of three replicates on wet basis and were determined by the air oven method (130°C for 24 h) (*ASAE Standards*, 1995).

Milling Procedures

The samples (1000 g each) prepared as described in the previous section were milled with a laboratory mill (McGill No. 3) at California Agriculture Inspection Co. Ltd. (CAICL). The samples were milled using three different procedures: the standard western milling procedure with and without cooling, referred to as low-temperature milling (LM) and normal milling (NM), respectively, and the standard southern milling procedure (SMP) of the FGIS (USDA-FGIS, 2005). All milling tests were conducted in triplicate. For each 30 s milling cycle, the standard western milling procedures used a 4.45 kg (10 lbs) weight for milling and a 0.98 kg (2 lbs) weight for polishing, while the standard southern milling procedure used a 3.18 kg (7 lbs) weight for milling and zero pound weight for polishing. The current milling practice for the standard western milling procedure is to cool the cutter bar with a fan to an initial temperature of 48°C to 54°C (115°F to 130°F) before a new rice sample is milled. The cutter bar was therefore cooled after each milling cycle using this practice. The cutter bar temperature was measured using an infrared thermometer (OSXL653, Omega Engineering, Inc., Stamford, Conn.). The high reflectivity of the metal surface of the cutter bar may cause inaccurate temperature measurement, so it was covered with a piece of thin paper.

Cooling Devices

To reduce the milling temperature (cutter bar and rice in mill) of the McGill No. 3 mill, two external and internal heat exchanger devices were developed at the University of California, Davis. The cooling mechanism using the heat exchangers was described in detail in a previous publication (Pan et al., 2005). Since the external heat exchanger added additional weight to the milling chamber, the milling weight was adjusted to keep the same milling pressure as generated by the milling weight specified by the standard western milling procedure at CAICL. This milling procedure is called low-temperature milling (LM) in this study. The temperature of the milled rice was measured using a type-T thermocouple (time constant 0.15 s, Omega Engineering, Inc., Stamford, Conn.) immediately after the milled rice was unloaded into a container. The thermocouple was kept at the center of the rice mass until the temperature reading was stabilized, which normally took 10 to 30 s.

Samples with Different Preparation Procedures

To study the effect of rice sample preparation procedures on appraised milling quality, due to seasonality, another freshly harvested medium-grain rice (variety M202) with initial MC of 25.1% ±0.2% was used. To create rice sample with different original moisture contents, the harvested sample was split in half, with one of the halves was dried to 20.5% moisture content using the procedure described earlier. Rice samples with initial MC of 25.1% and 20.5% were dried from their initial MCs to a final MC of 14% with three different drying procedures. The first procedure is the current drying practice used in the rice industry for each drying pass, which involves drying a 12 cm rice bed at 43°C for 20 min followed by a 4 h tempering at room temperature. In the second procedure, rice samples were dried using ambient air at 23°C ±1°C to remove 2% moisture in each drying pass followed by a 4 h tempering at room temperature. The third drying procedure involved ambient air (23°C ±1°C) drying to dry the rice samples from their original moisture contents to 14% in one pass and without tempering. The moisture removal and drying time during each pass for the different drying procedures were recorded. After drying, the rice samples were stored in ziplock bags until the milling analysis. To determine the effect of storage time after drying on milling quality appraisals, the milling quality of the rice samples was measured at 1, 4, 7, 14, and 28 days of storage after drying. These storage periods were selected to cover the recommended storage time of up to one month after drying. To examine the accuracy of different moisture measurement methods, three moisture measurement methods were used: standard oven method (130°C, 24 h), GAC 2100 (Dickey-John, Auburn, Ill.), and single-kernel moisture meter (PQ-510, Kett Electronic Laboratory, Tokyo, Japan). The moisture contents of the original samples and dried samples before milling were measured using all three methods. The samples were milled using the standard western milling procedure. All tests were conducted in triplicate.

Milling Quality Evaluation

The evaluated quality indicators specified in the standard milling procedures were total rice yield (TRY), head rice yield (HRY), whiteness index (WI), and lipid content (LC). The TRY and HRY were determined using a Grainchecker (Foss North America, Eden Prairie, Minn.). The whiteness of milled rice was evaluated based on the whiteness index (WI), as determined with a whiteness tester (C-300, Kett Electronic Laboratory, Tokyo, Japan). A higher index number indicates whiter milled rice. The lipid content (LC) was measured with NIR (model 5000, Foss NIR Systems).

Statistical Analysis

Data on rice milling quality were statistically analyzed with SigmaStat (version 2.0, Jandel Corp., San Rafael, Cal.) using one-way RM ANOVA and multiple comparisons to compare milling quality results for significant differences. Least square (LS) means with Tukey's adjustment method were used to compare means. Significance is reported at $p < 0.05$ for all data. In addition, regression models were developed to predict HRY reduction under the tested rice conditions and milling procedures.

Results and Discussion

Effect of Initial Moisture Content on Appraised Milling Quality

The milling quality results of rough rice with different initial MCs are shown in tables 1, 2, and 3. In general, rough rice with high initial MC had low TRY and HRY compared to rice with low initial MC. This difference was not significant for TRY but was significant for HRY at $p < 0.05$. For example, when the initial MC increased from 20.2% to 24.8%, the average TRY decreases were 0.02, 0.62, and 0.47 percentage points and the corresponding HRY decreases were 2.07, 1.96, and 2.38 percentage points at a drying temperature of 43°C with LM, NM, and SMP, respectively. The average WI and LC values of milled rice were not affected by initial MCs of rice samples. This trend was observed for all tested drying temperatures and milling procedures. This means that HRY was more sensitive than TRY to variation in initial moisture contents in the tested ranges. These results were in agreement with those reported by Thompson and Mutters (2006). They reported that HRY

Table 1. Appraised milling quality with different drying temperatures and milling procedures for paddy rice with initial MC of 20.2%.

Drying Air Temperature	Milling[a] Procedure	Quality of Milled Rice[b]			
		TRY	HRY	WI	LC
23°C	LM	68.95 a	65.59 a	42.27 c	0.45 a
	NM	67.05 b	62.91 c	43.10 a	0.41 a
	SMP	68.04 a	64.30 b	42.73 abc	0.43 a
36°C	LM	69.43 a	65.84 a	42.30 a	0.53 a
	NM	67.93 bc	63.67 c	42.77 a	0.42 a
	SMP	68.43 b	64.27 b	42.47 a	0.35 a
43°C	LM	68.79 a	64.32 a	42.37 b	0.43 a
	NM	67.40 c	61.31 c	43.07 a	0.31 a
	SMP	68.21 ab	62.68 b	42.27 b	0.39 a
53°C	LM	68.38 a	57.56 a	42.40 a	0.38 a
	NM	66.83 bc	54.14 c	43.00 a	0.32 a
	SMP	67.08 b	54.92 bc	42.47 a	0.33 a

[a] LM = low-temperature milling (western milling procedure with cooling), NM = normal milling (western milling procedure without cooling), and SMP = southern milling procedure.

[b] TRY = total rice yield, HRY = head rice yield, WI = whiteness index, and LC = lipid content. In each category, values followed by the same letter are not significantly different at $p < 0.05$.

Table 2. Appraised milling quality with different drying temperatures and milling procedures for paddy rice with initial MC of 22.7%.

Drying Air Temperature	Milling[a] Procedure	Quality of Milled Rice[b]			
		TRY	HRY	WI	LC
23°C	LM	68.35 a	65.14 a	41.10 a	0.29 a
	NM	66.46 c	61.63 c	41.30 a	0.24 a
	SMP	67.49 b	63.65 b	40.43 b	0.31 a
36°C	LM	69.13 a	66.12 a	41.60 b	0.27 b
	NM	67.41 b	62.42 c	42.23 a	0.25 b
	SMP	68.71 a	64.38 b	41.20 b	0.43 a
43°C	LM	68.70 a	60.89 a	42.17 a	0.31 a
	NM	67.53 bc	57.70 c	42.37 a	0.28 a
	SMP	68.20 ab	59.41 b	41.77 a	0.39 a
53°C	LM	69.10 a	49.41 a	42.23 b	0.48 a
	NM	67.61 bc	45.05 c	43.10 a	0.33 a
	SMP	68.19 ab	47.83 b	42.47 b	0.38 a

[a] LM = low-temperature milling (western milling procedure with cooling), NM = normal milling (western milling procedure without cooling), and SMP = southern milling procedure.

[b] TRY = total rice yield, HRY = head rice yield, WI = whiteness index, and LC = lipid content. In each category, values followed by the same letter are not significantly different at $p < 0.05$.

Table 3. Appraised milling quality with different drying temperatures and milling procedures for paddy rice with initial MC of 24.8%.

Drying Air Temperature	Milling[a] Procedure	Quality of Milled Rice[b]			
		TRY	HRY	WI	LC
23°C	LM	66.74 a	63.52 a	41.80 a	0.35 a
	NM	65.49 a	60.95 bc	41.57 a	0.30 a
	SMP	65.78 a	61.92 b	41.77 a	0.34 a
36°C	LM	68.27 a	64.49 a	42.07 ab	0.35 a
	NM	66.74 c	61.54 b	42.53 a	0.43 a
	SMP	67.39 abc	63.21 a	41.87 ac	0.36 a
43°C	LM	68.77 a	60.15 a	42.20 ab	0.42 a
	NM	66.78 c	55.27 c	42.47 a	0.36 a
	SMP	67.74 abc	58.14 b	41.73 ac	0.36 a
53°C	LM	68.59 a	54.99 a	42.23 a	0.45 a
	NM	67.27 bc	50.85 b	42.57 a	0.31 a
	SMP	67.40 b	51.91 b	42.17 a	0.39 a

[a] LM = low-temperature milling (western milling procedure with cooling), NM = normal milling (western milling procedure without cooling), and SMP = southern milling procedure.

[b] TRY = total rice yield, HRY = head rice yield, WI = whiteness index, and LC = lipid content. In each category, values followed by the same letter are not significantly different at $p < 0.05$.

of California medium-grain rice decreased with increase in harvest MC. Siebenmorgen et al. (2007) reported that peak HRY for medium-grain rice was obtained at initial MC of 21% ±1% (w.b.). The decreased TRY and HRY could be due to fissures created as a result of the longer time and greater moisture loss required to dry rice from the high initial moisture content to 17%. Geng et al. (1984) indicated that the quantity of moisture removed during each drying cycle influenced rice quality. Since medium-grain rice in California is harvested at MC ranging from 23% to 25% (Thompson and Mutters, 2006), special care should be taken during the preparation of samples with high initial MCs for milling quality analysis to be an accurate representation of the true quality of rice lots. Proper preparation procedures, including drying temperature, tempering treatments, milling procedure, and storage period, after drying will be discussed in detail in the next sections.

Appraised Milling Quality under Different Drying Temperatures

For all tested conditions, a clear trend was obtained in reduction of milled rice quality (as measured by HRY yield) as drying temperature increased. By increasing the drying temperature from 23°C to 43°C during preparation of the samples, HRY for rough rice with initial MC between 20.2% and 24.8% decreased by 5.44, 7.64, and 6.16 percentage points for LM, NM, and SMP, respectively (tables 1 and 3). Over the same range of moisture, HRY decreased by 10.85, 12.82, and 12.36 percent points by increasing the drying temperature from 36°C to 53°C for LM, NM, and SMP, respectively. There was no significant difference at $p < 0.05$ in appraised quality parameters of rice samples at 23°C and 36°C drying temperatures. The decreased HRY could be due to the higher moisture loss rate and higher breakage associated with higher-temperature drying conditions. These results are in agreement with those reported by Pan and Thompson (2002) and Pan et al. (2005) for appraised milling quality of rough rice with different qualities. High correlations were found between appraised milling quality (HRY) and drying temperatures under tested moisture ranges and milling procedures. Regression models were developed to predict HRY under different drying conditions and milling procedures (table 4). To illustrate the accuracy of the predicted milled rice quality, the model-predicted and measured HRY values are plotted against various drying temperatures for different milling procedures in figure 1.

The effect of drying temperature on WI and LC was not significant, and WI values were greater than 39 for all tested drying temperatures. This means that all the samples were well milled and had acceptable whiteness for market purposes (Mutters and Thompson, 2009). The obtained results clearly demonstrated that the air temperature used for sample drying has a profound effect on appraised milling quality and can result in a wide inconsistency of HRY. Maximum head quality was obtained using an air temperature of 36°C for appraisal sample drying. However, high HRY can also be achieved using a drying air temperature of 43°C followed by proper tempering and

Table 4. Regression equations for HRY values under tested moisture ranges, drying temperatures, and milling procedures.

Milling[a] Procedure	Model	R^2	SEE[b]
LM	$HRY = -10.439 + 6.371T - 0.164T^2 + 0.00127T^3$	0.93	1.4
NM	$HRY = 27.804 + 2.658T - 0.0587T^2 + 0.0003247T^3$	0.92	1.5
SMP	$HRY = 16.976 + 3.735T - 0.0878T^2 + 0.0005657T^3$	0.91	1.7

[a] LM = low-temperature milling (western milling procedure with cooling), NM = normal milling (western milling procedure without cooling), and SMP = southern milling procedure.

[b] SEE = standard error of estimate.

milling procedures. These procedures will be discussed in subsequent sections.

Effect of Milling Procedure on Appraised Milling Quality

The milling results showed that the LM and NM procedures had the highest and lowest TRY and HRY, respectively, for any sample milled with the three milling procedures. The differences in WI and LC of rice milled with the three procedures were not significantly different at $p < 0.05$, even though the rice milled with NM was slightly whiter than others (tables 1, 2, and 3).

To illustrate the improvement in milling quality by using LM, the differences in HRY and WI of milled rice using the LM and SMP procedures were calculated and are shown in figures 2 and 3. It is clear that the low-temperature and southern milling procedures have significantly improved HRY, from 2.7% to 4.8% and from 0.7% to 2.8%, respectively, on average, but not much difference in color of the milled rice was detected. The results confirmed our previous findings that low-temperature milling improved the milling quality (Pan et al., 2005, 2007, 2013). From this study, it has been observed that the improvement with LM was more significant for samples dried at an air temper-

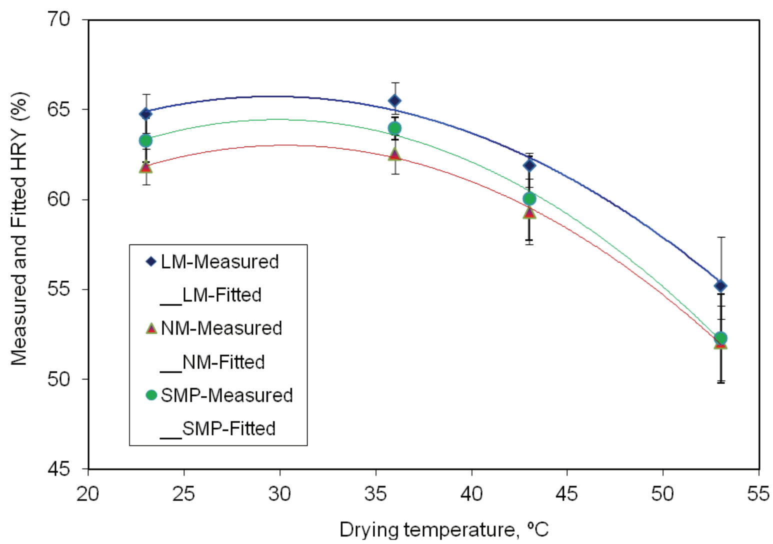


Figure 1. Measured and fitted HRY of medium-grain rice M202 under tested moisture ranges, drying temperatures, and milling procedures.

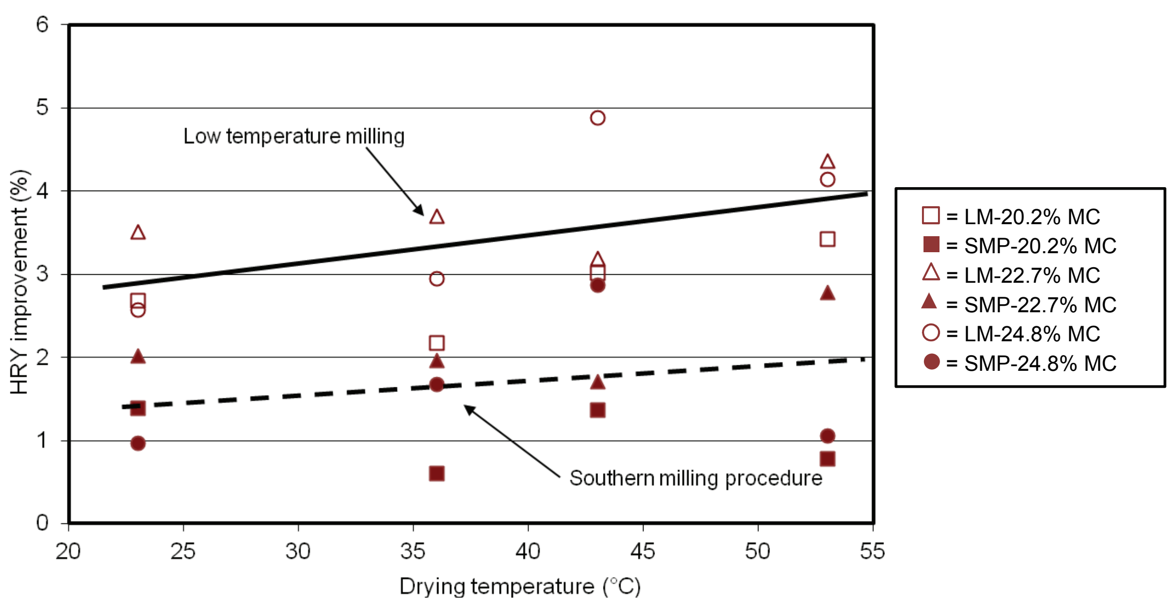


Figure 2. HRY improvement with low-temperature and southern milling procedures (LM and SMP) compared to NM.

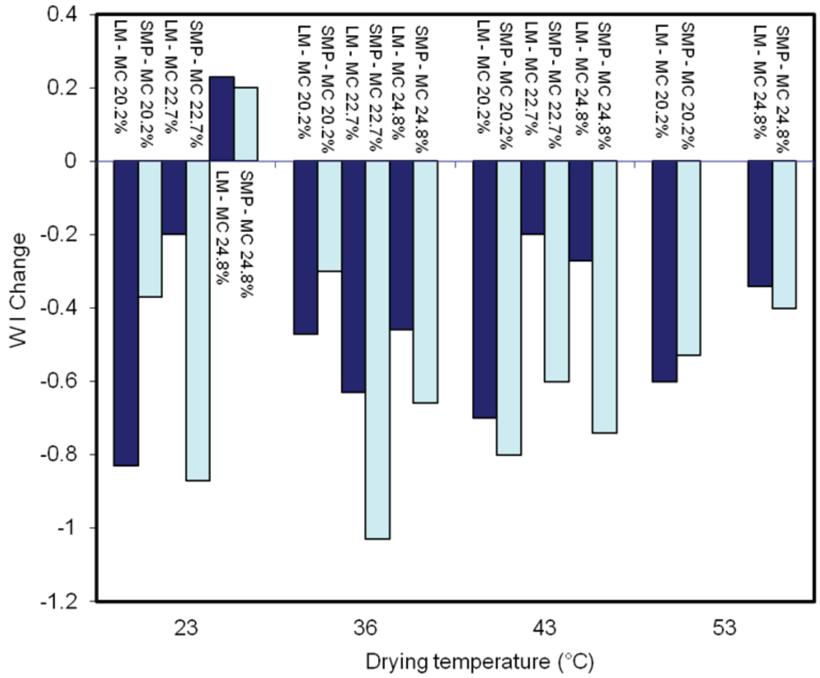


Figure 3. WI changes with low-temperature and southern milling procedures (LM and SMP) compared to NM.

ature of 43°C than for samples dried at low temperatures. The reason for the difference in appraised milling quality could be mainly due to the temperatures of the different milling procedures. It is clear that low-temperature milling had significantly lower milled rice temperature than the normal milling and southern milling procedures, which resulted in reduced breakage of milled rice. The milled rice temperatures were 51.7°C ±0.7°C, 60.7°C ±0.4°C, and 67.0°C ±0.4°C for LM, SMP, and NM, respectively.

Based on the above results and analysis, milling procedures can cause a greater variation in appraised milling quality. Therefore, it is relevant to apply appropriate milling procedures to reflect the real milling quality appraisals of rice lots. Low-temperature milling can lead to significant improvement in milling quality appraisals for rough rice harvested at high moisture content and dried using an air temperature of 43°C.

Effect of Drying Procedure and Storage Time

This section discusses the effects of drying procedure, moisture measurement method, moisture change during storage, and storage period on milling quality appraisals. In general, the drying method and storage period did not cause any significant change in measured moisture contents of rice samples during storage of up to 28 days after drying (table 5). However, it is clearly observed that the moisture contents measured with the single-kernel moisture meter

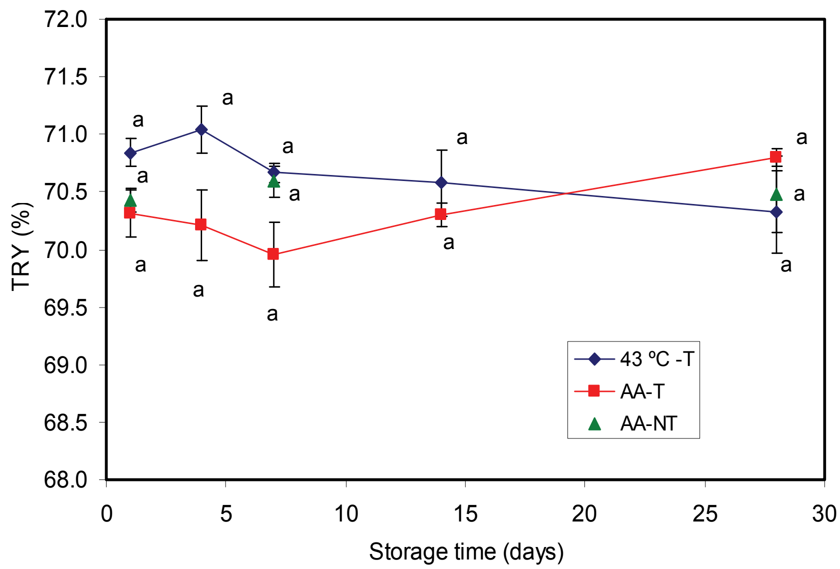
Table 5. Moisture contents of rice samples at different storage times.[a]

Initial MC	Drying Method	Measurement Method	Storage Time 1 day	4 days	7 days	14 days	28 days	Average
20.5%	43°C	Oven	12.86 ±0.10	13.01 ±0.08	13.24 ±0.27	13.58 ±0.29	13.48 ±0.32	13.23 ±0.11
		DKJ	12.60 ±0.08	12.70 ±0.08	12.55 ±0.06	12.48 ±0.05	12.55 ±0.06	12.58 ±0.01
		SKM	13.88 ±0.05	14.15 ±0.06	14.23 ±0.05	13.78 ±0.10	13.75 ±0.06	13.96 ±0.02
	AA-T	Oven	13.12 ±0.09	13.41 ±0.35	13.42 ±0.36	13.70 ±0.20	13.90 ±0.30	13.51 ±0.12
		DKJ	12.80 ±0.08	12.98 ±0.15	13.00 ±0.08	13.05 ±0.10	13.08 ±0.05	12.98 ±0.04
		SKM	14.15 ±0.06	14.30 ±0.08	14.55 ±0.06	14.23 ±0.05	14.28 ±0.10	14.30 ±0.02
	AA	Oven	14.01 ±0.14	-	14.38 ±0.32	-	14.50 ±0.09	14.30 ±0.12
		DKJ	13.60 ±0.00	-	13.75 ±0.13	-	13.90 ±0.08	13.75 ±0.07
		SKM	14.73 ±0.10	-	14.88 ±0.05	-	15.05 ±0.06	14.88 ±0.02
25.1%	43°C	Oven	12.38 ±0.17	12.61 ±0.15	12.63 ±0.15	12.57 ±0.11	12.85 ±0.06	12.61 ±0.04
		DKJ	12.40 ±0.14	12.50 ±0.12	12.53 ±0.05	12.43 ±0.13	12.43 ±0.10	12.46 ±0.04
		SKM	13.45 ±0.06	13.75 ±0.06	13.50 ±0.08	13.88 ±0.05	13.68 ±0.05	13.65 ±0.01
	AA-T	Oven	13.83 ±0.05	14.00 ±0.46	14.03 ±0.31	14.13 ±0.12	14.28 ±0.13	14.05 ±0.17
		DKJ	13.30 ±0.14	13.53 ±0.05	13.55 ±0.13	13.53 ±0.15	13.48 ±0.10	13.48 ±0.04
		SKM	14.43 ±0.10	14.60 ±0.14	14.43 ±0.10	14.85 ±0.06	14.68 ±0.05	14.60 ±0.04
	AA	Oven	14.02 ±0.45	-	14.17 ±0.33	-	14.2 0.09	14.13 ±0.18
		DKJ	13.05 ±0.13	-	13.45 ±0.06	-	13.30 ±0.08	13.27 ±0.04
		SKM	14.33 ±0.10	-	14.45 ±0.10	-	14.55 ±0.06	14.44 ±0.02

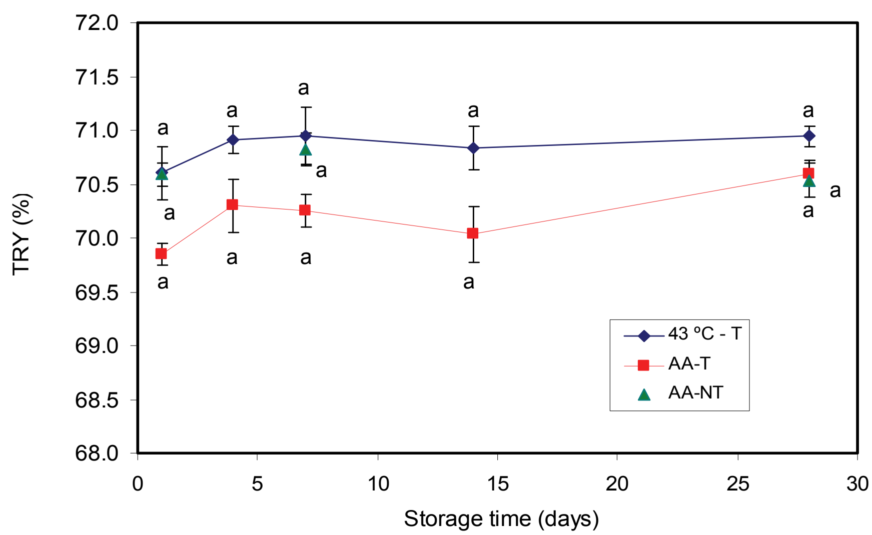
[a] AA = ambient air drying, AA-T = ambient air drying followed by tempering, DKJ = Dickey-John, and SKM = single-kernel moisture.

(SKM) were consistently higher than those measured with the oven and Dickey-John (DKJ) methods. For example, the overall average moisture contents of rice samples with initial MC of 25.1% dried at 43°C followed by 4 h tempering were 12.61% ±0.04%, 12.46% ±0.04%, and 13.65% ±0.01% as measured with the oven, DKJ, and SKM methods, respectively. The average maximum difference among the three methods was less than 1.22%. DKJ had lowest MC value, which was about 0.56% lower than the oven result. Additionally, the variation in moisture contents as measured with the different methods was very small at high MC values. When these methods were used for measuring the moisture contents before drying, the results were 25.10% ±0.20%, 25.27% ±0.15%, and 25.07% ±0.15% for rough rice with an initial MC of about 25%, and 20.50% ±0.19%, 20.3% ±0.1%, and 20.2% ±0.1% for rice with an initial MC of about 20%, as measured with the oven, DKJ, and SKM methods, respectively. This means that a direct method of measuring MC, i.e., the standard oven method, should be used to periodically calibrate the indirect methods, such as DKJ and SKM, that are widely used in the rice industry to ensure accurate results of moisture measurement.

The milling quality results for rice at different storage times are shown in figures 4 and 5. For TRY, the maximum variation (less than 1%) among the different treatments was found to be not significant at $p < 0.05$. For all tested drying methods and storage times, the TRY values ranged from 69.96 ±0.28 to 70.84 ±0.12 percentage points and from 69.96 ±0.28 to 70.84 ±0.12 percentage points for rice with an initial MC of 20.5%, and 25.1%, respectively (figs. 4a and 4b). However, significant variation in HRY was

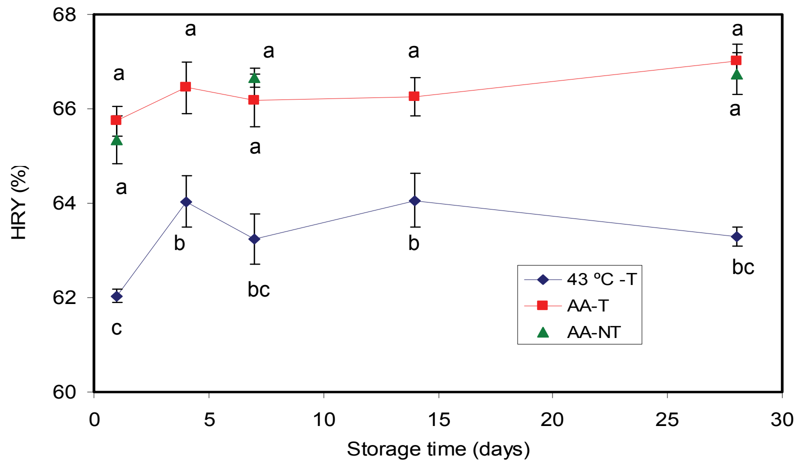


(a)

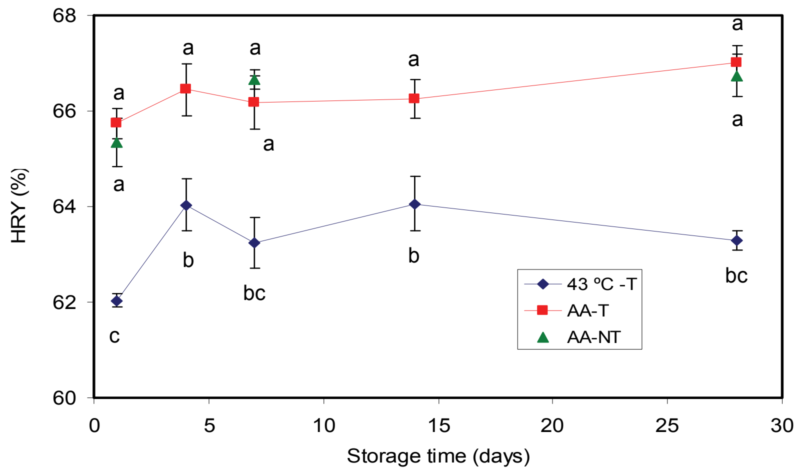


(b)

Figure 4. Effect of storage time on TRY of paddy rice with initial MC of (a) 20.5% and (b) 25.1% (AA = ambient air, T = tempering, and NT = no tempering). Values followed by the same letter are not significantly different at p < 0.05.



(a)



(b)

Figure 5. Effect of storage time on HRY of paddy rice with initial MC of (a) 20.5% and (b) 25.10% (AA = ambient air, T = tempering, and NT = no tempering). Values followed by the same letter are not significantly different at p < 0.05.

observed during the first four days of storage. Beyond four days of storage, HRY was not affected by storage time. The HRY of rice dried at 43°C increased from 62.04 ±0.14 to 64.03 ±0.14 percentage points and from 56.14 ±0.23 to 58.39 ±0.29 percentage points for rough rice with an initial MC of 20.5% and 25.1%, respectively (figs. 5a and 5b). The whiteness of 43°C dried rice was slightly lower than that of ambient air dried rice with an initial MC of 25.10%, but no difference was observed for rice with an initial MC of 20.50% (table 6). These results showed the same trend as those reported by Wasserman (1961) for short-grain rice and Pominski et al. (1965) for long-grain rice. Those researchers found that HRYs remained unchanged over a storage period of nine weeks, even though HRY had an increasing trend after one week of storage. Thompson et al. (1990) found that rice milling appraisals were unaffected by storage times of 10 to 118 days prior to milling for medium-grain rice. However, based on the aforementioned results, it is still unknown if the minimum required storage is less than four days, which needs to be further studied.

Additionally, when the moisture removal at each 20 min drying pass was examined, it was found that the moisture removal was less 2% with different drying procedures. For example, moisture removal for samples dried at 43°C followed by 4 h tempering were 1.7%, 1.8%, 1.8%, 1.5%, 1.4%, 1.3%, 1.1%, 0.7%, and 0.7% for rice with an initial MC of 25.1%, and 1.3%, 1.3%, 1.3%, 1.0%, 1.0%, and 0.6% for rough rice with an initial MC of 20.50%. It is more important to notice that the difference in HRY between rough rice with an initial MC of 25.1% dried with ambient air and at 43°C was much higher than that of rice

Table 6. Whiteness index of rice samples at different storage times.

Initial MC	Drying Method[a]	Storage Time[b]				
		1 day	4 days	7 days	14 days	28 days
20.5%	43°C-T	42.33 a	41.70 a	40.45 a	41.17 a	41.43 a
	AA-T	42.10 a	41.53 a	41.27 a	41.60 a	40.97 a
	AA-NT	41.47 a	-	40.83 a	-	40.83 a
25.1%	43°C-T	42.33 a	41.93 a	41.70 a	41.50 a	41.73 a
	AA-T	41.30 a	40.93 a	40.57 a	40.87 a	40.80 a
	AA-NT	38.70 b	-	39.07 a	-	39.07 a

[a] AA = ambient air drying, AA-T = ambient air drying followed by tempering, and AA-NT = ambient air drying with no tempering.

[b] In each category, values followed by the same letter are not significantly different at p < 0.05.

with an initial MC of 20.5%. It was unexpected that the rice dried at 43°C would have so much HRY reduction compared to ambient air dried rice, given that the moisture removal was less than 2% at each drying pass, with tempering for the rice dried at 43°C. Normally, it has been believed that less than 2% MC removal at each drying pass should not cause significant HRY loss. The exact reason for the significant HRY loss, especially for rice with 25.1% initial MC, is not known, but we suspect it is related to the tempering temperature. A further study of the effect of tempering temperature after drying on appraised milling quality is needed. Since the current procedure for drying rice from 25% to 14% moisture content requires nine time-consuming steps, heated tempering treatments may improve moisture removal during each drying pass, and may improve milling quality as well.

Based on the results obtained in this study, rice with high initial moisture content is more sensitive to preparation procedures. After four days of storage, dried rice milling appraisals were found to be unaffected by storage time. However there are possibilities of obtaining increased head yields by milling rice within a short period of time after drying. This would permit rice dryer operators to have open schedules in programming their drying operations. Additionally, to gain consistent appraised qualities, there is a need to apply an accurate approach to sample preparation procedures, including drying temperatures and tempering procedures, especially for rough rice with high initial MC.

Conclusions

The research results demonstrated that the appraised milling quality of rough rice was affected by initial MC, drying procedure, storage time after drying, and milling procedure. Rough rice with high initial MC had low TRY and HRY compared to rice with low initial MC. This means that rough rice with high initial moisture content is more sensitive to preparation procedures. A significant HRY quality reduction was observed for rice samples dried with air at temperatures of 43°C and 53°C compared to samples dried with air at temperatures of 23°C and 36°C. However, for rice samples with high initial MC dried at 43°C, the LM and SMP procedures significantly improved HRY up to 4.8% and 2.8%, respectively, compared to the NM procedure. The effect of sample preparation and milling procedure on WI and LC was not significant. It was observed that after four days of storage, dried rice milling appraisals were unaffected by storage time. Since FGIS standard milling procedures specify NM and SMP and do not specify proper sample preparation procedures, it is suggested that samples be milled for quality appraisals, be dried with 43°C air, stored for at least four days, and be subjected to the LM procedure. Further studies should be done to investigate the effects of heated tempering treatments and less than four days storage on milling quality. These findings constitute valuable information for improving the consistency and accuracy of rice milling quality appraisals.

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