e-**X**tra*

Effect of Milling Temperature and Postmilling Cooling Procedures on Rice Milling Quality Appraisals

Zhongli Pan,[1,2,3] Ragab Khir,[1,4] and James F. Thompson[1]

ABSTRACT

Cereal Chem. 90(2):107–113

The objective of this research was to study the effects of different milling conditions and postmilling handling procedures on appraised milling quality of rough rice. Rough rice (M202) with moisture content of 11.5 ± 0.2% was used for this study. The samples were milled with a McGill number 3 mill under four milling conditions, including normal milling, milling at high temperature, milling with cooling using ice water, and room temperature water. The milled rice samples were cooled in closed and open plastic containers and in open pans with three temperatures: 15, 23, and 35°C. The effects of milling and postmilling conditions on milled rice temperature, moisture loss, cooling rate, single and multiple fissuring rates, total rice yield (TRY), head rice yield (HRY), whiteness index (WI), and total lipid content (TLC) were evaluated. Results showed that high single and multiple fissuring rates and low TRY and HRY were inherent in improper milling and postmilling conditions. Single fissuring rates were 15.9 and 17.6% and multiple fissuring rates were 3.5 and 7.2% for rice samples milled under normal and high-temperature conditions, respectively. Cooling methods that used open containers and pans had more moisture losses and further resulted in lowering appraised milling quality than methods that used closed containers. Low-temperature milling conditions followed by cooling in closed containers significantly reduced single and multiple fissuring rates and improved TRY and HRY by 0.9 and 1.5 percentage points, respectively. The effects of tested milling and postmilling conditions on WI and TLC were not significant. Obtained results constitute valuable information for developing milling and cooling procedures to achieve consistent, accurate, and reliable milling quality appraisals for rough rice.

Milling quality is an important property that plays a decisive role in determining the market value of rough rice. Consequently, the appraisal of milling quality is considered as an important analytical evaluation step that should reflect the real value of rough rice. Appraisal processes of rice samples are normally done in a laboratory with a specific mill (McGill number 3 mill) following standard procedures prescribed by the USDA Federal Grain Inspection Service (FGIS) (USDA-FGIS 2005) in the United States. As milling with a McGill number 3 mill is a batch, single process that is different from the current commercial continuous, multipass milling process, heat generation and accumulation in the cutter bar and rice during milling could cause a reduction in the appraised milling quality. After milling, the milled rice is exposed to varying environments that may affect quality appraisals (USDA-FGIS 1979; Pan and Thompson 2002; Mutters and Thompson 2009; Bhattacharya 2011). However, the reason for such a potential source of difference in milling quality appraisals triggered by milling and postmilling conditions during quality analysis is not given a pride of position in the literature.

The standard milling procedures have been updated several times (USDA-FGIS 1979, 1982, 1994, 2005). However, there is only limited information describing the effect of rice sample preparation procedures, milling conditions, and postmilling handling procedures on milling quality appraisals (Thompson et al 1990; Pan and Thompson 2002, 2005). We have been conducting a series of studies to investigate the influence of sample preparation procedures, including initial moisture contents, drying and tempering treatments, storage time after drying, and milling procedures on milling appraisals. We found that the appraised milling quality was sensitive to variation in rough rice conditions, sample preparation, and milling procedures (Pan and Thompson 2005, 2007). Because inappropriate milling conditions followed by improper postmilling handling procedures can negatively impact the milling quality and lead to inconsistent and unreliable appraisals of rough rice (Bhattacharya 2011), there is a great need to quantitatively understand the effects of milling conditions and postmilling handling procedures on the milled rice temperature, moisture loss, cooling rate, and single and multiple fissuring rates that eventually affect milling quality.

Milling quality appraisal is specified by three aspects: total rice yield (TRY), head rice yield (HRY), and whiteness index (WI). Milling and postmilling practices can affect appraised TRY and HRY. Pan and Thompson (2002) studied the relationships between mill heat generation, milled rice temperature, and quality indicators (TRY, HRY, and WI) of medium-grain rice samples milled with a McGill number 3 mill. They found that the highest temperatures of the cutter bar and milled rice reached 74 and 84°C, respectively. The high cutter bar and milled rice temperatures caused significant reduction in the appraised TRY and HRY of milled rice. Archer and Siebenmorgen (1995) reported that HRY was improved by lowering the brown rice temperature before milling. Also, Mohapatra and Bal (2004) did a similar study with a laboratory-scale abrasive mill and found that the HRY decreased linearly with an increase in milled rice temperature. Milling for a longer duration (overmilling) could result in low TRY and HRY, without any further improvement in the whiteness or degree of milling. In contrast, a shorter duration milling (undermilling) could result in high TRY and HRY and produce a darker appearance and high lipid content in the milled rice. Both overmilling and undermilling are undesirable in rice sample milling, because they produce an appraised quality that does not reflect the potential quality in commercial milling (Andrews et al 1992).

In addition, fissured milled rice kernels cause great financial losses in monetary value of rough rice; hence, fissures in the grain are probably the greatest concern in rice milling (Sharma and Kunze 1982). Quantifying the rates of fissure formation in rice kernels at all stages of rice sample handling, milling, transportation, and end-use processing is necessary to design equipment and implement procedures for minimizing fissure formation

---

*The *e*-**X**tra logo stands for "electronic extra" and indicates that Figures 1–8 appear in color online.

[1] Department of Biological and Agricultural Engineering, University of California, Davis, One Shields Avenue, Davis, CA 95616, U.S.A.

[2] Processed Foods Research Unit, USDA-ARS Western Regional Research Center, 800 Buchanan St., Albany, CA 94710, U.S.A.

[3] Corresponding author. Phone: (510) 559-5861. Fax: (510) 559-5851. E-mail: zhongli.pan@ars.usda.gov or zlpan@ucdavis.edu

[4] Department of Agricultural Engineering, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt.

http://dx.doi.org/10.1094/CCHEM-08-12-0095-R

(Siebenmorgen and Qin 2005). The fissuring can not only accrue during milling but also occur upon subsequent postmilling handling procedures. Depending on the temperature to which the kernel is exposed immediately after milling, a sufficient volume of the outer kernel may be forced to transition to the glassy state because of the rapid movement of the intrakernel cooling front, whereas the center remains in the rubbery state. This change causes the surface and center portions of the kernel to experience different magnitudes of material properties, which causes fissure formation (Cnossen et al 2000, 2003; Perdon et al 2000; Cnossen and Siebenmorgen 2002; Schulterman and Siebenmorgen 2007). However, fissuring may be avoided by controlling the environmental conditions during the postmilling cooling process (Bhattacharya 2011). Many millers have observed that rice kernel breakage can be minimized by controlling the temperature and humidity change during milled rice cooling; doing so positively affected HRY (Stermer 1968; Noomhorm and Yubai 1991; Siebenmorgen et al 1998; Chen et al 1999; Lloyd and Siebenmorgen 1999). It has also been noticed that cooling milled rice grains in closed containers after milling reduced grain breakage (Autrey et al 1955).

Moreover, our previous studies (Pan and Thompson 2005; Pan et al 2005, 2007) have shown that rice milled with the McGill number 3 mill under the standard FGIS milling procedures had significantly higher temperature than the rice from current commercial mills. The high-temperature milled rice in the rice sample milling needs to be cooled to room temperature before the quality evaluation is conducted. The current rice sample cooling procedures with different containers and conditions may cause moisture loss and fissure of milled rice. Based on the aforementioned facts, there is clear evidence that improper milling and postmilling practices can cause reduction in appraised milling quality. However, documented information describing the effects of milling conditions and postmilling handling procedures on milling quality appraisals of rough rice is limited. Therefore, the specific objectives of this study were to 1) study the effect of milling conditions and postmilling handling procedures on temperature, moisture loss, cooling rate, fissure rate, and total lipid content (TLC) of milled rice; 2) determine the impact of milling procedures and postmilling cooling method on milling quality appraisals; and 3) develop regression models to predict fissuring rates and HRY change under tested rice milling and postmilling conditions.

MATERIALS AND METHODS

Milling Procedures

A medium-grain rice lot, variety M202, obtained from Pacific International Rice Mills (Woodland, CA, U.S.A.) was used for this study. The initial moisture content (MC) of the rice lot was 11.5 ± 0.2%. The MC was determined by the air oven method (130°C for 24 hr) (ASAE 1995). All reported MCs in this study are averages of three replicates on a wet basis. The rice lot was split into 1,000 g samples with a standard FGIS grain sample divider. The samples were milled in triplicate in a laboratory mill (McGill number 3) at the California Department of Food and Agriculture (CDFA) Laboratory (West Sacramento, CA, U.S.A.) according to the standard Western milling procedure of FGIS (USDA-FGIS 2005). The four milling conditions included normal milling, milling at high temperature, milling with cooling using ice water, and normal water at room temperature as the cooling medium, as shown in Table I. Each condition is described in detail in the following sections.

TABLE I
Experimental Design of Milling and Postmilling Cooling Conditions

Milling Conditions	Temperature of Postmilling Cooling (°C)	Cooling Container Conditions
Ice water cooling	Low, 15	Closed
	Room, 23	Closed
	High, 35	Closed
Room temperature water cooling	Low, 15	Closed
	Room, 23	Closed
	High, 35	Closed
Normal milling	Low, 15	Closed
	Room, 23	Closed
	Room, 23	Open
	Room, 23	Open pan
	High, 35	Closed
High-temperature milling	Low, 15	Closed
	Room, 23	Closed
	High, 35	Closed

Cooling Procedures

To reduce the temperatures of milled rice and the cutter bar of the McGill number 3 mill during milling, two external and internal cooling devices (heat exchangers) were developed in the Food Processing Laboratory in the Department of Biological and Agricultural Engineering, University of California, Davis (Pan et al 2005). The cooling mechanism with the heat exchangers was described in detail in our previous publications (Pan et al 2005, 2007). The cooling medium was pumped through the heat exchangers at a flow rate of 0.98 kg/min. Both the external and internal heat exchangers were used at the same time for the milling study. Ice-cooled water (2 ± 1°C) and normal water at ambient temperature (21 ± 1°C) were used as cooling media during milling with cooling conditions as presented in Table I. Because 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 current standard Western milling procedures. Aforementioned cooling procedures were followed to conduct the milling with cooling using ice water and normal water at room temperature.

Adjustment and Measurement of Temperatures

To avoid reduction in TRY and HRY of milled rice caused by extensive rice breakage and moisture loss resulting from high temperature of milling, the milling practice at the CDFA laboratory is to keep the temperature of the cutter bar of the mill at 48–52°C before rice sample milling. Hence, if the cutter bar is below the aforementioned temperature range, one or two rice samples are milled before an official rice sample is milled. Additionally, if the cuter bar temperature is above the aforementioned temperature range, a small fan is used to cool the temperature to the required range (Pan et al 2005). In this study, the temperature of the cutter bar prior to the start of milling was designated as initial cutter bar temperature. The initial temperatures of the cutter bar were 13, 23, 49, and 70°C for ice water cooling, normal room temperature water cooling, normal milling, and high-temperature milling conditions, respectively. After the rice sample was milled and unloaded from the rice mill, the temperature of the cutter bar was measured again and designated as ending cutter bar temperature. Both initial and ending cutter bar temperatures were measured with an infrared thermometer (OSXL653, Omega Engineering, Stamford, CT, U.S.A.) and reported under different milling conditions. 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. Also, the temperatures of milled rice and rice bran were measured with a type T thermocouple with a time constant of 0.15 sec (Omega Engineering) immediately after the milled rice was unloaded from the mill. The thermocouple was kept at the center of the rice and bran mass until the temperature reading stabilized, which normally took 10–30 sec.

Postmilling Cooling Procedures

To study the effects of postmilling cooling conditions on the rice milling quality, the milled samples were handled according to the experimental design shown in Table I. The rice samples milled under different conditions, as described before, were transferred immediately after each milling batch to plastic containers for cooling. The containers had dimensions of 10 cm (length), 10 cm (width), and 15 cm (height). The samples were cooled with three temperatures, 15, 23, and 35°C, which were used to simulate different cooling environmental temperatures. For the rice milled with the normal milling conditions, the samples were cooled in open containers and pans. To cool the milled samples with temperatures of 15 and 35°C, the samples were transferred to incubators set at those temperatures. The samples were cooled from their temperatures recorded after milling to a temperature close to aforementioned temperatures for cooling environment. The maximum difference between the cooled samples and surrounding environment was less than 2°C. The temperature changes under different postmilling conditions were measured with thermocouples (Omega Engineering) and recorded with a data logger (multichannel data acquisition). All postmilling cooling tests were conducted in triplicate. The temperature and relative humidity in the lab were 23 ± 1°C and 44 ± 3%, respectively.

Evaluation of Milled Rice Quality

The milling evaluation was based on FGIS procedures. Evaluation parameters involved TRY, HRY, WI, fissuring rate, and TLC. The TRY, HRY, WI, and TLC were measured at Pacific International Rice Mills. The WI was used to evaluate the whiteness of milled rice determined with whiteness tester C-300 (Kett Electronic Laboratory, Tokyo, Japan). A high index number indicated whiter milled rice. The TLC was measured following a NIR method with an Infratech 1221 grain analyzer (Foss North America, Eden Prairie, MN, U.S.A.). The TLC was reported as percentage of sample weight on a dry basis. The fissuring rates of whole rice kernels were examined visually under light. The numbers of whole kernel rice with a single fissure (one crack) or multiple fissures (more than one crack) were recorded. Three samples (100 kernels each) from each milling batch and cooling condition were used. The numbers of kernels with fissures were reported as percentage of the total kernels. The moisture contents of rough rice and milling fractions were also measured following the standard oven method (ASAE 1995; AOAC 1995), and then the mass balance of the different fractions and moisture loss caused by the milling were determined.

Statistical Analysis

Data were analyzed statistically with Sigma State software (version 2.0, Jandel, San Rafael, CA, U.S.A.) with one-way repeated measures ANOVA and multiple comparisons. The least square means with Tukey's adjustment method was used to compare treatment means. Significance was reported at the $P < 0.05$ level for all data. Also, regression models were developed to predict HRY change under tested milling and postmilling conditions.

RESULTS AND DISCUSSION

Temperature, Moisture, and TLC Changes Under Different Milling Conditions

The temperatures of the cutter bar (end of milling), milled rice, and rice bran under different milling conditions are shown in Figure 1. It can clearly be seen that the temperatures were closely related to the milling conditions. High initial cutter bar temperatures corresponded to high milled rice temperatures. The milled rice temperatures with ice water cooling during milling were 14.8 and 23.9°C lower than those with the current milling practice (normal milling) and milling with high temperature, respectively. Similarly, the milled rice temperatures with normal room temperature water cooling during milling were 12.2 and 21.3°C lower than those with the current milling practice and milling with high temperature, respectively. Additionally, the milled rice temperature was very high and reached a level of 79.5°C when the rice samples were milled at high temperature (70°C initial cutter bar temperature). This situation means that the current milling practices according to FGIS procedures resulted in high milled rice temperature, which may negatively affect the appraised milling quality. On the other hand, rice milling under cooling conditions significantly reduced the milled rice temperature, which may positively affect the appraised milling quality. These results were consistent with those we reported before (Pan and Thompson 2002; Pan et al 2005, 2007).

In addition, after examining the MC and TLC of milled rice and MC of rice bran under different milling conditions, there was no significant difference (at $P < 0.05$) in MC and TLC values. However, the high-temperature milling condition resulted in lower MCs in milled rice and rice bran because of water evaporation (Fig. 2). On the other hand, the TLC of rice samples milled at a high temperature was slightly higher than those milled at a low temperature or under cooling conditions. The obtained results could be implemented to control the milled rice temperatures during milling with a McGill number 3 mill for matching with commercial milling practice to reflect the real milling quality of rough rice.

Effects of Postmilling Cooling Conditions on Cooling Rates and Moisture Loss

The typical cooling curves of rice samples milled under normal milling conditions and cooled with different methods are shown in Figure 3. It is clear that a cooling process with an open pan

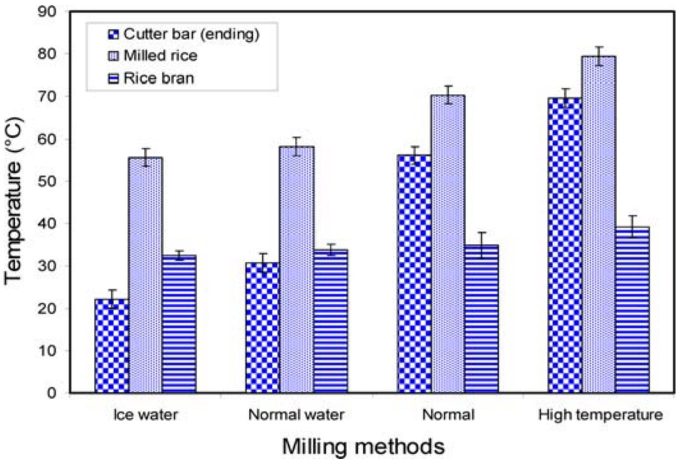

Fig. 1. Temperatures of ending cutter bar, milled rice, and rice bran under different milling conditions.

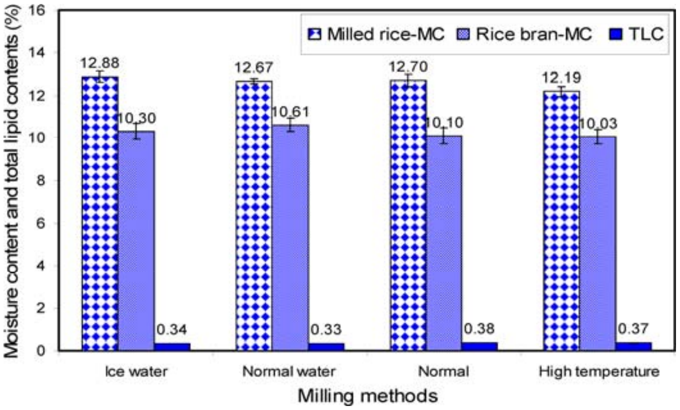

Fig. 2. Moisture contents (MC) of milled rice and rice bran and total lipid contents (TLC) of milled rice obtained under different milling conditions.

significantly reduced the required cooling time, because of the high cooling rate of the thin layer of rice in the pan. The half-cooling times were 25, 55, 65, 70, and 80 min for rice samples milled under normal milling conditions and cooled under conditions of open pan at room temperature, closed container at low temperature, open container at room temperature, closed container at room temperature, and closed container at high temperature, respectively (Fig. 3). As expected, the high postmilling cooling temperature reduced the cooling rate or increased the cooling time required to reach ambient temperature. The low temperature and open container cooling methods did not improve the cooling much. Similar trends were observed for rice milled under the other tested milling conditions.

Moreover, high cooling rate associated with the use of open container and open pan cooling methods resulted in slightly more moisture losses compared with closed container cooling (Fig. 4). The total weights of milled rice cooled by open container and open pan were about 5 g lower than the weight of the rice cooled in the closed containers, which means about a 0.8 percentage point reduction in TRY. The reduction could partially result from the moisture loss that occurred during cooling. Therefore, open container and open pan cooling methods are not recommended to be used for milled rice cooling during sample analysis for milling quality appraisals.

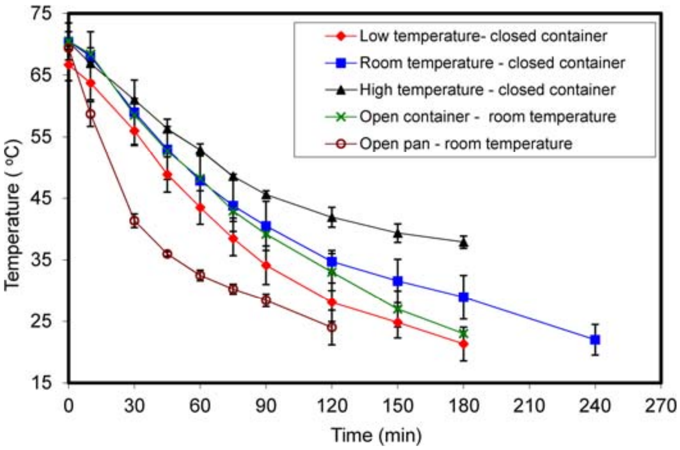

Fig. 3. Cooling curves of milled rice under normal milling conditions.

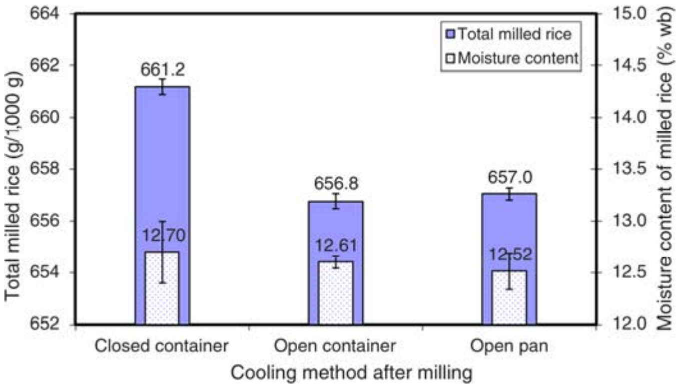

Fig. 4. Total milled rice weights and moisture contents obtained under different cooling conditions at room temperature.

Additionally, it is important to observe from the mass balance data shown in Table II that the average total moisture loss from rice bran and milled rice was 2.5% under the tested milling conditions. The high moisture loss should result in lower HRY, which is calculated based on the weight of milled rice. Therefore, the HRY loss caused by moisture evaporation in the rice samples milled under normal and high-temperature milling conditions could be higher than that of samples milled under cooling conditions. Consequently, to achieve a consistent appraisal for rice quality, it is essential to control the milled rice temperatures and moisture loss for the current rice sample milling practice. Also, it will be useful for commercial milling processes to control moisture loss that occurs during the rice milling process.

Effect of Milling and Postmilling Conditions on Rice Fissuring Rates

Fissuring rates of rice samples under tested milling and postmilling conditions are presented in Figure 5. In general, high milling temperature led to higher single and multiple fissuring rates (SFR and MFR, respectively) in the milled rice. The average SFRs were 12.3, 10.0, 15.9, and 17.6% for rice samples milled under milling conditions of ice water, normal room temperature water, normal milling, and high-temperature milling, respectively. The corresponding MFRs were 1.4, 2.7, 3.5, and 7.2%. The results indicated that normal and high-temperature milling significantly increased both SFR and MFR for milled rice. In contrast, under each milling condition, high cooling temperatures decreased both SFR and MFR compared with low and room temperature cooling conditions (Fig. 5). When the rice samples were milled under ice water milling conditions, the SFRs and MFRs were 10.3 and 0.7% for high-temperature cooling, 15.3 and 1.0% for room temperature cooling, and 11.3 and 2.7% for low-temperature cooling. A similar trend was observed for all tested milling and postmilling conditions. Also, the SFRs and MFRs were 13.0 and 4.3% for open container and 13.0 and 5.5% for open pan cooling methods, respectively. The increased fissuring rates that occurred during milling under high-temperature conditions and under low and room temperature cooling conditions may result from dramatic changes in kernel material properties. As rice kernels with MC levels ranging from 12 to 14% were exposed to temperature levels more than 60°C or cooled from high to low temperatures without being tempered, the starch properties such as density, diffusivity, and expansion coefficient dramatically changed from low to high levels or vice versa. These changes played a significant role in the fissure formation. This phenomenon was previously explained and reported by Cnossen et al (2000), Perdon et al (2000), Cnossen and Siebenmorgen (2002), and Schluterman and Siebenmorgen (2007). Based on the obtained results, improper milling and postmilling procedures can cause kernel fissuring and reduce nonfissured rice kernels.

It can be seen that normal and high-temperature milling had significantly ($P < 0.05$) low percentages of nonfissured rice kernels (Fig. 6). The average nonfissured rice kernel percentages were 85.1, 87.1, 81.8, and 75.3% for rice samples milled under

TABLE II
Mass Balance of Rice Milled Under Different Milling Conditions (g)

Milling Conditions	Dockage	Rough Rice	Hull	Brown Rice	Milled Rice	Bran	Moisture Loss
Ice water	12.5 ± 2.1	987.5 ± 2.1	181.4 ± 3.6	806.1 ± 5.1	660.7 ± 5.4	122.1 ± 2.1	23.3 ± 1.4
Room temperature water	11.2 ± 0.8	988.8 ± 0.6	179.2 ± 2.2	809.6 ± 2.3	661.2 ± 1.9	122.9 ± 6.2	25.5 ± 1.3
Normal	13.2 ± 1.8	986.8 ± 1.8	181.4 ± 3.4	805.5 ± 5.0	665.2 ± 3.5	116.8 ± 2.9	23.4 ± 1.6
High temperature	11.2 ± 1.5	988.8 ± 1.5	178.9 ± 3.1	809.9 ± 4.1	660.9 ± 5.1	119.5 ± 6.4	29.4 ± 1.8
Average (%)	1.2 ± 1.0	98.8 ± 1.0	18.0 ± 1.4	80.8 ± 2.3	66.2 ± 2.1	12.0 ± 2.7	2.5 ± 0.3

milling conditions of ice water, normal room temperature water, normal milling, and high-temperature milling, respectively. This observation shows the advantage of low-temperature milling conditions, which is in agreement with what we reported previously (Pan et al 2005, 2007). Additionally, high correlations were found between rice milled temperatures and SFR, MFR, and nonfissuring rates (NFR). Hence, regression models were developed to predict SFR, MFR, and NFR of rice samples, medium-grain M202, under tested milling and postmilling conditions (Table III).

TABLE III
Regression Equations for Fissuring Rate and Milled Rice Temperatures Under Different Tested Milling and Cooling Conditions[z]

Fissuring	Model	R^2	EES
Single	SFR = 4.671 + (0.157 × MRT)	0.94	0.49
Multiple	MFR = –10.068 + (0.212 × MRT)	0.96	0.53
Nonfissured	NFR = 113.198 – (0.460 × MRT)	0.95	1.20

[z] SFR = single fissure rate; MFR = multiple fissure rate; NFR = nonfissure rate; MRT = milled rice temperature; and EES = standard error of estimate.

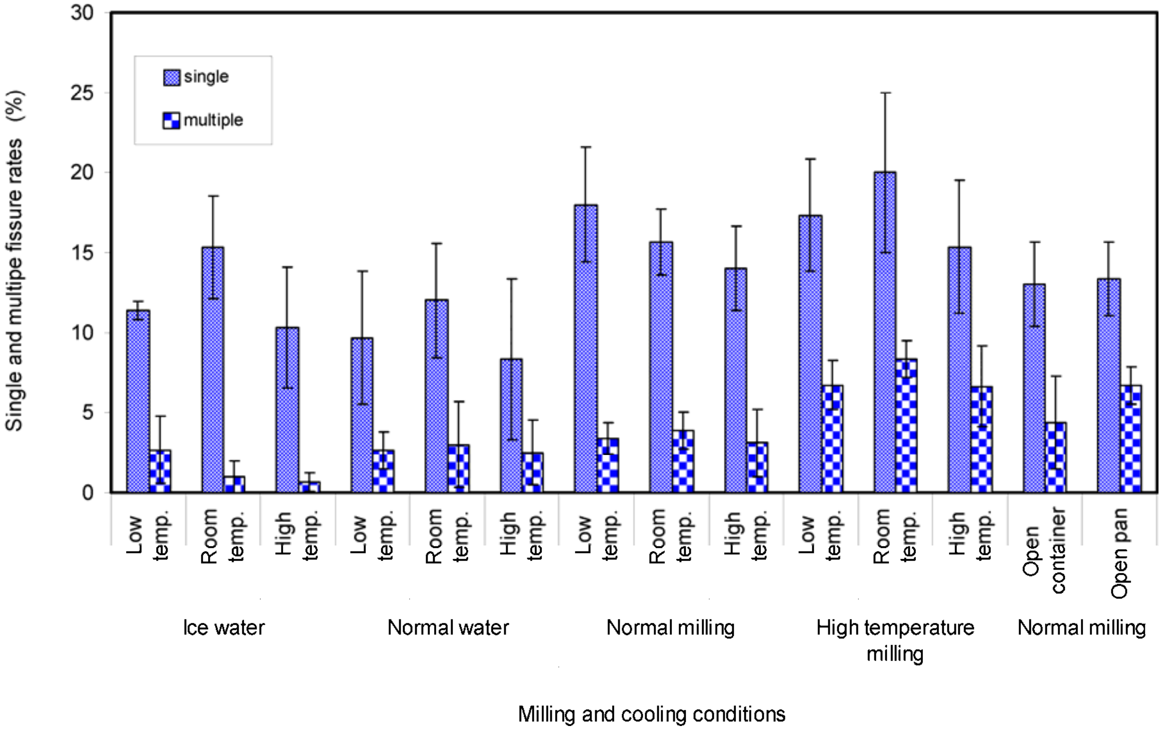

Fig. 5. Fissure rates of milled rice under different milling and postmilling cooling conditions.

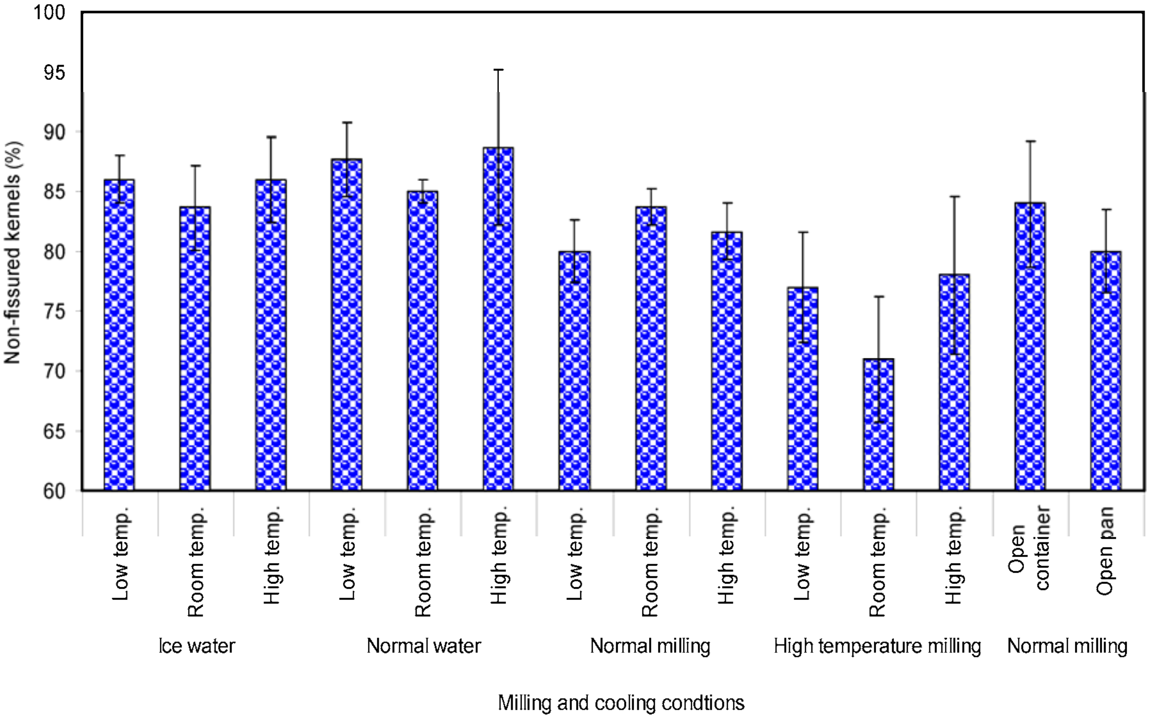

Fig. 6. Nonfissured kernels of milled rice obtained under different milling and postmilling cooling conditions.

The model-predicted and measured SFR, MFR, and NFR were plotted against rice milled temperature ranges under tested milling conditions (Fig. 7). The maximum differences between predicted and measured values were 2.1% for SFR, 1.85% for MFR, and 2.9% for NFR.

Based on these results, postmilling cooling procedures that use closed containers are appropriate compared with the open container and open pan cooling methods. Different cooling temperatures may only affect the cooling rates but not the quality results. Because the low milling temperature followed by postmilling cooling procedures that used closed containers reduced the fissure rate in milled rice, it is recommended for use in rice sample milling analysis.

Milling Quality Under Different Milling and Postmilling Conditions

Milling quality parameters including TRY, HRY, and WI of rice samples under different milling and postmilling conditions are presented in Table IV. The TRYs did not change much under different milling conditions. However, TRYs were significantly affected by cooling methods, particularly for open container and open pan cooling methods. The corresponding average TRYs were 66.2, 66.1, 65.9, and 65.8% for rice samples milled under milling conditions of ice water, normal room temperature water, normal milling, and high-temperature milling, respectively. The average TRYs for rice samples cooled with open container and open pan methods decreased by 0.8 and 0.9 percentage points compared with those cooled with the closed container method.

The HRYs were significantly affected by both milling and postmilling conditions. The average HRY for rice samples milled under normal milling conditions decreased by 1.2 and 1.5 percentage points compared with those milled under the room temperature water and ice water milling conditions, respectively. Also, the average HRYs for rice samples milled under high-temperature milling conditions decreased by 2.1 and 2.4 percentage points compared with those milled under the room temperature water and ice water milling conditions, respectively. Additionally, the average HRY for rice samples cooled with the high-temperature cooling method was higher than those cooled with low and room temperature cooling methods. The decreased HRY trend against milled rice temperatures under different milling conditions is shown in Figure 8. These results are consistent with those we reported before (Pan et al 2005). The decreased HRYs under normal and high-temperature milling conditions followed by low and room temperature cooling methods resulted from a high fissuring rate induced by the high temperature during the milling process and the subsequent improper cooling method.

There was no significant difference among WI values for rice samples under different milling and postmilling conditions. However, all WI values were higher than 41 units, which means that the white appearance was commercially acceptable according to FGIS standards for rice samples under tested conditions. Such results showed that the rice milling quality appraisals are very sensitive for milling and postmilling conditions. It is recommended to use low-temperature milling followed by cooling in

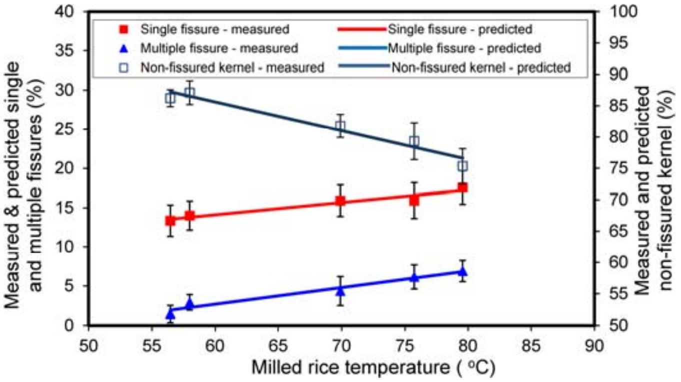

Fig. 7. Measured and predicted single and multiple fissures and nonfissured kernels over milled temperatures.

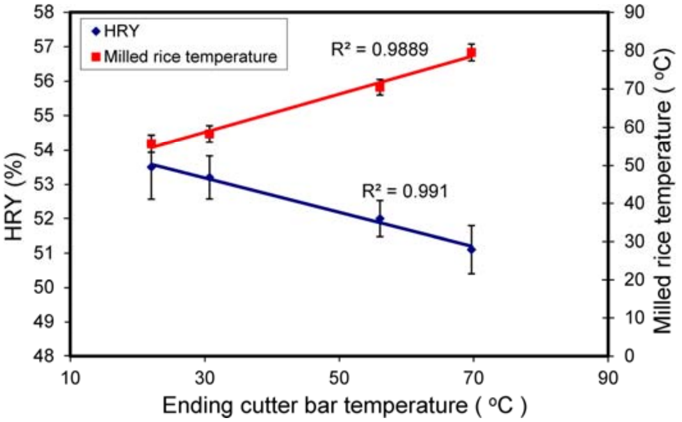

Fig. 8. Relationship between ending cutter bar temperature and head rice yield (HRY) and milled rice temperature.

TABLE IV
Total Rice Yield (TRY), Head Rice Yield (HRY), and Whiteness Index (WI) Obtained Under Different Milling and Postmilling Conditions^z

Milling Conditions	Temperature of Postmilling Cooling (°C)	Cooling Container Conditions	Milling Quality TRY (%)	HRY (%)	WI (unit)
Ice water cooling	Low, 15	Closed	66.2 ± 0.4a	53.2 ± 0.1b	41.7 ± 0.2a
	Room, 23	Closed	66.1 ± 0.7a	53.6 ± 1.8ab	41.6 ± 0.3a
	High, 35	Closed	66.2 ± 0.7a	53.7 ± 0.5a	41.4 ± 0.2a
Room temperature water cooling	Low, 15	Closed	66.1 ± 0.2a	53.0 ± 0.4b	41.7 ± 0.1a
	Room, 23	Closed	66.1 ± 0.2a	53.1 ± 0.6ab	41.8 ± 0.3a
	High, 35	Closed	66.1 ± 0.2a	53.5 ± 0.5a	41.8 ± 0.2a
Normal milling	Low, 15	Closed	66.1 ± 0.1a	52.1 ± 0.4bc	41.5 ± 0.2a
	Room, 23	Closed	66.1 ± 0.1a	52.2 ± 0.5bc	41.4 ± 0.3a
	Room, 23	Open	65.3 ± 0.2b	51.8 ± 0.4c	41.4 ± 0.3a
	Room, 23	Open pan	65.2 ± 0.1b	51.6 ± 0.5cd	41.3 ± 0.3a
	High, 35	Closed	66.0 ± 0.2ab	52.2 ± 0.7bc	41.2 ± 0.3a
High-temperature milling	Low, 15	Closed	65.8 ± 0.2ab	50.9 ± 0.5d	41.8 ± 0.2a
	Room, 23	Closed	65.9 ± 0.2ab	51.1 ± 0.6d	41.8 ± 0.3a
	High, 35	Closed	65.6 ± 0.2b	51.2 ± 1.8cd	41.7 ± 0.2a

^{z} Averages followed by the same letter in each column are not significantly different at $P < 0.05$.

closed containers to achieve reliable and consistent milling quality appraisals.

CONCLUSIONS

This study showed that the milling quality appraisals of medium-grain rice (M202), particularly TRY and HRY, were affected by milling temperature and postmilling cooling conditions. Normal and high-temperature milling conditions resulted in high milled rice temperatures, which were associated with high SFRs and MFRs compared with milling under cooling conditions. The improper milling conditions also significantly reduced HRY. However, milling under cooling conditions with ice water and room temperature water significantly reduced milled rice temperatures, SFRs, and MFRs and improved HRY. Additionally, suitable postmilling cooling procedures led to improved milling quality. Open container and open pan cooling methods are not recommended because they had more moisture losses and resulted in lowered appraised quality than closed container cooling. An integrated positive effect for milling under cooling conditions followed by closed container cooling improved TRY and HRY by 0.9 and 1.5 percentage points, respectively. There was no significant effect of milling temperature and postmilling cooling conditions on WI and TLC. To accurately and reliably appraise rice milling quality, it is concluded that milling under cooling conditions followed by closed container cooling should be applied.

ACKNOWLEDGMENTS

The investigators express their appreciation for the partial financial support from the California Rice Research Board and supports received from the USDA, CDFA, FGIS, and Pacific International Rice Mills, Inc.

LITERATURE CITED

Andrews, S. B., Siebenmorgen, T. J., and Mauromoustakos, A. 1992. Evaluation of the McGill no. 2 rice miller. Cereal Chem. 69:35-43.

AOAC. 1995. Official Methods of Analysis, 16th Ed. Method 925.10. Solids and moisture in flour-air oven method—Final action. Association of Official Analytical Chemists: Washington, DC.

Archer, T. R., and Siebenmorgen, T. J. 1995. Milling quality as affected by brown rice temperature. Cereal Chem. 72:304-307.

ASAE. 1995. Standard S352.2, 42nd Ed. Moisture measurements—Unground grain seeds. Moisture relationships of grains. ASAE: St. Joseph, MI.

Autrey, H., Grigorieff, W. W., Altschul, A. M., and Hogan, J. T. 1955. Effects of milling conditions on breakage of rice grains. J. Agric. Food Chem. 3:593-599.

Bhattacharya, K. R. 2011. Rice Quality: A Guide to Rice Properties and Analysis. Woodhead: Philadelphia, PA.

Chen, H., Siebenmorgen, T. J., and Du, L. 1999. Quality characteristics of medium-grain rice milled in a three-break commercial milling system. Cereal Chem. 76:473-475.

Cnossen, A. G., and Siebenmorgen, T. J. 2002. The glass transition temperature concept in rice drying and tempering: Effect on drying rate. Trans. ASAE 45(3):759-766.

Cnossen, A. G., Siebenmorgen, T. J., Yang, W., and Bautista, R. C. 2000. The glass transition temperature concept in rice drying and tempering: Effect on milling quality. Trans. ASAE 43(6):1661-1667.

Cnossen, A. G., Jimenez, M. J., and Siebenmorgen, T. J. 2003. Rice fissuring response to high drying and tempering temperatures. J. Food Eng. 59:61-69.

Lloyd, B. J., and Siebenmorgen, T. J. 1999. Environmental conditions causing milled rice kernel breakage in medium-grain varieties. Cereal Chem. 76:426-427.

Mohapatra, D., and Bal, S. 2004. Wear of rice in an abrasive milling operation, part II: Prediction of bulk temperature rise. Biosyst. Eng. 89(1):101-108.

Mutters, R. G., and Thompson, J. F. 2009. Rice quality handbook. Publication 3514. University of California, Agriculture and Natural Resources: Oakland, CA.

Noomhorm, A., and Yubai, C. 1991. Effect of tropical environmental conditions on rice kernel breakage during milling. J. Sci. Food Agric. 55:521-528.

Pan, Z., and Thompson, J. F. 2002. Improvement of accuracy and consistency of rice sample milling. Research Progress Report. California Rice Research Board: Yuba City, CA.

Pan, Z., and Thompson, J. F. 2005. Improvement of accuracy and consistency of rice sample milling. Research Progress Report. California Rice Research Board: Yuba City, CA.

Pan, Z., and Thompson, J. F. 2007. Development of Standard Rice Sample Preparation Procedures. Research Progress Report. California Rice Research Board: Yuba City, CA.

Pan, Z., Thompson, J. F., Amaratunga, K. S. P., Anderson, T., and Zheng, X. 2005. Effect of cooling methods and milling procedures on the appraisal of rice milling quality. Trans. ASAE 48(5):1865-1871.

Pan, Z., Amaratunga, K. S. P., and Thompson, J. F. 2007. Relationship between rice sample milling conditions and milling quality. Trans. ASABE 50(4):1307-1313.

Perdon, A., Siebenmorgen, T. J., and Mauromoustakos, A. 2000. Glassy state transition and rice drying: Development of a brown rice state diagram. Cereal Chem. 77:708-713.

Schluterman, D. A., and Siebenmorgen, T. J. 2007. Relating rough rice moisture content reduction and tempering duration to head rice yield reduction. Trans. ASABE 50(1):137-142.

Sharma, A. D., and Kunze, O. R. 1982. Post-drying fissure development in rough rice. Trans. ASAE 25(2):465-468, 474.

Siebenmorgen, T. J., and Qin, G. 2005. Relating rice kernel breaking force distributions to milling quality. Trans. ASAE 48(1):223-228.

Siebenmorgen, T. J., Nehus, Z. T., and Archer, T. R. 1998. Milled rice breakage due to environmental conditions. Cereal Chem. 75:149-152.

Stermer, R. A. 1968. Environmental conditions and stress cracks in milled rice. Cereal Chem. 45:365-373.

Thompson, J. F., Knutson, J., and Jenkins, B. 1990. Analysis of variability in rice milling appraisals. Appl. Eng. Agric. 6(2):194-198.

USDA-FGIS. 1979. Rice Inspection Handbook for the Sampling, Grading, and Certification of Rice. HB 918-11. USDA Agricultural Marketing Service: Washington, DC.

USDA-FGIS. 1982. Rice Inspection Handbook. USDA Agricultural Marketing Service: Washington, DC.

USDA-FGIS. 1994. Rice Inspection Handbook. USDA Agricultural Marketing Service: Washington, DC.

USDA-FGIS. 2005. Rice Inspection Handbook. USDA Agricultural Marketing Service: Washington, DC.

[Received August 1, 2012. Accepted November 8, 2012.]