Effect of Cooling Methods and Milling Procedures on the Appraisal of Rice Milling Quality

Z. Pan, J. F. Thompson, K. S. P. Amaratunga, T. Anderson, X. Zheng

Abstract. *The objective of this research was to appraise the quality of medium-grain rice as affected by cooling and two different Federal Grain Inspection Service (FGIS) milling procedures. Milled rice quality was measured in terms of total rice yield (TRY), head rice yield (HRY), and whiteness. The cooling study used an internal and an external heat exchanger developed for the McGill No. 3 mill with room-temperature water and ice cooled water as cooling media. Californian M202 rough rice samples of three different qualities were milled using the McGill No. 3 mill with and without cooling following the standard FGIS Western rice milling procedure. The cooling methods increased the TRY and HRY, but decreased whiteness. Every 10°C reduction in the milled rice temperature due to cooling corresponded to an increase of 0.9 percentage points in TRY and 1.7 percentage points in HRY. The rice samples of M202 from California and Bengal from the Southern region milled with the Western milling procedure had lower TRY (1.0 to 1.4 percentage points) and HRY (2.3 percentage points) compared with the Southern milling procedure. Similar quality results obtained using the Southern milling procedure might be produced using the Western milling procedure with heat exchanger cooling.*

Keywords. *Cooling, Head rice yield, Heat exchanger, Milling, Quality, Rice sample, Temperature, Total rice yield, Whiteness.*

The economic value of rough rice is based on its milling quality. In the U.S., milling quality is typically determined by milling a small rough rice sample using the official procedures of the USDA Federal Grain Inspection Service (FGIS) (USDA-FGIS, 1994). In the procedures, one of the most important steps is milling, and the McGill No. 3 mill is specified as the official mill. The milling is a batch, single-pass process, which is different from the current commercial continuous, multi-pass milling process. Because of the batch milling process, a large amount of heat is generated and accumulated in the mill (mainly in the cutter bar) and rice during milling, which could cause a reduction of the appraised total rice yield (TRY) and head rice yield (HRY) (Pan and Thompson, 2002). Meanwhile, the standard FGIS milling procedures specify different milling weights (pressures) to be used for rice produced in the Western and Southern regions of the U.S. However, the effects of different milling weights on the appraised rice quality lack scientific documentation.

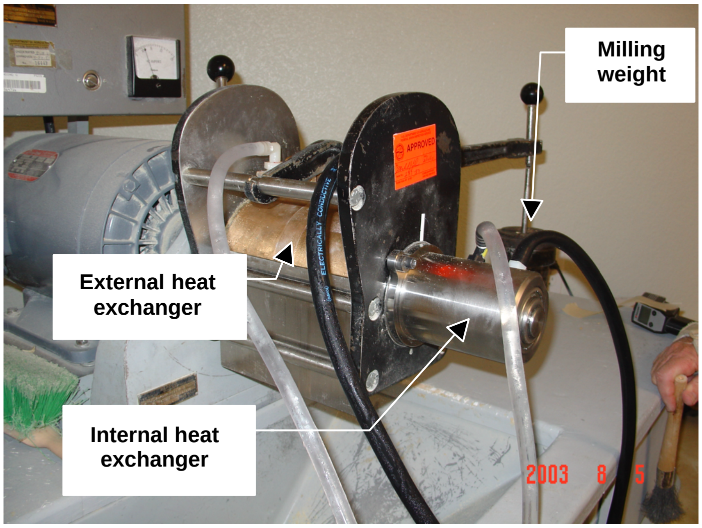
The McGill No. 3 mill holds a batch of rice in the milling chamber, a space between a lobed shaft (also called the cutter bar) and a surrounding metal screen and a cover. The milling action occurs in the milling chamber due to the relative motion between the rotary cutter bar and rice kernels and among the rice kernels while the batch of rice is under pressure. The pressure in the milling chamber is generated by a weight and lever arm assembly pressing a saddle against the top cover of the chamber (fig. 1a). The milling weights specified in the FGIS procedures vary with the rice varieties and regions of rice produced. For medium-grain rice, the FGIS milling procedures require that the rice sample is exposed to a 30 s milling cycle using a 4.54 kg (10 lb) or 3.18 kg (7 lb) milling weight for rice produced in the Western or Southern region, respectively (USDA-FGIS, 1994). After the milling cycle, the weights are reduced to 0.98 kg (2 lb) for Western rice or 0 kg for Southern rice and the mill is operated for an additional 30 s, which is normally referred to as a brushing cycle or polishing cycle. Due to the differences in milling weights, the rice sample milling procedures are called the Western or Southern rice sample milling procedure in this study. After the polishing cycle, the milled rice is unloaded and visually compared with a standard "well milled" sample. The polishing cycle may be repeated to achieve "well milled" rice.

There is only limited information about the development of the FGIS procedures and related research (Smith and McCrae, 1951; Smith, 1955a, 1955b, 1955c, 1955d). Smith (1955c) studied the effect of milling weight on rice quality and found that milling of medium- and short-grain rice required more time than milling of long-grain rice using the McGill No. 3 mill. The most recently reported rice sample milling research used either the McGill No. 2 mill or IRRI test tube mill (Takai and Barredo, 1981; Banaszek et al., 1989; Andrews et al., 1992; Sun and Siebenmorgen, 1993; Archer and Siebenmorgen, 1995; Reid et al., 1998; Bautista et al.,

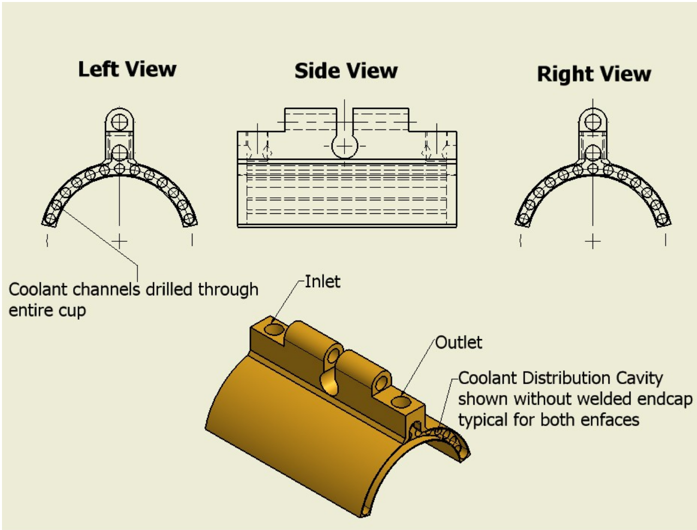
Article was submitted for review in March 2005; approved for publication by the Food & Process Engineering Institute Division of ASABE in August 2005.

The authors are **Zhongli Pan, ASABE Member Engineer,** Research Engineer, USDA-ARS Western Regional Research Center, Albany, California, and Assistant Adjunct Professor, Department of Biological and Agricultural Engineering, University of California, Davis, California; **James F. Thompson, ASABE Member Engineer,** Extension Specialist, **K. Sanath P. Amaratunga, ASABE Member Engineer,** Post-Doctoral Researcher, and **Tom Anderson,** Engineering Shop Manager, Department of Biological and Agricultural Engineering, University of California, Davis, California; and **Xianzhe Zheng, ASABE Member Engineer,** Professor, Northeast Agricultural University, Harbin, China. **Corresponding author:** Zhongli Pan, Processed Foods Research Unit, USDA-ARS Western Regional Research Center, 800 Buchanan St., Albany, CA 94710; phone: 510-559-5861; fax: 510-559-5864; e-mail: zpan@pw.usda.gov.

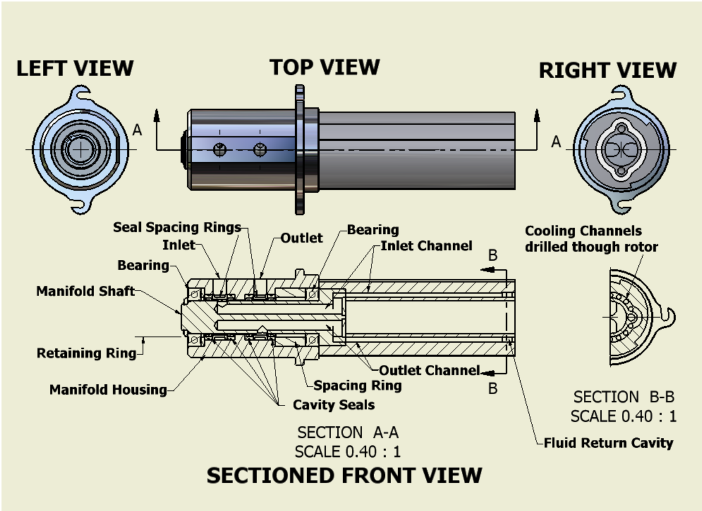
  ISSN 0001−2351



(a)



(b)



(c)

Figure 1. (a) McGill No. 3 mill set-up with the internal and external heat exchangers, (b) design of external heat exchanger, and (c) design of internal heat exchanger incorporated in the cutter bar.

2001). The McGill No. 2 mill uses about 100 to 150 g of rough rice, while McGill No. 3 mill uses 1000 g of rough rice, as defined in the USDA-FGIS milling procedures (USDA-FGIS, 1994). Andrews et al. (1992) reported that the HRY increased with reduced milling time or reduced milling weight (pressure) with the McGill No. 2 mill. The HRY was also improved by lowering the brown rice temperature before milling (Archer and Siebenmorgen, 1995). However, the HRY was inversely related to the degree of milling as measured by a Satake milling meter. Archer and Siebenmorgen (1995) also found that lower brown rice temperatures did not significantly improve the HRY if the HRY yield was mathematically adjusted to achieve an equal degree of milling. Mohapatra and Bal (2004) did a similar study using a laboratory-scale, abrasive mill and found that the whole kernel yield decreased linearly with an increase in milled rice temperature. However, the researchers did not report the milling degree of the white rice.

The rice sample milling procedures have been updated several times (USDA-FGIS, 1979, 1982, 1994), but the technical information related to the changes in the milling procedure is not available. Pan and Thompson (2002) studied the relationships between mill heat generation, rice temperature, and quality (TRY, HRY, and whiteness) using a McGill No. 3 mill. They found that the highest temperatures of the cutter bar and milled rice reached 74°C and 84°C, respectively, after six rice samples were successively milled. The high cutter bar and milled rice temperatures caused significant reduction in the appraised TRY and HRY of milled rice, especially for low quality rice. The high milling weight of the Western milling procedure may also cause higher milling temperature than the Southern milling procedure. The combination of high milling temperature and high milling weight (pressure) could produce lower appraised TRY and HRY, but higher whiteness with the Western milling procedure compared to the Southern procedure. Therefore, rice producers are interested in developing methods to prevent the quality changes caused by the high milling temperature and determining the difference in appraised quality obtained using the Southern and Western milling procedures.

The objectives of this study were to: (1) design heat exchangers for cooling a McGill No. 3 mill, (2) determine the effect of cooling methods on appraised milling quality of medium-grain rice, and (3) compare the appraised rice quality of medium-grain rough rice from the Western and Southern regions using the Southern and Western milling procedures.

MATERIALS AND METHODS

MATERIALS AND MILLING PROCEDURES

Three Western variety M202 rough rice lots with different qualities (low, medium, high) from California were used for studying the cooling effect on the appraised rice quality. The rice samples were obtained from Farmers Rice Cooperative (Sacramento, Cal.). The moisture contents were 12.6%, 13.1 %, and 12.9% for rough rice of low, medium, and high qualities, respectively. The lots were split into 1000 g samples and milled with McGill No. 3 mill (fig. 1a) at the California Department of Food and Agriculture (CDFA) Laboratory (West Sacramento, Cal.) with and without cooling using the standard milling weights of the Western milling procedure of the FGIS. The three Californian rice samples and one additional medium Southern variety Bengal rough rice sample, obtained from the Agricultural Experiment Station of Louisiana State University, were used to study the effect of the Western and Southern milling procedures on the appraised rice quality. The samples were milled using both standard Western and Southern milling procedures (USDA-FGIS, 1994).

Because high temperatures of the cutter bar and milled rice reduce the TRY and HRY of milled rice with excessive rice kernel breakage and moisture loss, the current milling practice at the CDFA Laboratory is to mill rice samples when the cutter bar temperature reaches a temperature of 46°C to 54°C (115°F to 130°F). If the cutter bar is below the prescribed temperature, one or two rice samples are milled before an official rice sample is milled. If the cutter bar temperature is above the prescribed temperature, a small fan is used to cool the cutter bar to the required temperature range. The temperature of the cutter bar at the start of milling was called the initial cutter bar temperature. After a rice sample was milled and unloaded from the rice mill, the temperature of the cutter bar was measured again, and this temperature was called the ending cutter bar temperature. Both the initial and ending temperatures at the working surface of the cutter bar were measured using an infrared thermometer. When an infrared thermometer is used to measure the temperature of cutter bar surface, the high reflectivity of the metal surface can result in inaccurate temperature measurement. Therefore, before measuring the temperature, the cutter bar surface was covered with a piece of thin paper tape to ensure an accurate temperature measurement. The temperature of milled rice was measured using a thermometer through a thermocouple immediately after the milled rice was unloaded from the mill.

HEAT EXCHANGERS

To reduce the milling temperature (cutter bar and milled rice temperatures) of the McGill No. 3 mill, an external heat exchanger and an internal heat exchanger were developed at the University of California, Davis. The external heat exchanger was placed on the top of the milling chamber and replaced the regular saddle. It was made of brass and had channels to allow cooling water to flow through it and remove heat during milling (fig. 1b). Since the 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 FGIS milling procedure. The internal heat exchanger was created by drilling holes through an existing cutter bar to allow cooling water to circulate inside it (fig. 1c). A stainless steel manifold was added to the cutter bar to supply cooling water to it. The two heat exchangers were operated simultaneously and individually. The cooling water had the flow rate of 0.98 kg min^{-1} for each exchanger and was pumped to circulate through the heat exchangers during milling.

MEASUREMENT OF MILLED RICE QUALITY

The major quantitative rice quality indicators specified in the standard rice sample milling procedures are TRY and HRY. Whiteness of the milled rice was also examined to

Table 1. Experimental design for studying effects of milling conditions.

Rice		Southern Milling Procedure	Western Milling Procedure (Control)	Western Milling Procedure with Different Cooling Conditions[a]				
				IHX-Water	IHX-EHX-Water	IHX-Ice	IHX-EHX-Ice	EHX-Ice
M202	Low quality	x	x	x	x	x	x	x
	Medium quality	x	x	x	x	x	x	x
	High quality	x	x	x	x	x	x	
Bengal		x	x					

[a] IHX = internal heat exchanger, EHX = external heat exchanger, Water = water at room temperature (20°C - 21°C), and Ice = ice water (1°C - 3°C).

ensure that it reached a level called "well milled" as defined by the FGIS standard. The TRY and HRY were determined by following the USDA-FGIS procedures. The TRY and HRY were defined as percentages of milled rice and milled whole kernels based on the initial rough rice weight, respectively. 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.

Experimental Design of Milling Test

The effects of cooling methods and milling procedures on quality appraisal were studied following the experimental design shown in table 1. Both room-temperature water (20°C to 21°C) and ice-cooled water (1°C to 3°C) were used for cooling through the heat exchangers. For the milling tests without cooling, the initial cutter bar temperature was 49°C, which was in the prescribed temperature range of the current practice at the CDFA Laboratory. When the internal heat exchanger with room-temperature water and ice water cooling was tested, the initial cutter bar temperature was cooled to 24°C and 12°C, respectively. If the ending cutter bar temperature was higher than the required temperature after milling a sample, the cooling water was pumped through the internal heat exchanger to achieve the desired cutter bar temperature before milling another sample. The initial and ending cutter bar temperatures were measured using the methods described in the Materials and Milling Procedures section. The milling tests of the Bengal and M202 rice were repeated six and three times at each miling condition, respectively. All reported values are the averages of the measured data. All quality data were analyzed using SAS software (SAS Institute, Inc., Raleigh, N.C.). Analysis of variance (ANOVA) and least significant difference (LSD) ($\alpha = 0.05$) were used to differentiate the means of rice quality parameters.

Results and Discussions

Effect of Cooling on Milling Temperature

The uses of different cooling methods reduced both initial and final cutter bar temperatures, which resulted in lower milled rice temperatures than the control (table 2). After examining the temperature changes of the cutter bar during milling and the milled rice temperatures for different quality rough rice samples under a specific cooling method, it seems that the quality of rough rice did not significantly affect the temperatures. Therefore, the following discussion is based on the average temperature values obtained from the samples with different rough rice qualities under a specific cooling treatment, unless otherwise specified. The external heat exchanger with ice water reduced both milled rice temperature and ending cutter bar temperature by 2°C on average compared with the control (no cooling). The internal heat exchanger with room-temperature water or ice water lowered the ending cutter bar temperature by 24°C or 34°C, respectively, and the milled rice temperature by 11°C or 26°C, respectively, compared with the control. Therefore, the internal heat exchanger was more effective than the external heat ex−

Table 2. Temperatures (°C) of cutter bar and milled rice under different milling treatments.

Rough Rice Quality	Temperature Measurement[a]	Treatment[b]					
		Control	IHX-Water	IHX-EHX-Water	IHX-Ice	IHX-EHX-Ice	EHX-Ice
Low	T_i	49	24	24	12	14	49
	T_e	58	31	31	21	22	54
	ΔT	9	7	7	9	8	5
	Rice	74	65	63	60	58	72
Medium	T_i	49	24	24	12	13	48
	T_e	56	34	34	22	23	55
	ΔT	7	10	10	10	10	7
	Rice	73	61	61	56	56	71
High	T_i	49	24	24	13	13	
	T_e	57	35	33	26	23	
	ΔT	7	11	9	13	10	
	Rice	74	62	59	58	54	
Average	T_i	49	24	24	12	13	49
	T_e	57	33	33	23	22	55
	ΔT	8	9	9	11	9	6
	Rice	74	63	61	58	56	72

[a] T_i = initial cutter bar temperature, T_e = ending cutter bar temperature, and ΔT = difference between T_i and T_e.
[b] Control = Western milling procedure without cooling, IHX = internal heat exchanger, EHX = external heat exchanger, Water = water at room temperature (20°C - 21°C), and Ice = ice water (1°C - 3°C).

changer in lowering the temperatures due to the direct contact of the internal heat exchanger with the rice during milling. The difference between the initial and ending cutter bar temperatures for all cooling methods except for EHX-ice was in the range of 9˚C to 11˚C, which was only slightly higher than 8˚C of the control test. The reason for the smaller temperature change (6˚C) during milling with the EHX-ice treatment than with the other cooling treatments is not known. The lowered ending cutter bar temperature in the cooling tests was primarily due to the lowered initial cutter bar temperature. This showed the importance of lowering the initial cutter bar temperature if a low ending cutter bar temperature and milled rice temperature are desired.

Using the internal and external heat exchangers at the same time resulted in an additional 2˚C reduction in milled rice temperature compared with using only the internal heat exchanger, even though the ending cutter bar temperature did not change much.

The ice water cooling reduced milled rice temperature by 5˚C more than room-temperature water cooling regardless of the combination of heat exchangers used. When both the internal and external heat exchangers were used, room-temperature water and ice water cooling treatments reduced milled rice temperatures by 13˚C and 18˚C, respectively, compared with the control. Since the accuracy of the surface temperature measurement could be up to ±2˚C, the effect of cooling medium and methods on the temperature difference between the initial and ending temperatures of cutter bar might not be significant.

Effect of Cooling on Appraised Rice Quality

The cooling treatments significantly increased the TRYs and HRYs compared with the control treatment (table 3). The milling test for high quality rice using EHX-ice was not conducted due to insufficient rice sample. The average quality parameters obtained with cooling were calculated without including the data obtained using EHX-ice. For low, medium, and high quality rice, the average HRY increases were 1.9, 2.0, and 3.2 percentage points, respectively, and corresponding TRY increases were 1.3, 1.2, and 1.7 percentage points. The increased HRY and TRY could be due to both reduced moisture loss and lowered breakage associated with the lower milled rice temperature (Pan and Thompson, 2002). However, the average WI values of milled low, medium, and high quality rice obtained with the cooling were 42.8, 42.0, and 42.5, respectively, compared to corresponding values of 43.8, 42.4, and 42.3 for the control samples, which may indicate that the low and medium quality rice samples were not milled to the same degree as the control samples. Using both the internal and external heat exchangers with ice water resulted in the highest average TRY (68.3%) and HRY (56.4%) compared with the control of 66.6% TRY and 53.3% HRY.

The ice water cooling caused more TRY and HRY increases than the cooling with room-temperature water. All quality parameters discussed below were the average for low, medium, and high quality. When only the internal heat exchanger was used, ice water cooling increased TRY and HRY by 1.4 and 2.6 percentage points, respectively, while room-temperature water cooling increased them by 1.1 and 1.6 percentage points. Similarly, when both the internal and external heat exchangers were used, the ice water cooling resulted in greater increases in TRY (1.7% percentage points) and HRY (3.1 percentage points) than the room-temperature water cooling (1.3 and 2.2 percentage points) compared with the control. The external heat exchanger contributed to the increases in TRY and HRY of 0.2 to 0.3 percentage points and 0.5 to 0.6 percentage points, respectively, in contrast to the greater increases of 1.1 to 1.4 percentage points in TRY and 1.6 to 2.6 percentage points in HRY by using the internal heat exchanger. Such results again showed that the internal heat exchanger was more effective than the external heat exchanger, which is consistent with the milling temperature data. The internal heat exchanger cooled with ice water caused condensation at the surface of the cutter bar after the milled rice was unloaded. Some rice bran absorbed the condensed water, formed small wet pieces, and became attached onto the cutter bar surface. The attached pieces needed to be cleaned after milling each sample.

The internal heat exchanger with ice water quickly cooled the cutter bar to a prescribed temperature before milling. The problem of water condensation on the cutter bar surface may be minimized by reducing the time of cutter bar exposure to room air before milling is conducted. The condensation is not a problem if cooling water is above the dew point temperature

Table 3. Quality of milled rice under different milling conditions.

Rough Rice Quality	Milled Rice Quality[a]	Treatment[b]					
		Control	IHX-Water	IHX-EHX-Water	IHX-Ice	IHX-EHX-Ice	EHX-Ice
Low	TRY	67.4 a	68.4 b	68.7 b	68.7 b	68.9 b	68.0 ab
	HRY	46.8 a	48.0 ab	48.4 b	48.9 b	49.4 b	46.9 a
	WI	43.8 a	43.0 b	42.8 b	42.5 b	42.4 b	43.0 b
Medium	TRY	66.7 a	67.7 b	67.8 b	68.0 b	68.1 b	68.1 b
	HRY	55.0 a	56.2 b	56.8 b	57.6 b	57.5 b	57.1 b
	WI	42.4 a	41.8 b	41.8 b	41.8 b	42.3 ab	42.4 a
High	TRY	65.6 a	66.9 b	67.2 b	67.3 bc	67.9 c	
	HRY	58.1 a	60.3 b	61.2 b	61.2 b	62.4 c	
	WI	42.3 a	42.0 a	42.7 a	42.8 a	42.6 a	
Average	TRY	66.6	67.7	67.9	68.0	68.3	
	HRY	53.3	54.9	55.5	55.9	56.4	
	WI	42.8	42.3	42.4	42.3	42.4	

[a] TRY = total rice yield, HRY = head rice yield, and WI = whiteness index.

[b] Control = Western milling procedure without cooling, IHX = internal heat exchanger, EHX = external heat exchanger, Water = water at room temperature (20°C - 21°C), and Ice = ice water (1°C - 3°C). Values in each row followed by different letters are significantly different at $P < 0.05$.

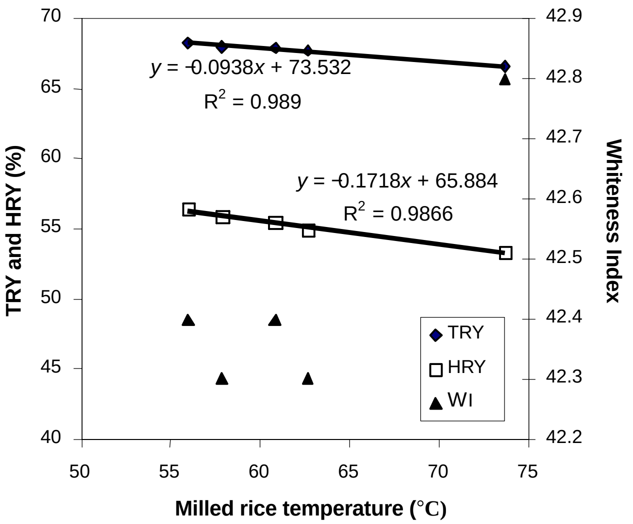


Figure 2. Relationship between averaged milled rice temperature and quality results.

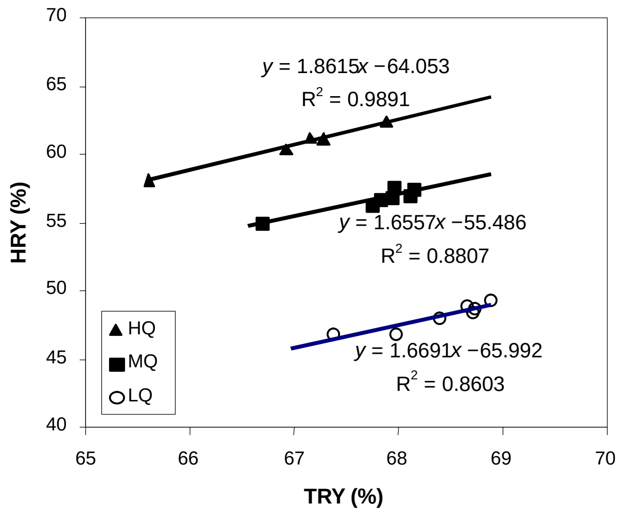


Figure 3. Relationship between head rice yields and total rice yields of various quality California rice (HQ = high quality rice; MQ = medium quality rice, and LQ = low quality rice).

of ambient air. It is not as convenient to use both heat exchangers for the McGill No. 3 mill compared with only using the internal heat exchanger. Besides the advantage of using the internal heat exchanger in minimizing the reduction of TRY and HRY, it also lowers the initial cutter bar temperature within a few seconds to the desired level, compared with several minutes required for the current air cooling practice.

The individual quality data showed that the HRY of high quality rice was improved more than the HRY of low and medium quality rice. This is different from the results from some of our other tests (Pan and Thompson, 2002). The difference could be due to the different histories of drying, harvest, and storage, although the exact reasons for the difference are not known.

In general, the effectiveness of the different cooling methods in reducing rice temperature followed an order from high to low: internal and external heat exchangers with ice water, internal heat exchanger with ice water, internal and external heat exchangers with room-temperature water, and internal heat exchanger with room-temperature water. In determining the order, the external heat exchanger with ice water treatment was not included since the milling quality data of high quality rice with external heat exchanger cooling were not available.

The TRY or HRY increased linearly with decreasing milled rice temperature (fig. 2). Every 10 °C increase in the milled rice temperature corresponded to a decrease of 0.9 percentage points in TRY or 1.7 percentage points in HRY in the range of temperatures produced by the various cooling methods. The milled rice quality results also verified our initial hypothesis that the milling temperature was a critical factor affecting the appraised rice quality using the Western milling procedure.

There was no consistent relationship between the milled rice temperature and whiteness index (WI). The heat exchangers used with low and medium quality rice caused a small but statistically significant reduction in WI. This was not observed in the high quality rice samples. The WI values of the cooling treatments averaged across all rice qualities were 0.4 to 0.5 units lower than the control. However, all the rice samples were “well milled” based on the FGIS standard.

Regardless of the cooling methods, the HRY and TRY had a positive linear relationship with similar slopes for different quality rice lots (fig. 3). This indicates that the increases in TRY and HRY were the same for each rice lot, despite differences in overall lot qualities. In other words, the TRY and HRY increases caused by cooling were similar in lots with HRYs ranging from about 45% to 60%.

Comparison of Western and Southern Milling Procedures

The Southern standard milling procedure resulted in higher TRY and HRY than the Western procedure (table 4). When the M202 rice was milled, the average TRY and HRY obtained with the Western milling procedure were 1.4 and 2.3 percentage points lower, respectively, than those obtained with the Southern procedure. Similarly, when the Bengal rice was milled, the TRY and HRY obtained with the Western milling procedure were 1.0 and 2.4 percentage points lower, respectively, than those obtained with the Southern procedure. The lower TRY and HRY obtained with the Western milling procedure were associated with the higher milling temperature, which was probably caused by the greater milling weights used with the Western produce.

The WI values of rough rice from both regions were 0.7 to 1.7 units lower (darker rice) when they were milled using the Southern milling procedure compared with the Western procedure. However, the current FGIS milling procedure does not specify the milling degree in terms of WI. If the rice samples were milled to the same whiteness, then the difference in HRYs from the different milling procedures might be reduced. However, there were not enough data in this study to make a mathematical adjustment based on the whiteness or degree of milling as reported by Archer and Siebenmorgen (1995). The higher WI values of the Bengal rice could be due to its variety and lower moisture content compared to the M202 rice used in the tests. It can also be seen that the M202 quality from the Southern procedure was very similar to the results from the Western procedure with two of the cooling treatments, i.e., the internal and external heat exchangers with room-temperature water, or the internal heat exchanger with ice water.

Table 4. Quality of rice milled with the Western and Southern procedures.

Rice	Rough Rice Quality	Milling Procedures	Quality of Milled Rice[a]			Milled Rice Temperature (°C)	Cutter Bar Temperature (°C)	
			TRY	HRY	WI		Ending	Initial
M202	Low	Western	67.4 a	46.8 a	43.8 a	74	58	49
		Southern	68.7 b	48.7 b	42.6 b	72	55	49
	Medium	Western	66.7 a	55.0 a	42.4 a	73	56	49
		Southern	67.9 b	56.9 b	41.5 b	69	54	49
	High	Western	65.6 a	58.1 a	42.3 a	74	57	49
		Southern	67.3 b	61.1 b	42.1 a	69	55	49
	Average	Western	66.6	53.3	42.8	74	57	49
		Southern	68.0	55.6	42.1	70	55	49
Bengal		Western	68.7 a	59.2 a	45.7 a	74	58	49
		Southern	69.7 b	61.6 b	44.0 b	72	54	49

[a] Values from the Western and Southern milling procedures in each category followed by different letters are significantly different at $P < 0.05$. The Bengal rice had 10.2% moisture. TRY = total rice yield, HRY = head rice yield, and WI = whiteness index.

CONCLUSIONS

This study showed that using the internal and external heat exchangers effectively reduced rice and mill temperatures, increased the TRY and HRY, and decreased whiteness of the milled samples. The internal heat exchanger lowered mill and rice temperatures more than the external heat exchanger, and ice water lowered the temperatures more than room-temperature water. The maximum improvements in average TRY and HRY of the three different quality rice samples were 1.7 and 3.1 percentage points when both the internal and external heat exchangers with ice water were used following the standard Western milling procedure. A 10°C decrease in milled rice temperature corresponded to an increase of 0.9 percentage points in TRY and 1.7 percentage points in HRY. The Western milling procedure caused significantly lower TRY and HRY than the Southern milling procedure, probably because of the high milling weight and high milling temperature in the Western milling procedure. Quality results similar to the Southern milling procedure can be produced by using the Western milling procedure with either room-temperature water cooling of both the internal and external heat exchangers, or with ice water cooling of the internal heat exchanger.

ACKNOWLEDGEMENTS

The authors wish to thank Homer Formenteta, Dale Rice, and Sandra Newell of the California Department of Food and Agriculture; Michael Johnson and Chuck Britton of the USDA Federal Grain Inspection Service for supporting the experiments; Farmer's Rice Cooperative for supplying the rice samples; and the California Rice Research Board for providing partial financial support for the project.

REFERENCES

Andrews, S. B., T. J. Siebenmorgen, and A. Mauromostakos. 1992. Evaluation of the McGill No. 2 miller. *Cereal Chem.* 69(1): 35-43.

Archer, T. A., and T. J. Siebenmorgen. 1995. Milling quality as affected by brown rice temperature. *Cereal Chem.* 72(3): 304-307.

Bautista, R. C., T. J. Siebenmorgen, S. C. Millsap, and B. K. Goh. 2001. Evaluation of the IRRI test tube mill for use in milling small samples of rice. ASAE Paper No. 016100. St. Joseph, Mich.: ASAE.

Banaszek, M. M., T. J. Siebenmorgen, and R. N. Sharp. 1989. Effects of moisture content at milling on head rice yield and degree of milling. *Arkansas Farm Research Series* 38: 15.

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

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

Reid, J. D., T. J. Siebenmorgen, and A. Mauromoustakos. 1998. Factors affecting the head rice yield versus degree of milling slope. *Cereal Chem.* 75(5): 738-741.

Smith, W. D. 1955a. The use of the Carter dockage tester to remove weed seeds and other foreign material from rough rice. *Rice J.* 58(9): 26-27.

Smith, W. D. 1955b. The use of the McGill sheller for removing hulls from rough rice. *Rice J.* 58(10): 20.

Smith, W. D. 1955c. The use of the McGill miller for milling samples of rice. *Rice J.* 58(11): 20.

Smith, W. D. 1955d. The determination of the estimate of head rice and total yield with the use of the sizing device. *Rice J.* 58(12): 9.

Smith, W. D., and W. McCrea Jr. 1951. Where breakage occurs in the milling of rice. *Rice J.* 54(2): 14-15.

Sun, H., and T. J. Siebenmorgen. 1993. Milling characteristics of various rough rice thickness fractions. *Cereal Chem.* 70(6): 727-733.

Takai, H., and I. R. Barredo. 1981. Milling characteristics of a friction laboratory rice mill. *J. Agric. Eng. Res.* 26(5): 441-448.

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

USDA-FGIS. 1982. *Rice Inspection Handbook*. Washington, D.C.: USDA Agricultural Marketing Service.

USDA-FGIS. 1994. *Rice Inspection Handbook*. Washington, D.C.: USDA Agricultural Marketing Service.