ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2003 – December 31, 2003

PROJECT TITLE:

Improvement of Consistency and Accuracy of Rice Sample Milling

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OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

Objectives

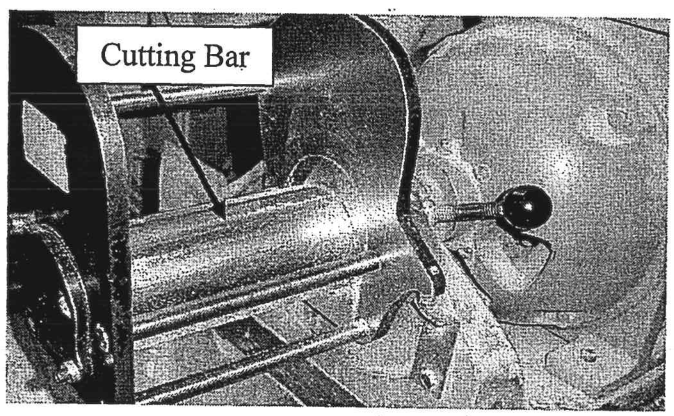
The ultimate goal of this research project was to develop a new milling procedure/method for improving the consistency and accuracy of rice sample milling. The research results will lead to minimizing the Californian rice producers' economic loss caused by milling yield variation due to the high milling temperature in rice sample milling. For current year's research, the specific objectives were:

1. Develop an efficient cooling method by modifying the cutting bar of the mill.
2. Study the quality characteristics of milled rice with different cooling methods.
3. Investigate the effects of milling pressure and time (milling conditions) on the quality of milled rice.

Experimental Procedures

Materials

Two different M202 rice samples with moisture content of 12.1% and 12.3%, respectively, obtained from Farmer's Rice Co-operatives were used for this study. The samples (1000g each) were milled with McGill No. 3 laboratory mill (Fig. 1) at CDFA Lab under various conditions with and without cooling and following the standard post-milling handling procedures of Federal Grain Inspection Service (FGIS).



(a)

Fig. 1 McGill No.3 rice sample mill and location of cutting bar temperature measurement

Cooling Methods

The current milling practice at CDFA is to cool the cutting bar to 48-52°C (115 -130°F) before milling a new rice sample. The temperature of cutting bar prior to the start of milling is called initial cutting bar temperature in this study. After rice is milled and unloaded from the rice mill, the temperature of cutting bar is called end cutting bar temperature. Both initial and end cutting bar temperatures were measured using an infrared temperature meter.

To reduce the milling temperature (including rice and equipment temperatures) during milling, a new internal cooling device was developed by modifying the cutting bar. The cooling medium is pumped through the cutting bar during milling process. Both the internal and external cooling devices (heat exchangers) were used for the milling study. The quality results of medium paddy rice samples were compared after the rice samples were milled under various conditions, including control (no cooling), internal cooling only, external cooling only, and combination of internal and external cooling. Ice water and water at ambient temperature were used as milling media. The experimental set up of the cooing tests is shown in Fig 2.

When it was used, the external heat exchanger added additional weight to the milling chamber. Therefore, the weight load of mill was adjusted to keep the milling pressure to be the same as the current milling practice at CDFA. The temperatures of cooling medium, milled rice, and cutting bar were measured during milling.

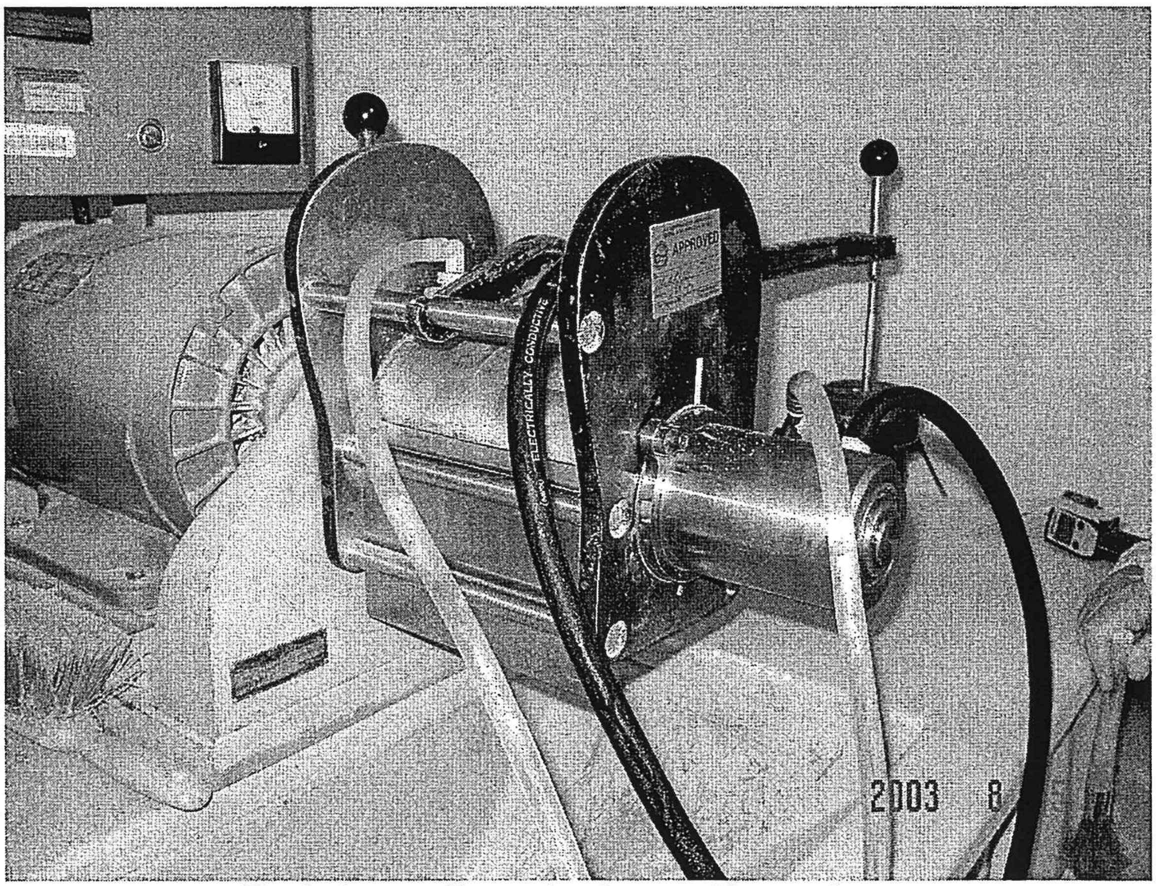


Fig. 2 Set-up of internal and external heat exchanger

Milling condition tests

The effects of four variables, weight and time periods of milling and polishing, were studied using a composite experimental design (Table 1). These four variables are independent variables. The dependent variables included TRY, HRY, Whiteness Index (WI), rice temperature, total fat content, free fat content and cutting bar temperatures. The relationships among the dependent variables were examined by regression analysis. The regression model between dependent variable (Y) and independent variables can be written as:

Y= a + a1*MT + a2*MW + a3*PT +a4*PW + b12*MT*MW + b13*MT*PT + b14*MT*PW + b23*MW*PT + b24*MW*PW + b34*PT*PW + c1*MT2 + c2*MW2 + c3*PT2 + c4*PW2

The effects of independent variables on dependent variables were determined by using the response surface method. The significance of contribution of each dependent variable and interaction to the dependent variables were statistically investigated.

Table 1. Experimental design for studying effects of milling conditions

Variables	Milling Weight (lb)	Milling time (s)	Polishing weight (lb)	Polishing time (s)
Levels	6	10	0	10
	8	20	1	20
	10	30	2	30
	12	40	3	40
	14	50	4	50

Measurement of Milled Rice Quality

The evaluated quality indicators included TRY, HRY, Whiteness Index, fat content and free fatty content. The whiteness of milled rice was evaluated based on Whiteness Index determined with Whiteness Tester, C-300, (Kett Electronic Laboratory, Tokyo, Japan). A higher the index number indicates a whiter milled rice. Total fat content and free fatty content were determined at CDFA lab following USDA FGIS standard procedures.

SUMMARY OF 2003 RESEARCH (MAJOR ACCOMPLISMENTS) BY OBJECTIVES

Develop an efficient cooling method by modifying the cutting bar of the mill.

An internal cooling device (heat exchanger) was developed by modifying the cutting bar of rice sample mill at UC Davis. The modified cutting bar allows cooling medium to flow through channels milled into the material of the cutting bar prior to or during the milling process. The developed internal heat exchanger could quickly remove heat from cutting bar in seconds instead of current fan cooling taking more than 10 minutes. The high cooling efficiency of the internal cooling was also demonstrated during milling test, which is discussed in the next section.

Study the quality characteristics of milled rice with different cooling methods

The cooling effects on rice quality and temperature are shown in Table 2. It showed that both internal and external cooling were effective in improving the HRY (1.3% on average) and lowering temperatures of milled rice, and cutting bar. When the milled rice samples were visually examined, it was found that the cooling significantly improved whole kernel percentage by 5.7% (Fig. 3). This indicated that cooling not only improved HRY, but also increased whole kernel rice, which is an additional advantage of cooling. It was also observed that the cooling efficiency of the internal heat exchanger was very high. The temperature of cutting bar was very close to the room temperature right after unloading the rice sample for the mill. It solved the problem of cooling the cutting bar, which takes a long time with current air cooling practice.

Table 2 Effects of cooling methods on milled rice quality and temperatures

Cooling Method	Temp. of Cooling Medium (°F)	TRY (%)	HRY (%)	WI	Rice Temp. (°F)	Initial Temp. of Cutting Bar (°F)	End Temp. of Cutting Bar (°F)
Control		83.0	65.2	42.8	150	121	134
External	32	83.0	66.1	42.9	148	124	132
Internal	32	83.5	66.9	42.3	130	75	77
Internal + external	32	83.0	66.5	42.5	125	73	73

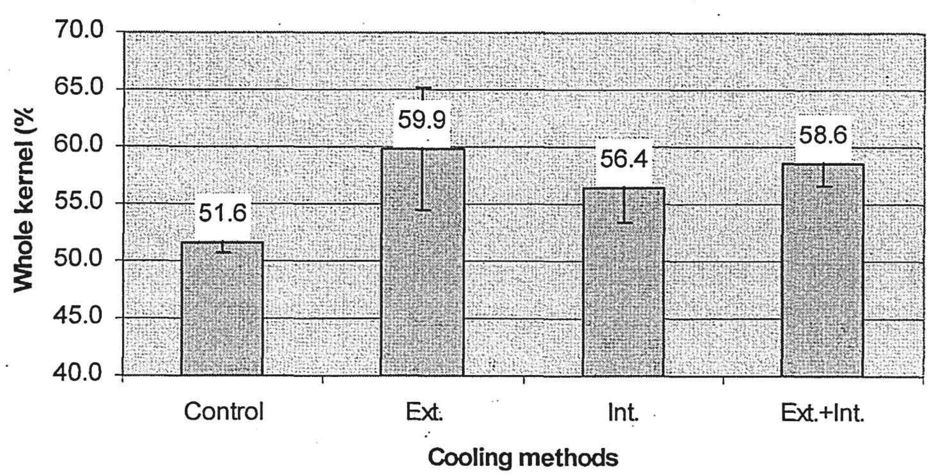


Fig. 3 Whole kernel improvement under different cooling methods

Preliminary cooling tests for a paddy rice sample with different quality were also conducted with ice water and water at a room temperature as cooling media. The results were inconclusive and are not reported here. More tests will be conducted to study the effects of cooling methods on rice quality by using different quality rice, especially low quality rice, and mediums with different temperature.

Investigate the effects of milling pressure and time (milling conditions) on the quality of milled rice.

The quality results and temperatures of milled rice with different milling conditions are shown in Table 2. The relationships among these parameters were examined. Fig. 4 shows the correlation between total rice yield and head rice yield. The head rice yield increased linearly with the increase of total rice yield.

Table 3. Quality and temperature of milled rice with different milling conditions

MT (s)	MW (%)	PT (%)	PW (%)	TRY (%)	HRY (%)	WI	RT (°F)	TF (%)	FFA (%)
20	8	20	1	72.7	60.4	36.8	149	0.26	0.02
40	8	20	1	71.6	57.8	41.1	158	0.34	0.02
20	12	20	1	71.7	57.8	38.7	155	0.34	0.02
40	12	20	1	69.8	53.3	42.7	167	0.21	0.02
20	8	40	1	72.1	60.3	38.4	160	0.34	0.02
40	8	40	1	70.7	57.3	41.4	172	0.31	0.02
20	12	40	1	71.4	58.9	39.4	160	0.24	0.02
40	12	40	1	67.6	54.4	43.1	170	0.50	0.02
20	8	20	3	72.5	59.5	37.7	153	0.28	0.02
40	8	20	3	70.7	57.4	41.1	162	0.21	0.02
20	12	20	3	71.6	58.8	38.9	155	0.33	0.02
40	12	20	3	69.5	54.2	42.4	169	0.26	0.02
20	8	40	3	71.7	58.7	39.7	161	0.23	0.02
40	8	40	3	70.5	56.4	41.3	176	0.43	0.02
20	12	40	3	71	57.3	40.1	164	0.43	0.03
40	12	40	3	69.6	54.4	41.5	180	0.26	0.02
10	10	30	2	73	61.6	36.3	146	0.25	0.02
50	10	30	2	69.7	54.9	42.8	179	0.51	0.03
30	6	30	2	71.8	59.5	40.5	158	0.30	0.02
30	14	30	2	70.1	55.2	41.6	173	0.39	0.03
30	10	10	2	71.7	58.4	39.4	155	0.32	0.03
30	10	50	2	70.6	56.6	41.3	171	0.29	0.02
30	10	30	0	71	57.2	41.4	164	0.29	0.02
30	10	30	4	70.7	56.8	41.8	167	0.32	0.02
30	10	30	2	71.1	57.3	40.8	165	0.22	0.02
30	10	30	2	70.9	57.4	41.4	162	0.25	0.02
30	10	30	2	70.9	57.3	41	167	0.33	0.02
30	10	30	2	70.9	57.2	41.2	169	0.29	0.02
30	10	30	2	71	57.4	40.6	168	0.23	0.02
30	10	30	2	71	57.5	40.3	167	0.29	0.02
30	10	30	2	71	57	40.9	168	0.29	0.02

Note: MT – milling time, MW – milling weight, PT – polishing time, PW – polishing weight, TRY – total rice yield, HRY – head rice yield, WI – whiteness index, RT – rice temperature, TF – total fat content, FFA – free fatty content.

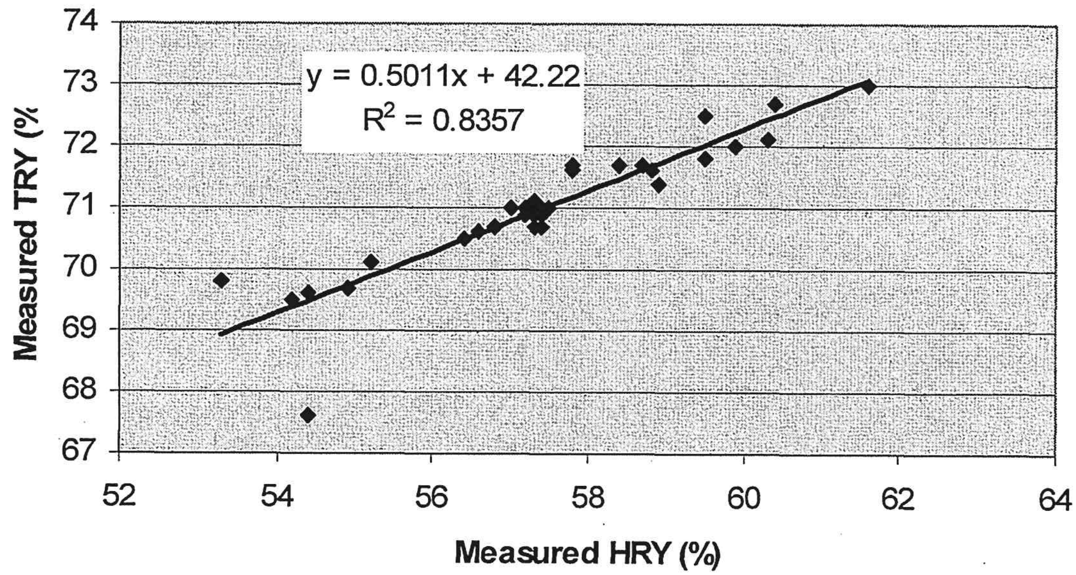


Fig. 4 Correlation between measured TRY and HRY

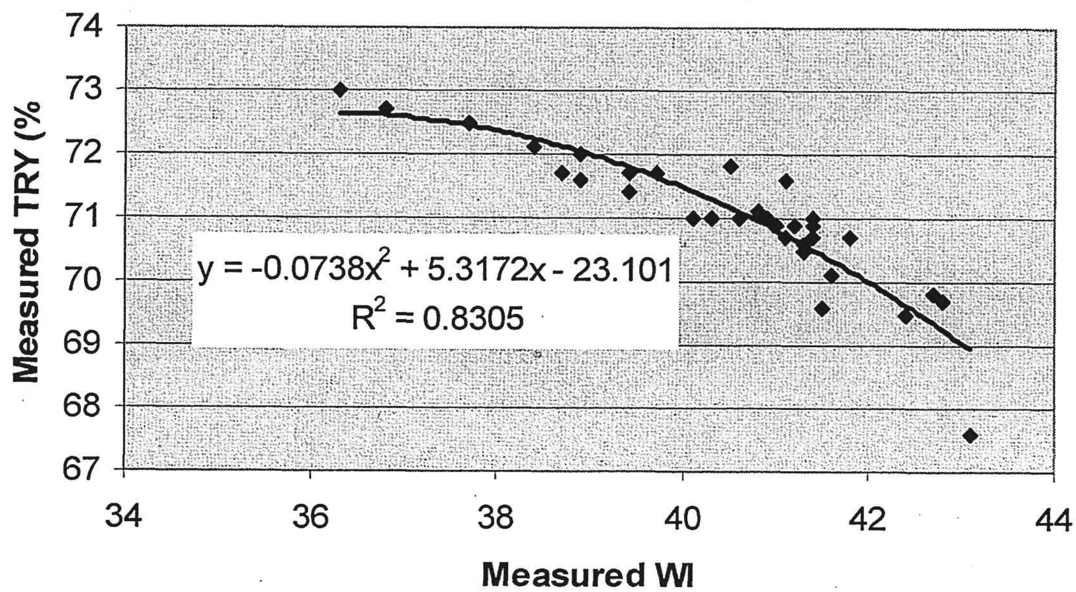


Fig. 5 Correlation between measure TRY and WI

The results also showed that TRY and HRY decreased significantly with increase of WI following a second order polynomial trend (Figs. 5 and 6). It is important to notice that the decrease of HRY was accelerated with the increase of whiteness of milled rice (Table 4). Therefore, over-milling must be avoided in rice sample milling to ensure that the quality appraisal results truly reflect the quality of paddy rice. However, this is no significant correlation between total fat and WI determined (Fig. 7). This leads to a question: how should the milling degree of milled rice be evaluated and to what degree should the rice be considered to be well milled? At present, FGIS's does not have specified quantitative method to evaluate the degree of milling. It is necessary to investigate the current practice in commercial mill about the degree of milling.

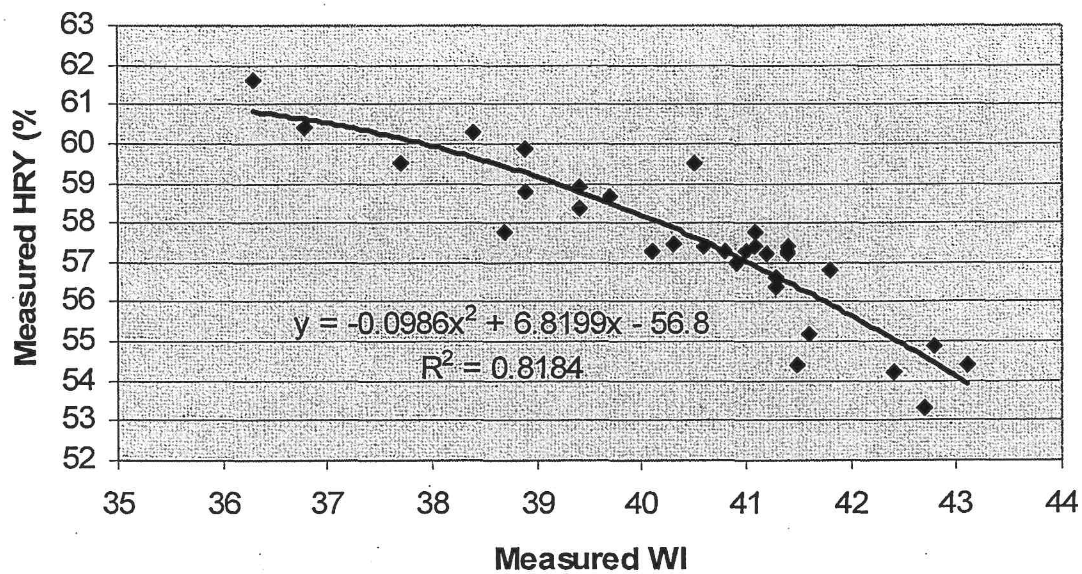


Fig. 6 Correlation between HRY and WI

Table 4. HRY change vs. WI

WI	Predicted HRY	Change of HRY/per WI
36	60.9	0.3
37	60.6	0.6
38	60.0	0.8
39	59.2	1.0
40	58.2	1.2
41	57.1	1.4
42	55.7	1.6
43	54.1	1.8

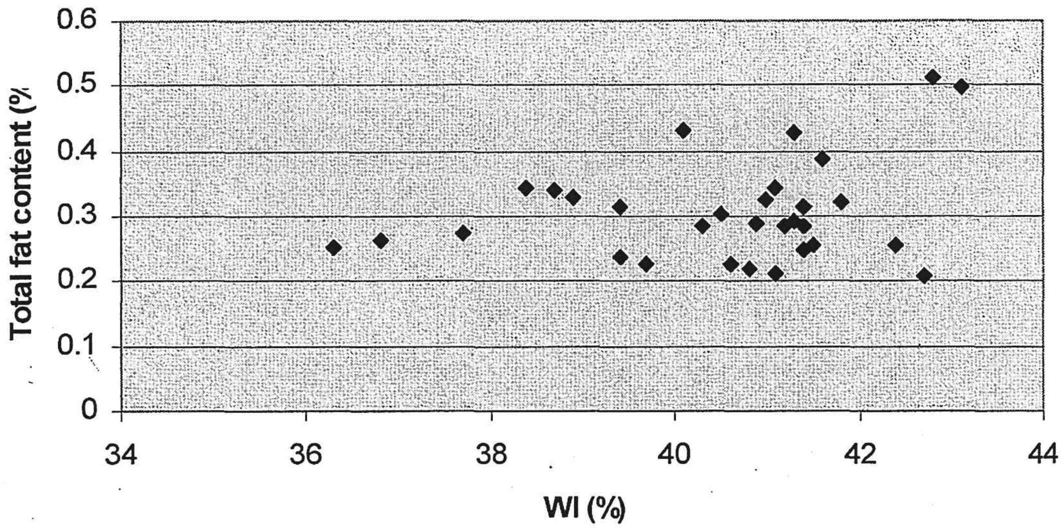


Fig. 7 Relationship between total fat and WI

As expected, HRY decreased with the increase of rice temperature (Fig. 8). A 28°F increase of rice temperature corresponded to a 9% reduction of HRY. Therefore, controlling milling temperature is important for achieving accurate and consistent quality appraisal results. At the same time, it seems that there is correlation between rice temperature and whiteness (Fig. 9). But the trend was different from what was obtained with cooling last year.

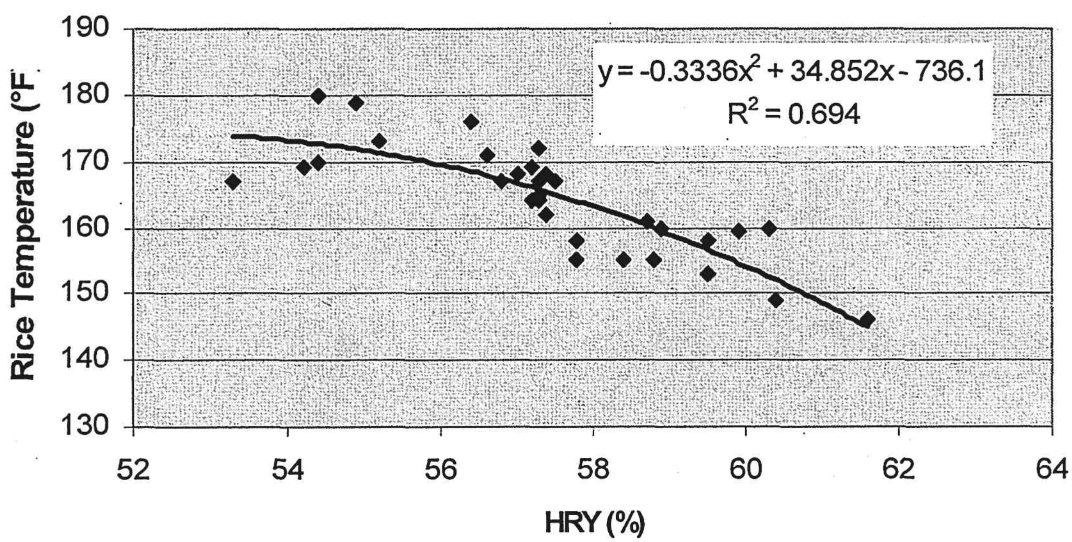


Fig. 8 Correlation between rice temperature and HRY

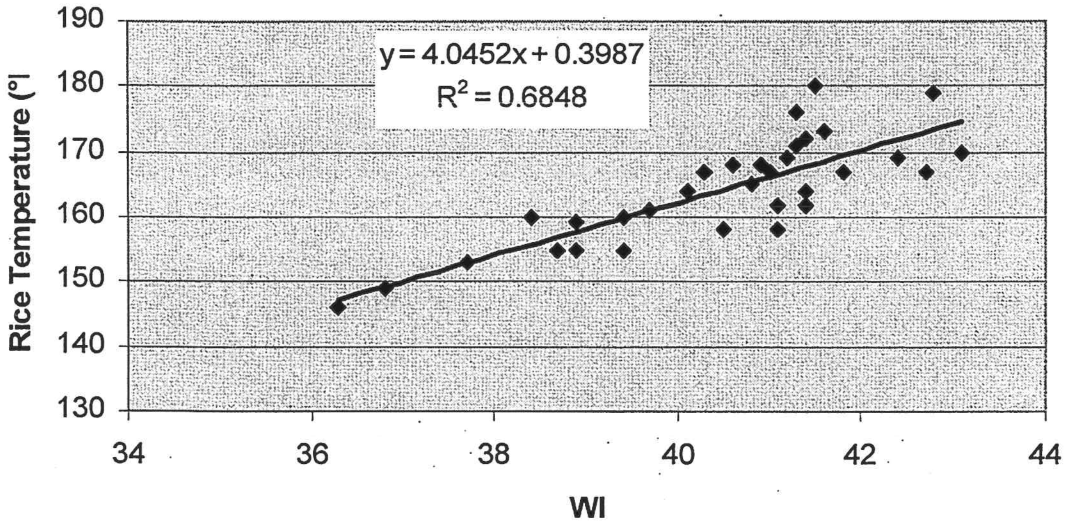


Fig. 9 Correlation between rice temperature and WI

The significance levels of the regression models and coefficient of each term in the regression models are shown in Table 5. All regression models, except for total fat content (TF), in the table were significant at $P<0.001$, which indicated the models were appropriate to be used for prediction of rice quality at different milling conditions. The correlation (R^2) between observed and predicted HRYs and WIs were greater than 0.95, which also indicated that the models are appropriate (Figs. 10 and 11). Therefore, the regression models can be used to predict the quality of milled rice when independent variables are known. However, the model for total fat content was not significant. The degree of significance of each coefficient in the regression models was examined using the t test. If the t value of a coefficient was significant as a lower P value, the term was more important than others in the model and made a significant contribution to the dependent variable.

Table 5. Coefficients and significance of regression models

Variables	Coefficients	HRY	TRY	WI	RT	TF
	A	69.285****	76.257****	17.693****	88.692***	0.737
MT	A1	-0.138*	-0.0186	0.553****	0.856*	-0.00743
MW	A2	-0.405	0.0845	0.76*	4.263*	-0.0538
PT	A3	-0.0943*	-0.042	0.35****	1.385**	-0.0118
PW	A4	-0.639	-1.514**	1.629**	-1.545	-0.00605
MT*MW	B12	-0.0203****	-0.0116**	0.000938	0.022	-0.00095
MT*PT	b13	0.000687	-0.00056	-0.00344***	0.00564	0.000276*
MT*PW	b14	0.0169**	0.0106*	-0.0319***	0.0688	-0.00183
MW*PT	b23	0.0103**	-0.00156	-0.00844*	-0.0592**	0.000224
MW*PW	b24	0.128**	0.0906**	-0.0969**	0.0944	0.00345
PT*PW	b34	-0.0294***	0.0156*	-0.00312	0.0563	0.000162
MT^2	c1	0.00201**	0.000686	-0.0039****	-0.0117**	0.000246*
MW^2	c2	-0.006	-0.00786	-0.00509	-0.105	0.00377

PT^2	c3	0.000135	0.000186	-0.00195**	-0.0105**	4.85E-05
PW^2	c4	-0.111*	-0.0564	0.117*	-0.424	0.00476
Equation		P<0.001	P<0.001	P<0.001	P<0.001	P=0.667

Note: **** P<0.001, *** P<0.01, ** P<0.1, * P<0.3

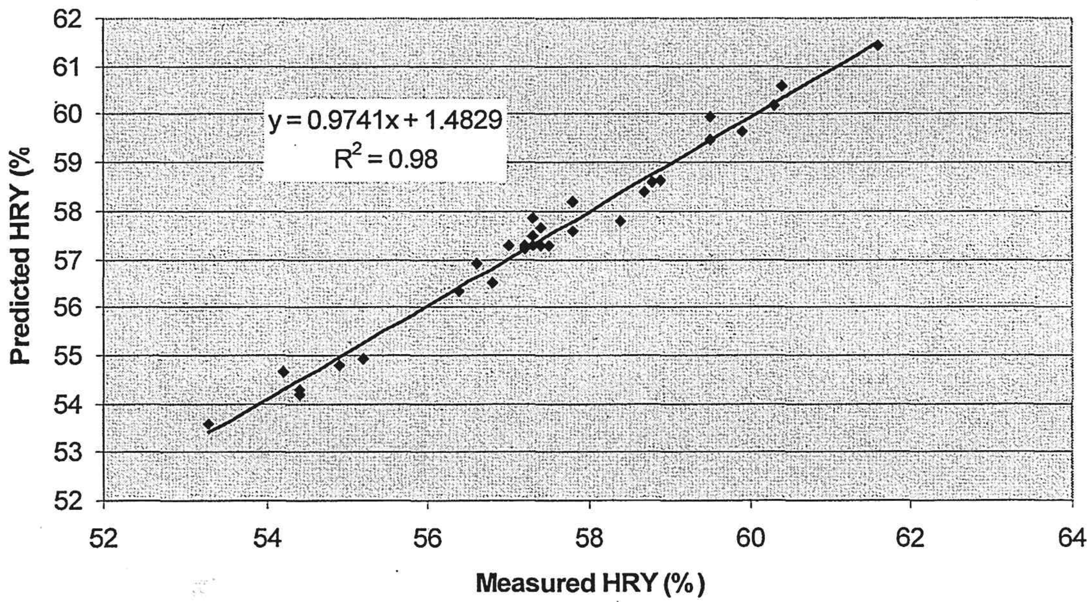


Fig. 10 Correlation between measured HRY and predicted HRY

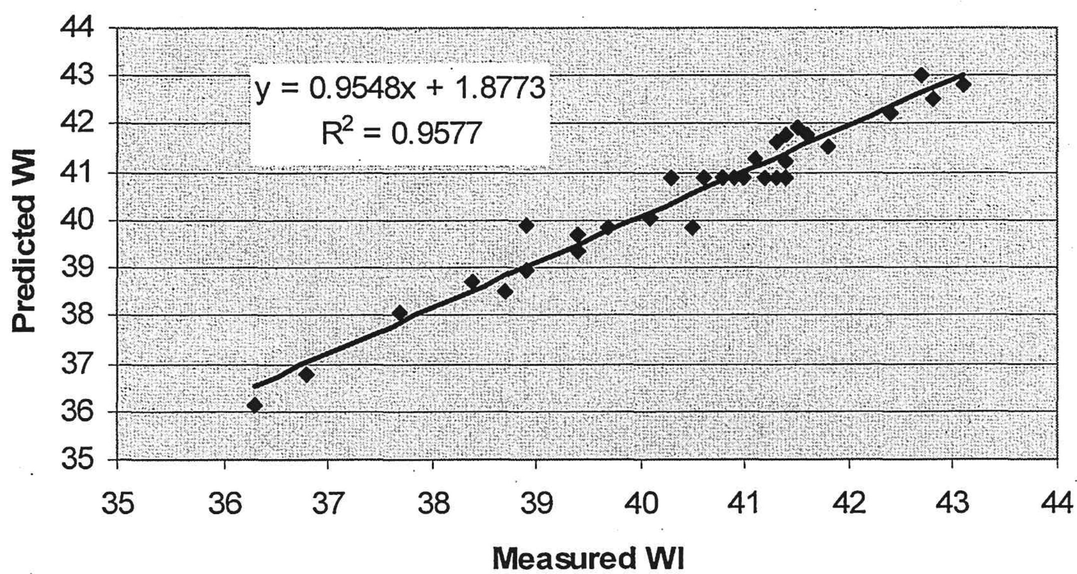


Fig. 11 Correlation between measured WI and predicted WI

To illustrate the effects of independent variables on dependent variables with graphs, only two independent variables were varied in the experimental range and another two independent variables were fixed at their central levels. Since the HRY and WI were the most important quality indicators of milled rice in this research, they were selected from the regression models to show the relationship between dependent and independent variables (Figs 12-15). It is clearly seen that the HRY and WI varied with the variation of time periods and weights of milling and polishing. In general, the HRY decreased and WI increased with the increase of time periods and weights of milling and polishing. They were more sensitive to the time periods of milling and polishing than the weight. Slight longer time periods and lighter weights of milling and polishing could produce higher HRY with a similar whiteness compared to shorter time periods and higher weights.

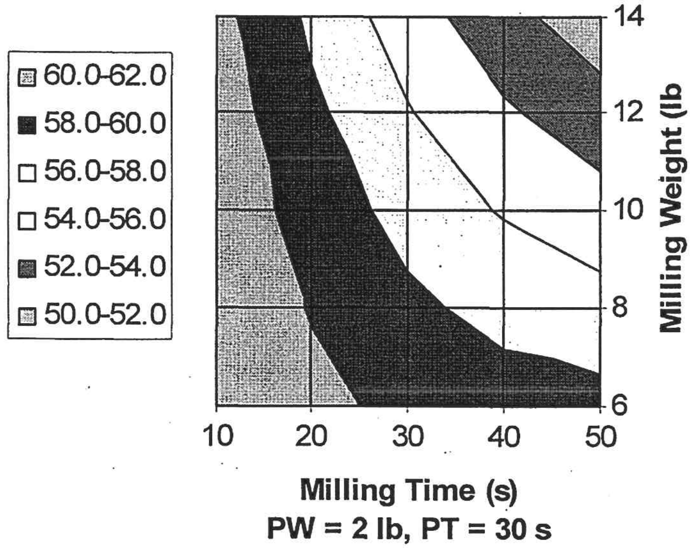


Fig. 12 Effects of milling time and weight on HRY

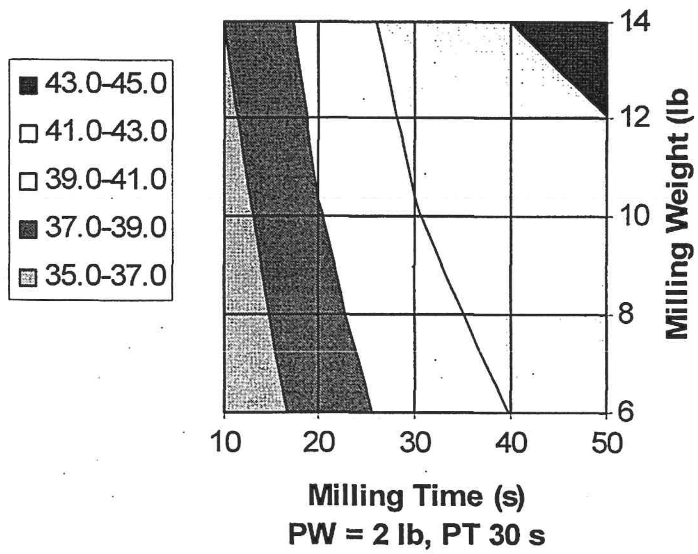


Fig. 13 Effect of milling time weight on WI

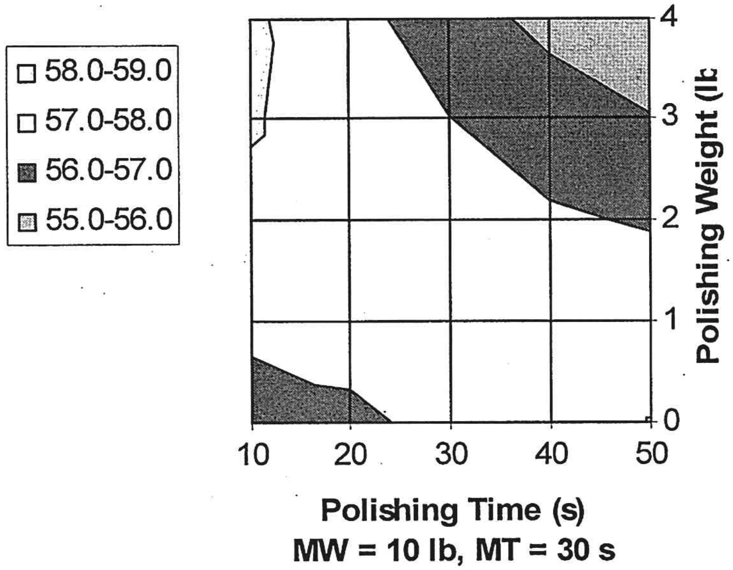


Fig. 14 Effect of polishing time and weight

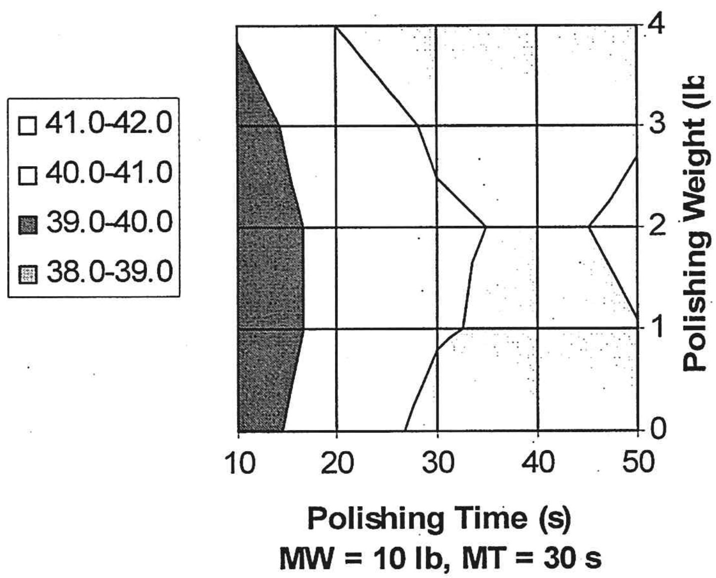


Fig. 15 Effect of polishing time and weight on whiteness index

If the regression models are used to predict the TRY, HRY and WI under the Southern standard milling condition, the obtained TRY, HRY and WI were 72.2%, 59.6% and 39.9. The quality results of six rice samples milled with the Western and Southern procedures are shown in Fig. 16. It can be seen that the Southern procedures produced higher HRY (by 2.6%) and lower WI (by 2 units) than the Western procedures did. The predicted TRY, HRY and WI values obtained with the regression models were very close to the measured values. Due to the significant difference in the quality appraisal results obtained from the Western and Southern standards, it is necessary to standardize the rice sample milling procedures in the United States.

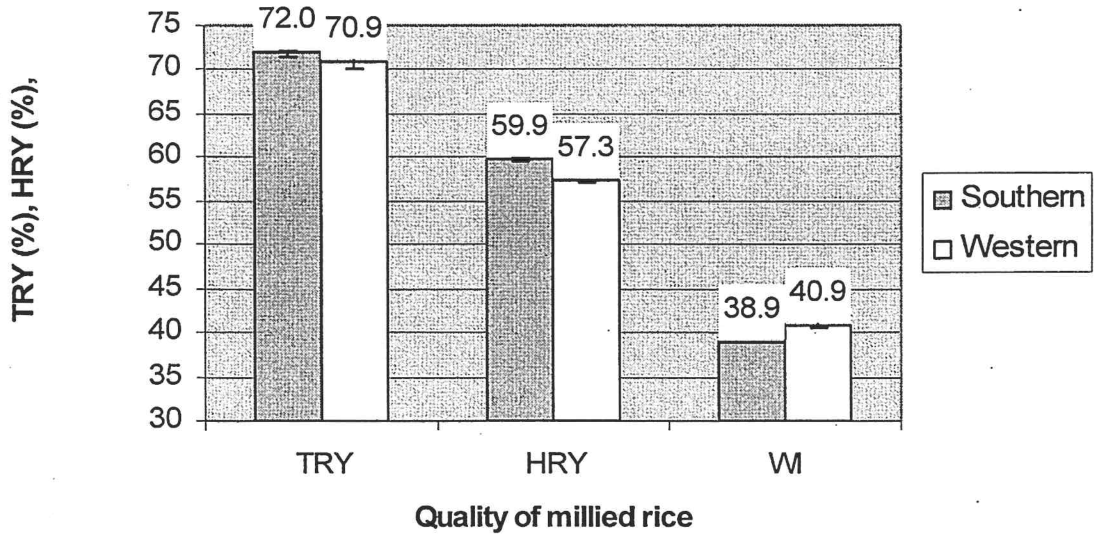


Fig. 15 Comparison of the Western and Southern procedures

Conclusions

The results from this research clearly show that using both internal and external heat exchangers for cooling were effective in reducing milling temperature and improving the TRY and HRY, as well as accurately reflecting the milling quality of rice samples. The newly developed internal heat exchanger could cool the cutting bar to a desired temperature in seconds. The milling conditions were found to be very important factors affecting the rice quality appraisal results. The Western and Southern milling procedures produced significantly different quality appraisal results.

PUBLICATIONS OR REPORTS

N/A

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS

Since the commercial rice milling industry has been updating its milling technology and equipment, it is believed that the milling temperature of commercial rice mill could be significantly lower than that of the lab mill used for the rice quality appraisal. Also, there are two different rice sample milling standards in the United States. Therefore, to assess the impact of the current milling standard on the quality appraisal result, it is important to develop an efficient cooling device for rice sample mill and determine the effect of milling conditions on the quality of milled rice, as well as to compare the Southern and Western standard procedures. The main objectives of the current research were to develop an efficient cooling device and study the effects of cooling methods and milling conditions on the rice quality appraisal results.

In this research, a new internal heat exchanger was developed by modifying the standard cutting bar. The internal heat exchanger was very effective in removing the heat prior to and during milling. It took seconds to lower the cutting bar temperature compared to more than 10 min in the current practice using air cooling. The internal heat exchanger and external heat exchanger developed last year were used for studying the effects of cooling methods on the improvement of quality of milled rice. The results showed that for high quality paddy rice sample the cooling improved head rice by 1.6%. At the same time, the whole kernel percentage examined by visual inspection improved by 5.7%. Both internal and external heat exchangers were effective for controlling milling temperature and improving the accuracy and consistency of rice sample milling. It is expected that the improvement will be even more significant for low quality rice.

To study the effects of milling conditions on the quality of milled rice, a central composite design and regression analysis were used to determine the relationships between milling conditions and quality indicators. The studied four milling conditions included milling time and weight, and polishing time and weight. The milling time and polishing time varied from 10 to 50 seconds and milling weight and polishing weight varied from 6 to 14 lbs and 0 to 4 lbs, respectively. The quality results obtained with current FGIS's Western and Southern procedures were also compared. For medium grain, the Western procedures use 30 seconds for milling, 30 seconds for polishing, and 10 lbs and 2 lbs for milling and polishing, respectively. The Southern procedures use different weights, 7 lbs for milling and 0 lbs for polishing. The research results showed that significant relationships existed among milling temperature, total rice yield, head rice yield and whiteness. Over-mill could result in increase of whiteness and milling temperature, but significant decrease of total and head rice yields. The head rice yield obtained with the Western procedures was 2.6% lower than the head rice yield obtained with the Southern procedures. The rice produced with the Western produces was also significantly whiter than that produced with the Southern procedures. But there is no quantitative standard from FGIS that can be used to determine if the rice was over-milled with the current Western procedures. It will be important to identify the need for the whiteness or degree of milling in commercial rice industry, which can be used as reference for rice sample milling to avoid over-mill.

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