Milling Quality as Affected by Brown Rice Temperature[1]

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ABSTRACT

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Three cultivars of long grain rice were used to evaluate the effects of cooling brown rice before milling on head rice yield (HRY) and degree of milling (DOM). Brown rice at initial temperatures (T_i) ranging from 0 to 25°C was milled for 15, 30, 45, or 60 sec in a McGill No. 2 laboratory mill. The HRY versus T_i and the HRY versus DOM relationships were inversely linear. The three cultivars showed HRY increases of 1.4–1.8 percentage points for T_i reduction from 25 to 0°C at the standard 30-sec milling time (MT). However, when HRYs were adjusted to equivalent DOMs using a commercial milling meter, there was no significant improvement in HRY due to cooling the brown rice.

Rough rice is characterized by an abrasive, loosely attached hull enclosing the brown rice kernel. After hulling, brown rice is typically milled to produce a white, polished rice that is preferred by consumers. The efficiency of milling is judged by the quality and quantity of the resulting white rice. The quantity of interest is the amount of unbroken kernels remaining, expressed as a mass percentage of the initial rough rice sample. This ratio is the head rice yield (HRY). Head rice is milled rice that comprises kernels that are three-fourths kernel or more in length (USDA 1979). The primary factor for determining the quality of milled rice is the degree of milling (DOM). The DOM is a measure of the amount of bran remaining on milled rice kernels.

There are several methods to measure the DOM of white rice. A subjective method is used by the Federal Grain Inspection Service (FGIS). Graders compare the samples to be evaluated to interpretive line-reference samples used as standards. This subjective grading method allows rice to be classified into broad DOM categories of well-milled, reasonably well-milled, lightly milled, and undermilled, but does not provide a quantitative method to express DOM. Another method uses optical measurement of transparency and whiteness. A commercial milling meter, (model MM-1B, Satake) uses both reflectance and transmittance measurements from a milled rice sample to quantify the DOM level on a scale between 0 and 199.

Milling time affects both HRY and DOM. Andrews et al (1992) showed that as milling time increased, HRY decreased and DOM increased. Sun and Siebenmorgen (1993) reported a linear inverse relationship between HRY and DOM for various rice kernel thickness fractions by using a Satake milling meter to quantify DOM. Siebenmorgen and Sun (1994) also showed high correlations between DOM readings taken by the Satake milling meter and surface fat concentration measurements. This information was used in their study to adjust HRYs to equivalent DOMs to make direct comparisons between millings of different kernel thickness fractions.

During milling, while bran is being removed, the bran remaining on the kernel is simultaneously increasing in temperature. Rice processors have posed the question as to the effects of rice temperature at the initiation of milling on milling quality. Bhatia (1969) reported that breakage decreases exponentially with the increase of initial grain temperature. In their experiment, rice was only milled at three initial grain temperatures: −21.1, 26.7, and 32.2°C No literature was found concerning the effects of cooling the grain before milling. The purpose of this study was to quantify these effects in terms of milling quality. The objectives of this study were to: 1) determine the effects of milling brown rice at various initial brown rice kernel temperatures (T_i) on HRY and DOM; 2) determine the relationship between HRY and DOM for several T_i; 3) use the relationships to adjust for DOM effects and determine whether cooling brown rice before milling can increase HRY.

MATERIALS AND METHODS

Three long grain rice cultivars (Adair, Alan, and Newbonnet) were used. The rough rice was cleaned and dried to 14% mc (wb) immediately after harvest. It was then bagged in paper sacks and placed in storage at 1°C for 10 months until being removed for milling. Moisture content for each of the cultivars was measured by drying in an oven at 130°C for 24 hr. At the time of milling, the Adair, Alan, and Newbonnet lots had 13.1, 13.6, and 14.0% mc (wb), respectively.

Experimental Procedure

After being removed from cold storage, rough rice from each cultivar was allowed to remain at 22°C in plastic bags for at least 24 hr. The bulk rice was separated into samples of ~150 g using a Boerner divider. These samples were hulled with a Seedboro sheller-huller at a rate of ~500 g/min (USDA 1984) to yield a brown rice sample of at least 123 g. Each brown rice sample was placed in doubled, sealable plastic bags to prevent any change in moisture content. Twelve samples for each T_i to be tested within each cultivar were held at temperatures ranging from −10 to 25°C. The lower temperatures of −10 and 5°C were achieved by placing samples in a walk-in freezer and walk-in cooler, respectively. Other temperatures were obtained using an air-relative humidity-temperature control unit. Samples were held in the respective temperature conditions for at least 24 hr to allow all kernels to come to a uniform temperature. Samples were removed from their respective temperature conditions just before milling and placed in an insulated cup. The T_i was measured using a thermocouple. The mean temperature of the 12 samples taken from a set condition was reported as the T_i for those samples. Standard deviations ranged from 0.95 to 0.06°C, with the average standard deviation being 0.50°C.

McGill No. 2 Milling Procedure

A McGill No. 2 mill was instrumented with thermocouples on the outside and inside of the mill chamber. These temperatures, as well as the laboratory temperature, were continuously monitored during milling. The mill was warmed by milling ~120 g of brown rice until the external mill temperature reached at least 28.5°C. Milling of each of the subsequent samples began when the external mill temperature cooled to 28.5°C. This was done to reduce variability that might occur due to mill temperature. Brown rice samples of 123.0 g were milled for 15, 30, 45, or 60 sec in the McGill No. 2 laboratory mill, which was equipped with an automatic timer. A 1,500-g mass was placed on the mill lever arm, 15 cm from the center of the milling chamber. Immedi-

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ately after milling, the rice was placed in an insulated cup and the final milled rice temperature (T_f) was measured using a thermocouple. The mill was thoroughly cleaned between each milling. Milled rice mass was measured. Head rice was separated from broken rice (sized) using a Seedboro shaker-sizer. Three milling replicates were made at each of the four milling times (MT) for each T_i.

DOM Determination

DOM of the sized white rice was measured using a Satake milling meter, model MM-1B. The milling meter displays DOM as a value from 0 (brown rice) to 199 (pure white rice). Therefore, the larger the DOM number, the more well-milled the sample. DOM levels of 85–95 are target levels for most commercial rice mills. Three DOM readings were taken on a subsample of ~25 g. The meter displayed the average DOM value for the subsample. This procedure was repeated for two additional subsamples, and the mean of the three average DOM readings was reported as the DOM for the sample.

RESULTS AND DISCUSSION

HRY vs. Initial Temperature

Regression analyses were performed on the milling data using the general linear models procedure PROC GLM (SAS 1989). The regression that related HRY to T_i for Adair, Alan, and Newbonnet showed HRY increases of 1.4, 1.6, and 1.8 percentage points, respectively, for T_i reduction from 25 to 0°C. Figure 1 shows the relationship of milled rice yield (MRY) and HRY to T_i for the three cultivars for the standard 30 sec MT. MRY and HRY were linearly correlated with brown rice T_i. The R^2 values for HRY versus T_i at the 30-sec milling time were 0.67, 0.51, and 0.45 for Adair, Alan, and Newbonnet, respectively.

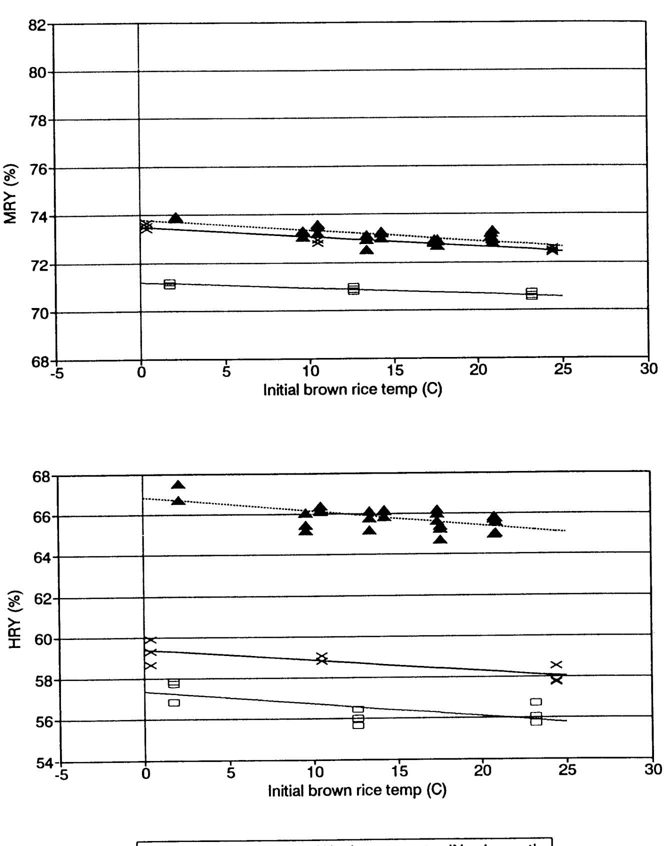

Fig. 1. Milled rice (MRY) and head rice yields (HRY) vs. initial brown rice temperature for 30-sec milling times for the three cultivars tested. Regression lines were generated from Equations 1 and 2. Data does not include an adjustment for degree of milling.

DOM vs. MT

The relationship of DOM to MT at measured T_i for the three cultivars is depicted in Figure 2. The graphs of DOM versus MT for different T_is show that HRY for a given MT should not be directly compared from one T_i level to another because of differences in DOM between the T_i levels. HRY for the various T_i levels needed to be adjusted to equivalent DOM before comparisons could be made. For a given MT, a sample with a lower T_i tended to mill to a lesser DOM. As MT increased, the disparity in DOM between warmer and cooler T_i samples decreased.

HRY vs. DOM

The regressions shown in Figure 1 do not include an adjustment for DOM. A wide range of DOM and associated HRY was created by the various MT. These data were used to regress MRY and HRY against DOM. The HRY versus DOM trend for Adair can be seen in Figure 3. For clarity, data points are shown for only three T_i for Adair. However, the regression line shown was developed from the data from all nine T_i. Model equations that correlated MRY and HRY (at a given T_i) to DOM were:

$$MRY_{(Ti)} = a_{MRY} + b_{MRY} \times DOM \quad (1)$$

$$HRY_{(Ti)} = a_{HRY} + b_{HRY} \times DOM \quad (2)$$

where a and b are regression coefficients. Values for a and b are given in Table I. The relationship between HRY and DOM was linear for each T_i, with most R^2 values being >0.93. If all T_i were grouped together within each cultivar, the R^2 values were 0.91, 0.89, and 0.85 for Adair, Alan, and Newbonnet, respectively. These high R^2 values indicate that the relationship between HRY and DOM was independent of T_i.

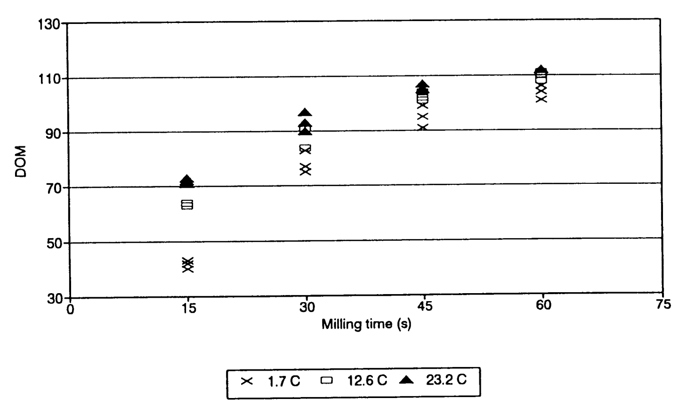

Fig. 2. Degree of milling (DOM) versus milling time for the cultivar Alan at the indicated initial brown rice temperature.

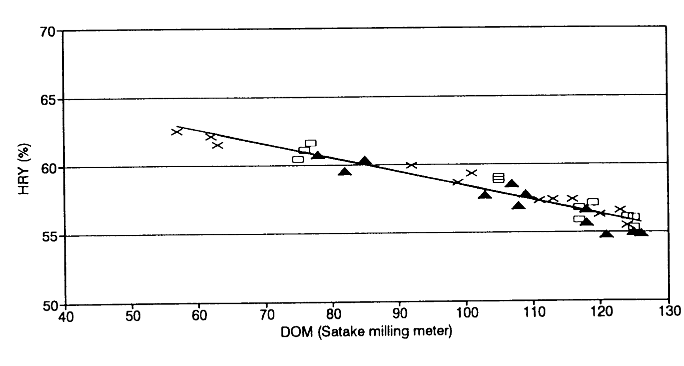

Fig. 3. Head rice yield (HRY) vs. degree of milling (DOM) for the cultivar Adair at the indicated initial brown rice temperature. Regression line fitting data from all initial brown rice temperatures across all milling times is shown.

TABLE I
Coefficients of Linear Regression of Equations 1 and 2[a]

Cultivar	T_i (°C)	Coefficients					
		a_{MRY}	b_{MRY}	R^2_{MRY}	a_{HRY}	b_{HRY}	R^2_{HRY}
Adair	0.4	80.325	−0.0730	0.974	67.913	−0.0935	0.962
	10.5	81.551	−0.0840	0.985	69.580	−0.1082	0.909
	24.4	81.697	−0.0884	0.960	70.206	−0.1201	0.914
	All	80.983	−0.0800	0.962	68.914	−0.1046	0.910
Alan	1.7	76.887	−0.0747	0.983	63.520	−0.0851	0.926
	12.6	79.124	−0.0938	0.978	65.023	−0.1050	0.912
	23.2	80.032	−0.1005	0.960	68.799	−0.1379	0.955
	All	77.723	−0.0797	0.922	64.750	−0.0992	0.889
Newbonnet	2.1	84.979	−0.1179	0.984	77.257	−0.1117	0.942
	9.6	85.484	−0.1292	0.980	77.038	−0.1254	0.935
	10.5	86.123	−0.1337	0.965	78.088	−0.1285	0.929
	13.4	84.414	−0.1210	0.987	77.807	−0.1298	0.948
	14.3	86.953	−0.1424	0.957	80.013	−0.1446	0.939
	17.4	85.337	−0.1331	0.924	78.132	−0.1352	0.879
	17.6	85.809	−0.1361	0.972	79.199	−0.1495	0.933
	20.8	88.282	−0.1500	0.982	80.430	−0.1511	0.916
	20.9	86.043	−0.1366	0.981	77.650	−0.1302	0.923
	All	85.503	−0.1291	0.923	78.068	−0.1308	0.848

[a]($MRY_{(Ti)}$ [or $HRY_{(Ti)}$] = a + b × DOM) at measured initial brown rice temperatures (T_i) to DOM for Adair, Alan, and Newbonnet. All = coefficients of regression when all T_i are grouped together in the regression analysis; MRY = milled rice yield; HRY = head rice yield; DOM = degree of milling.

TABLE III
Coefficients of Linear Regression of Equation 3[a]

Cultivar	T_i (°C)	Coefficients			Time (sec) to Reach DOM		
		c	*d*	R^2	80	90	100
Adair	0.4	48.167	1.3400	0.898	24_1[b]	31_1	39_1
	10.5	66.167	1.0578	0.907	13_2	23_2	32_2
	24.4	72.833	0.9022	0.888	8_3	19_3	30_3
Alan	1.7	29.000	1.3511	0.899	38_1	45_1	53_1
	12.6	52.833	1.0178	0.923	27_2	37_2	46_2
	23.2	62.667	0.8822	0.929	20_3	31_3	42_3
Newbonnet	2.1	62.833	0.9200	0.932	19_1	30_1	40_3
	9.6	67.000	0.8067	0.901	16_2	29_3	41_2
	10.5	70.333	0.7489	0.937	13_5	26_5	40_5
	13.4	67.000	0.8356	0.952	16_3	28_4	39_6
	14.3	72.667	0.7111	0.934	10_9	24_9	38_9
	17.4	69.167	0.7200	0.930	15_4	29_2	43_1
	17.6	71.667	0.7133	0.914	12_6	26_6	40_4
	20.8	71.617	0.7368	0.933	11_8	25_8	39_8
	20.9	71.667	0.7311	0.931	11_7	25_7	39_7

[a]$DOM_{(Ti)}$ = c + d × MT relating degree of milling (DOM) to milling time (MT) for Adair, Alan, and Newbonnet. MT required to reach DOM of 80, 90, and 100 are given.
[b]Relative rankings are shown for highest to lowest MT required to reach the given DOM within each cultivar.

TABLE II
Estimated Milled Rice Yields (MRY) and Head Rice Yields (HRY) for Measured Initial Brown Rice Temperatures (T_i)[a]

Cultivar	T_i (°C)	MRY (%)			HRY (%)		
		80	90	100	80	90	100
Adair	0.4	74	74	73	60	59	59
	10.5	75	74	73	61	60	59
	24.4	75	74	73	61	59	58
	All	75	74	73	61	59	58
Alan	1.7	71	70	69	57	56	55
	12.6	72	71	70	57	56	55
	23.2	72	71	70	58	56	55
	All	71	71	70	57	56	55
Newbonnet	2.1	76	74	73	68	67	66
	9.6	75	74	73	67	66	64
	10.5	75	74	73	68	67	65
	13.4	75	74	72	67	66	65
	14.3	76	74	73	68	67	66
	17.4	75	73	72	67	66	65
	17.6	75	74	72	67	66	64
	20.8	76	75	73	68	67	65
	20.9	75	74	72	67	66	65
	All	75	74	73	68	66	65

[a]For given degrees of milling using Equations 1 and 2 for Adair, Alan, and Newbonnet cultivars. All = estimate when the regression analysis is performed for all T_i grouped together.

DOM Adjustment

MRY and HRY were dependent on DOM, which in turn was affected by T_i (Fig. 2). To directly compare the MRY and HRY of samples with different T_i, the samples from each T_i were adjusted to equivalent DOM. This was done by using Equations 1 and 2 for each T_i and using 80, 90, and 100 for the DOM level. This range encompasses the target DOM values for rice millers. The results of these calculations are shown in Table II. After MRY and HRY were corrected for DOM, there was no significant improvement in HRY as initial milling T_i were decreased.

MT Required to Reach a Given DOM

Regression analysis was performed to determine the relationship between MT and resulting DOM for each T_i within each cultivar. The model equation was:

$$DOM_{(Ti)} = c + d \times MT \quad (3)$$

where *c* and *d* are regression coefficients. Values for *c* and *d* and estimated times required to reach a given DOM for each T_i are given in Table III. R^2 values were >0.90 for 15 out of 18 regressions. The trend was that the lower the T_i, the longer the sample had to be milled to reach a desired DOM level. For example, Alan rice at a T_i of 23.2°C reached a DOM of 90 in 31 sec, whereas 44 sec of milling was required to reach a DOM of 90 for a T_i of 1.7°C.

Final Milled Rice Temperature vs. MT

The relationship between final milled rice temperature (T_f) and MT was examined. As MT increased, the range in T_f from the coldest to warmest T_i lessened. Figure 4 shows this trend for Adair. The initial temperature difference of 24°C between the 24.4 and 0.4°C samples became 10°C at the 15-sec MT and was reduced to only 5°C at the 60-sec MT. Greater heat transfer from the mill during the longer MT would explain this trend.

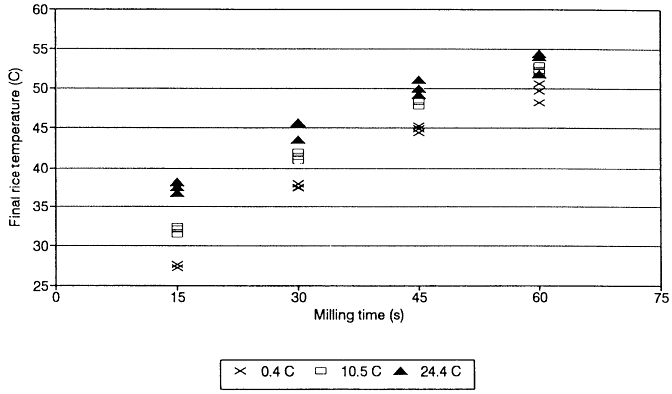

Fig. 4. Final rice temperature vs. milling time for the cultivar Adair at the indicated initial brown rice temperature.

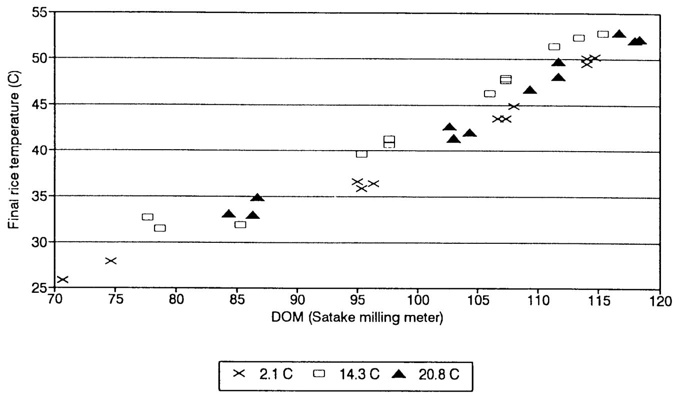

Fig. 5. Final rice temperature vs. degree of milling (DOM) for the cultivar Newbonnet at the indicated initial brown rice temperature. For clarity, only data points for a high, medium, and low initial brown rice temperature are shown.

Final Milled Rice Temperature vs. DOM

There was a strong relationship for T_f regressed against DOM for each T_i in each cultivar. Figure 5 shows this relationship for Newbonnet. For clarity, data points are shown only for a representative high, medium, and low T_i. The equation that was used to model the relationship was:

$$T_{f(Ti)} = e + f \times \text{DOM} \tag{4}$$

where e and f are regression coefficients. These coefficients and the estimated T_f at specified levels of DOM for each T_i are listed in Table IV. Most R^2 values for the three cultivars exceeded 0.92. When all T_i within a cultivar were grouped, and a single regression performed, the R^2 values were also high. These R^2 values were 0.92, 0.96, and 0.89 for Adair, Alan, and Newbonnet, respectively, when relating T_f to DOM.

No trends were noted when comparing sample T_f to T_i at a given DOM. The initial wide spread in temperature between the T_i treatments was greatly diminished when comparing associated T_f at equivalent DOM. A 24°C difference in T_i for Adair was reduced to only 3.3°C difference in T_f at the DOM level of 80. The changes for the Alan was 21.5 to only 0.7°C, and the changes for Newbonnet were 18.8 to 6.2°C.

During a batch-milling process, such as that used in in the McGill No. 2 mill, many factors and their interrelationships should receive consideration, including: ambient temperature surrounding the mill, mill temperature, T_i, MT, T_f, and DOM. The R^2 values for the T_f versus DOM relationships of 0.92 and above indicate that 92% of the variability in T_f is explained by DOM. This is evidence that the properties of rice bran are affected by temperature. At low temperatures, the oil in the bran is more viscous and more difficult to remove from the kernel than it is when it is at a warmer, less viscous state. It is speculated that the bran must reach a high enough temperature before it can be readily removed from the kernel. Brown rice at lower T_is requires more energy input from the mill to reach the proper temperature range for bran removal than does rice at a higher T_i, and therefore must be milled longer to reach an equivalent DOM.

TABLE IV
Coefficients of Linear Regression of Equation 4[a]

		Coefficients			T_f (°C) to Reach DOM		
Cultivar	**T_i (°C)**	**e**	**f**	**R^2**	**80**	**90**	**100**
Adair	0.4	5.846	0.3455	0.964	33_2[b]	37_1	40_1
	10.5	0.415	0.4069	0.975	33_1	37_2	41_2
	24.4	7.597	0.3644	0.922	37_3	40_3	44_3
	All	4.034	0.3785	0.922	34	38	42
Alan	1.7	12.167	0.3437	0.953	40_3	43_3	47_2
	12.6	6.784	0.4026	0.983	39_1	43_2	47_3
	23.2	13.743	0.3235	0.935	40_2	43_1	46_1
	All	11.244	0.3526	0.957	39	43	47
Newbonnet	2.1	−13.649	0.5428	0.976	30_1	35_1	41_1
	9.6	−13.506	0.5811	0.960	33_5	39_5	45_5
	10.5	−18.367	0.6254	0.976	32_4	38_4	44_4
	13.4	−8.469	0.5359	0.984	34_6	40_6	45_6
	14.3	−17.254	0.6068	0.970	31_3	37_3	43_3
	17.4	−9.149	0.5661	0.956	36_9	42_8	47_8
	17.6	−12.333	0.5850	0.970	34_7	40_7	46_7
	20.8	−17.006	0.5849	0.979	30_2	36_2	41_2
	20.9	−11.278	0.5904	0.981	36_8	42_9	48_9
	All	−11.920	0.5645	0.892	33	39	45

[a] $T_{f(Ti)} = e + f \times$ DOM relating final milled rice temperature (T_f) to degree of milling (DOM) for Adair, Alan, and Newbonnet. T_f at DOM of 80, 90, and 100 are given. All = coefficients of regression and estimates when all T_i are grouped together in the regression analysis.
[b] Relative rankings are shown for T_f from low to high required T_f at the given DOM within each cultivar.

CONCLUSIONS

MRY and HRY were affected by brown rice T_i. This apparent effect was due primarily, if not totally, to resulting DOM of the samples. HRY versus DOM curves were obtained for each T_i, and these curves were used to adjust for DOM differences between samples. After adjustment to given DOM levels, there was no change in MRY and HRY due to milling at different T_i. Thus, no practical improvement in HRY was obtained by cooling brown rice before milling when DOM was considered. Brown rice that had been cooled had a lower DOM after being milled for the same length of time as a sample that had not been cooled. Bran properties were apparently affected by kernel temperature, as there was a strong correlation between T_f and DOM. It is speculated that bran is not removed by the milling process until it reaches a sufficiently high temperature.

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