Milling Characteristics of Various Rough Rice Kernel Thickness Fractions[1]

H. SUN and T. J. SIEBENMORGEN[2]

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ABSTRACT

Rough rice from three cultivars of long-grain rice was separated into six kernel-thickness fractions and milled in a McGill No. 2 mill. The degree of milling (DOM) was measured with a milling meter (Satake). Rough rice kernel thickness, milling time, and cultivar had significant effects on both head rice yield (HRY) and DOM. Results showed that DOM and HRY were linearly related in all thickness fractions, as well as in the bulk, unfractionated rice. HRY for each thickness fraction within each cultivar was calculated for set levels of DOM using these linear relationships. Compared to the HRY of unfractionated, bulk rice, the overall HRY was increased by milling the fractionated rice separately only in the Newbonnet cultivar, which has a large percentage of thin kernels. The Newbonnet weighted-average HRY was increased by as much as 3.8% over the HRY of unfractionated, bulk rice. When the thinnest thickness fraction of each cultivar was removed from consideration in the weighted-average procedure, the weighted-average HRY of the remaining thickness fractions was higher than that of the unfractionated control, not only for Newbonnet, but for Millie and Lemont cultivars as well.

Producing a milled, polished rice with minimum breakage is a universal goal of rice mills. Head rice yield (HRY) and degree of milling (DOM) are the primary factors determining the milling quality of rice. Head rice is milled rice kernels that are three-fourths or more intact (USDA 1979). HRY is the mass percentage of rough rice that remains head rice throughout milling. DOM is the extent to which the rice bran has been removed from the kernels. Milling rice to a minimum acceptable DOM can maximize HRY and avoid economic loss due to overmilling. Finding a method to increase HRY and yet mill to a given DOM would allow maximum economic return.

Significant differences in HRY among kernel-thickness fractions were found by separating long-grain rough rice into thickness fractions with a Carter-Day dockage tester (Wadsworth et al 1979, 1982; Matthews et al 1981a; Wadsworth and Hayes 1991). Initially, HRY increased with increasing kernel thickness, then it reached a maximum and decreased. Matthews and Spadaro (1976) indicated that the greater the breakage in milled, unfractionated rice, the greater the breakage tended to be in all the thickness fractions of a given lot. The breakage in the milled rice was greater for the thinner fractions. These experiments measured HRY attained by milling thickness-fractionated rice but did not determine the associated DOM, nor were possible HRY optimums investigated by milling thickness fractions for various time periods.

Milling time affects both HRY and DOM. Velupillai and Pandey (1987) reported that 65–73% of the bran was removed

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[2]Graduate assistant and professor, respectively, Biological and Agricultural Engineering Department, University of Arkansas, Fayetteville.

in the first 20 sec of milling. Andrews et al (1992) showed that as milling time increased, HRY decreased, and DOM increased. Little research has been done on the interaction between rice kernel thickness and milling time on resulting HRY and DOM.

The objectives of this study were to 1) determine the interactive effects of rough rice kernel thickness and milling time on HRY and DOM when milling rice in a McGill No. 2 mill, and 2) determine whether overall HRY can be increased by fractionating rough rice into thickness fractions and milling each size fraction separately for a time period that produces an acceptable level of DOM, thereby maximizing HRY.

MATERIALS AND METHODS

Experimental Design

Three long-grain cultivars were used: Newbonnet, Millie, and Lemont. Rough rice from each cultivar was separated into six thickness fractions with a commercial-scale Carter-Day precision grader. The six rough rice kernel-thickness fractions were: <1.83 mm, 1.83–1.88 mm, 1.88–1.93 mm, 1.93–1.98 mm, 1.98–2.03 mm, and >2.03 mm. The rice from each thickness fraction was hulled and then milled for 15, 30, 45, and 60 sec in a McGill No. 2 mill. Unfractionated, bulk rough rice was also milled for the same durations. Thus, 252 samples were milled: six thickness fractions + bulk rice × three cultivars × four milling times × three replicate determinations.

Experimental Procedure

Each long-grain rice cultivar was combine-harvested and dried, using natural air in commercial-scale bins, to about 15% mc (wb) in September, 1991. The rice was subsequently placed in paper bags and stored at 1°C.

Approximately 190 kg of each cultivar was removed from cold storage and cleaned with a laboratory-scale Carter-Day dockage tester. Three sieves (28, 25, and 22) were used in the top, middle, and bottom sieve carriages, respectively. The 28 sieve is a round-hole sieve, 3.57 mm in diameter; the 25 and 22 sieves are rectangular-hole sieves, with 2.58- and 1.54-mm slot widths, respectively. All rough rice was passed through the dockage tester twice to ensure thorough cleaning.

Bulk rough rice of each cultivar was fractionated using a commercial-scale Carter-Day precision grader. The screens were 254 mm (10 in.) in diameter and 1.57 m (5 ft. 2 in.) long with rectangular slots for the kernels of different thicknesses to pass through. Kernels that did not pass through the screens were discharged from the end of the screen. During the separating process, bulk rough rice was poured into a hopper on the top of the grader. The flow rate was adjusted to allow sufficient residence time over the screen to ensure complete separation. While the bulk rice was in the rotating screens, the thinner rough rice kernels passed through the screens to a container, and the thicker rough rice kernels flowed to the end of the screen where the rice was discharged to another container. After one pass over the screen, the thicker rice was passed over the screen again to ensure complete separation. The remaining thinner rice was passed through the precision grader again, with the next smaller screen. The procedure was repeated until the bulk rice was separated into six rough rice kernel-thickness fractions. Mass percentages were calculated by dividing the mass of each thickness fraction by the total mass of bulk rice. After separation, all rice was placed in plastic bags and stored at 1°C until milling.

The moisture content of all thickness fractions and the bulk rice for the three cultivars was determined by an oven-drying method (Jindal and Siebenmorgen 1987) before milling. All milling was conducted at ~12.5% mc for rough rice. Rice samples with moisture contents >12.5% were dried in air to 12.5%.

Rough rice subsamples of 150 g were hulled in a McGill sheller at ~500 g/min (USDA 1984). The clearance between the rollers was set at 0.483 mm (0.019 in.) (USDA 1984). No attempt was made to adjust the clearance between the rollers for the various thickness fractions. A McGill No. 2 mill was used for the resulting brown rice. A 1,500-g mass was placed on the mill lever arm, 6 cm from the center of the milling chamber. The milling times were from 15 to 60 sec in 15-sec increments.

The mass percentage of head rice for each milled sample was determined by the Federal Grain Inspection Service (FGIS) procedure that uses a Boerner divider to select a 40-g subsample from each milled rice sample. The 40-g subsample was hand-separated into head rice and brokens by trained personnel. The percentage of head rice from the 40-g subsample was multiplied by the milled rice mass to obtain the head rice mass. The head rice mass was then divided by the original amount of rough rice (150 g) to obtain the HRY.

DOM was measured using a Satake milling meter (model MM-1B) that uses both reflectance and transmittance measurements from the sample to determine DOM. The milling meter displays DOM as a value from 0 to 199: 0 represents a DOM level corresponding to brown rice; 199 represents a DOM level of snow white rice. Thus, a larger DOM number implies a more thorough or complete bran removal. Three instrument readings were taken on a single subsample, after which the average value of DOM was displayed.

RESULTS AND DISCUSSION

Thickness Distribution

Rough rice kernel-thickness distributions for each cultivar are shown in Figure 1. The greatest mass fraction for Newbonnet, Millie, and Lemont were 1.88–1.93 mm (31.9%, mass percentage), 1.93–1.98 mm (39.1%), and 1.98–2.03 mm (50.5%), respectively. Figure 1 indicates that the thinnest thickness fractions had higher mass percentages than the next thinnest fraction in all three cultivars, because some brown rice was mixed with the rough rice in the thinnest thickness fractions. Subsequently, the brown rice was removed by hand before milling. The mass percentages of brown rice in the thinnest fraction were 10.1%, 29.6%, and 14.0% for Newbonnet, Millie, and Lemont, respectively. Table I lists the original mass distribution percentages for each cultivar (Case 1), the mass percentages after brown rice was removed (Case 2), and the mass percentages corresponding to a situation in which the entire thinnest thickness fraction was removed (Case 3). These distributions are used in subsequent calculations.

Table II indicates the average rough rice kernel thickness for each kernel-thickness fraction and for unfractionated, bulk rice for the three cultivars. Within the same thickness fraction, the average kernel thickness of 100 rough rice kernels of each of the three cultivars was essentially equal, but the average thickness was less than the slot width of the corresponding screen used to separate the rice. The rotational action of the screen prevented some kernels with thicknesses less than the slot width to pass through the screen.

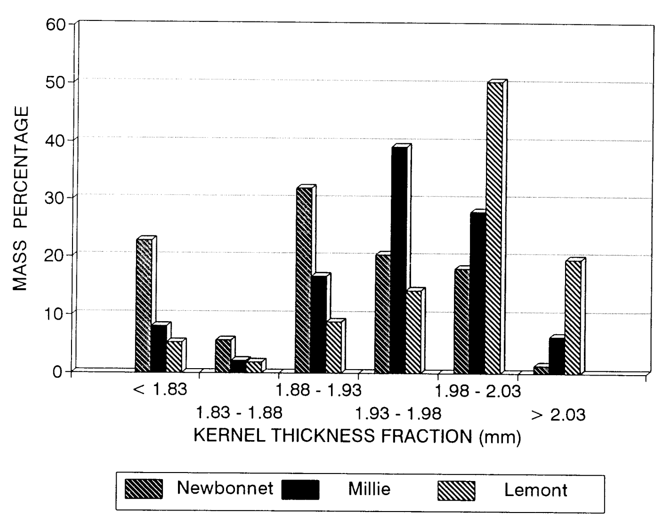

Fig. 1. Rough rice kernel mass distributions for three rice cultivars.

Moisture Content Distribution

Table III lists the moisture content of each thickness fraction and bulk rice for the three cultivars. No significant correlation was found between the average thickness fraction and the associated moisture content. The moisture content of the thickest fractions were higher than those of the intermediate thickness fractions for all three cultivars. The moisture content of the thinnest fractions for Newbonnet and Millie were also higher than those of the intermediate thickness fractions, while the moisture content of the thinnest fraction for Lemont was within the moisture content range of the intermediate thickness fractions.

Milled Rice Yield

Milled rice yields (MRY) varied with both thickness fraction and milling time. Figure 2 and Table IV show MRY changes with rough rice kernel thickness for the four milling times. Similar MRY profiles were found for each cultivar, from the thinnest to the thickest fraction for each milling time. Significant differences in MRY were found ($P = 0.05$) among the thickness fractions and milling times using Fisher's method (MSE = 0.1465, LSD = 0.62). MRY increased dramatically as thickness increased from the thinnest fraction to the 1.83–1.88-mm fraction. There were small, yet significant changes in MRY as the thickness fraction increased beyond the 1.83–1.88-mm fraction. There was no significant difference in MRY from the 1.93–1.98-mm fraction to the thickest fraction for any milling time for Newbonnet, Millie, and Lemont, except when milling Lemont for 15 sec (Table IV).

MRY decreased as milling time increased, reflecting the increased amount of bran and, possibly, endosperm removed as the milling time increased. Milling rice from 15 to 60 sec produced as much as 3–10.7% difference in MRY within given thickness fractions.

HRY

Figure 3 and Table V show the HRY trend with rough rice kernel thickness for the four milling times. Similar HRY profiles were found for each cultivar, from the thinnest to the thickest fraction for each milling time. Table V indicates significant differences in HRY ($P = 0.05$) among the thickness fractions and milling times using Fisher's method (MSE = 0.944, LSD = 1.57). Initially, for each cultivar, HRY dramatically increased with increasing thickness, reached a maximum, and then started decreasing. There was no significant difference in HRY between the 1.93–1.98 mm and the 1.98–2.03 mm thickness fractions of any milling time for Newbonnet, Millie, or Lemont, except when milling Newbonnet at 45 sec.

In general, increasing milling time decreased HRY for each thickness fraction and for bulk rice. For given thickness fractions, milling rice from 15 to 60 sec resulted in as much as 2.2–7.8% decrease in HRY.

DOM

Table VI shows significant differences in DOM ($P = 0.05$) among the thickness fractions and milling times using Fisher's method (MSE = 23.04, LSD = 7.74). In general, there was no significant difference in DOM from the 1.98–2.03-mm thickness fraction to the thickest fraction at 30-, 45-, or 60-sec milling times. At given thickness fractions, increasing milling time from 15 to 60 sec resulted in increases in DOM values of 40–90%.

Relationships of MRY and HRY with DOM

Tables IV–VI indicate that as milling time was increased, MRY and HRY decreased with a corresponding increase in DOM. Because of the dependence of MRY and HRY on DOM, it was necessary to quantify the relationship between these variables to assess true differences in HRY between the thickness fraction-milling time combinations.

Linear regressions of MRY ($_m$) and HRY ($_h$) against DOM were conducted for each thickness fraction for each cultivar. The linear equations used were:

$$\text{MRY} = a_m + b_m \cdot \text{DOM} \quad (1)$$

$$\text{HRY} = a_h + b_h \cdot \text{DOM} \quad (2)$$

where a and b are regression coefficients. Tables VII and VIII show the coefficients a and b, as well as the coefficients of determination for Equations 1 and 2, respectively. MRY was linearly correlated to DOM for each kernel-thickness fraction and for bulk rice in all three cultivars with R^2 values generally exceeding 90%. Figure 4 indicates that HRY was also linearly correlated to DOM for all kernel-thickness fractions and for bulk rice in

TABLE I
Mass Distributions (%)[a] of Fractionated Rice for Newbonnet, Millie, and Lemont Cultivars

Thickness Fraction (mm)	Newbonnet			Millie			Lemont		
	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3	Case 1	Case 2	Case 3
<1.83	22.9	21.0	...	8.0	5.8	...	5.2	4.5	...
1.93–1.88	5.6	5.7	7.2	2.0	2.1	2.2	1.7	1.7	1.8
1.88–1.93	31.9	32.7	41.4	16.7	17.2	18.2	8.8	8.9	9.3
1.93–1.98	20.4	20.9	26.5	39.1	40.1	42.6	14.2	14.3	14.9
1.98–2.03	18.0	18.4	23.3	27.8	28.5	30.2	50.5	50.8	53.2
>2.03	1.2	1.3	1.6	6.3	6.5	6.9	19.6	19.7	20.7

[a]Case 1: Original mass distribution, including the brown rice in the thinnest thickness fraction. Case 2: Mass distribution, excluding the brown rice in the thinnest thickness fraction. Case 3: Mass distribution if the thinnest thickness fraction were removed.

TABLE II
Average Thickness of Various Rough Rice Kernel Thickness Fractions for Newbonnet, Millie, and Lemont Cultivars[a]

Thickness Fraction (mm)	Average Kernel Thickness, mm		
	Newbonnet	Millie	Lemont
<1.83	1.49	1.56	1.56
1.83–1.88	1.76	1.78	1.76
1.88–1.93	1.81	1.83	1.82
1.93–1.98	1.88	1.89	1.87
1.98–2.03	1.92	1.94	1.93
>2.03	1.98	1.99	1.99
Bulk rice	1.77	1.88	1.91

[a]Each number represents the average thickness of 100 rough rice kernels.

TABLE III
Moisture Contents of Thickness Fractions and Nonfractionated Bulk Rice for Newbonnet, Millie, and Lemont Cultivars[a]

Thickness Fraction (mm)	Moisture Content, % wet basis		
	Newbonnet	Millie	Lemont
<1.83	14.7	15.1	14.1
1.83–1.88	14.4	14.6	14.3
1.88–1.93	14.6	14.6	14.1
1.93–1.98	14.5	13.9	14.1
1.98–2.03	14.5	14.2	14.3
>2.03	15.2	15.0	15.8
Bulk rice	14.4	14.8	15.3

[a]Dried in an oven at 130°C for 24 hr. Each value is the average of two determinations.

Newbonnet. The correlation of HRY to DOM in Millie and Lemont was similar to that in Newbonnet (Table VIII).

DOM Adjustment

Calculation of MRY and HRY at DOM levels normally accepted by the rice industry was necessary to evaluate the potential of milling fractionated rice separately. Tables IX and X show the MRYs and HRYs, respectively, that were estimated using Equations 1 and 2 for three DOM levels that span the normally accepted DOM range used by rice processors. The weighted-average MRY and HRY, based on these DOM-adjusted values, are also given in Tables IX and X, respectively:

$$MRY_{wt\ avg} = \sum_{i=1}^{6} \frac{MRY_i \cdot Wt_{\%\,i}}{100} \quad (3)$$

$$HRY_{wt\ avg} = \sum_{i=1}^{6} \frac{HRY_i \cdot Wt_{\%\,i}}{100} \quad (4)$$

where MRY_i and HRY_i are adjusted to a given DOM level for a thickness fraction (i). $Wt_{\%i}$ represents the mass fraction associated with each thickness fraction. The $Wt_{\%i}$ values are given in Table I (Case 1).

Milling rice separately by thickness fraction dramatically increased MRY and HRY over those values obtained for bulk rice only for the Newbonnet cultivar. Milling Newbonnet separately by thickness fraction increased MRY as much as 3.8% (Table IX), but it only increased MRY for Millie and Lemont cultivars from 0 to 0.4% over that of bulk rice. Newbonnet, which had the smallest average rough rice kernel thickness of the three cultivars, had lower bulk rice MRY than did Millie and Lemont.

Milling Newbonnet separately by thickness fraction increased HRY by at least 3.8%, and it did not increase HRY for Millie and Lemont at a given DOM over that of bulk rice (Table X). The weighted-average HRY of Millie and Lemont was 1.1–1.8% lower than those of the bulk rice. A high mass percentage of

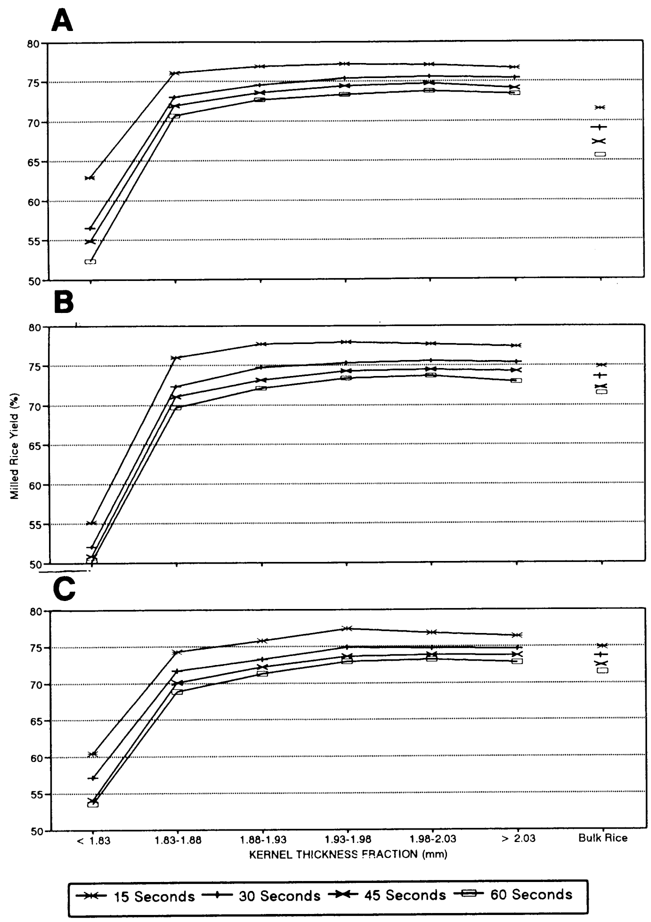

Fig. 2. Milled rice yield determinations from rough rice kernel-thickness fractions and bulk rice at 15, 30, 45, and 60 sec of milling. Each data point represents the average of three milled rice yield determinations. **A**, Newbonnet; **B**, Millie; **C**, Lemont.

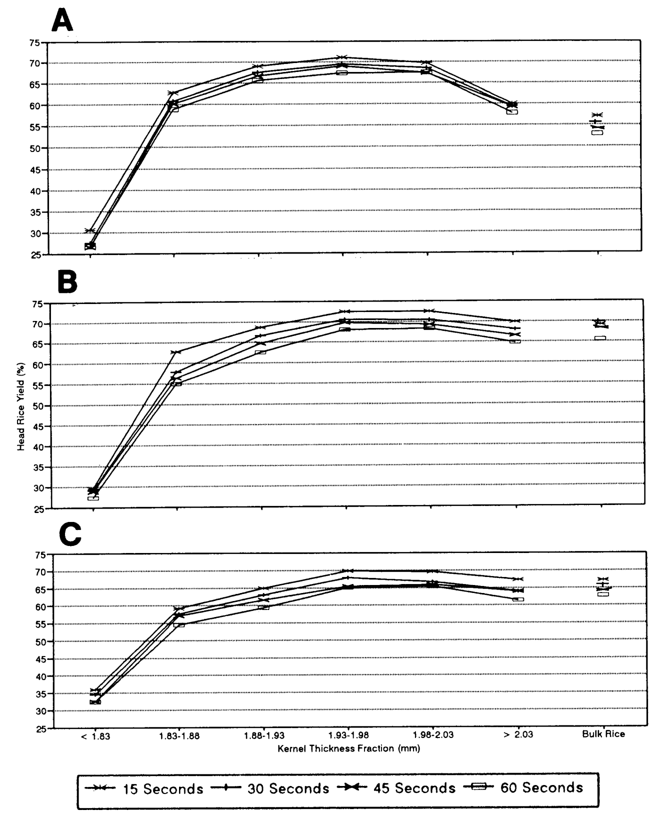

Fig. 3. Head rice yield determinations from rough rice kernel-thickness fractions and bulk rice at 15, 30, 45, and 60 sec of milling. Each data point represents the average of three head rice yield determinations. **A**, Newbonnet; **B**, Millie; **C**, Lemont.

TABLE IV
Milled Rice Yields (%) at Different Milling Times (sec) for Newbonnet, Millie, and Lemont Cultivars[a,b]

Thickness Fraction (mm)	Newbonnet				Millie				Lemont			
	15	30	45	60	15	30	45	60	15	30	45	60
<1.83	63.0 d	56.5 c	54.8 b	52.3 a	55.1 c	52.1 b	50.8 a	50.2 a	60.4 c	57.2 b	54.0 a	53.6 a
1.83–1.88	76.0 q	73.0 jk	71.9 i	70.6 h	76.0 q	72.4 gh	71.1 e	69.7 d	74.3 kl	71.7 f	70.1 e	68.9 d
1.88–1.93	76.9 r	74.5 o	73.6 klm	72.6 j	77.7 r	74.7 lmn	73.2 ij	72.1 fg	75.8 m	73.2 hi	71.3 f	77.4 o
1.93–1.98	77.2 r	75.4 p	74.4 o	73.3 kl	77.9 r	75.3 nop	74.2 kl	73.4 ij	77.4 o	74.9 l	73.6 ij	72.9 gh
1.98–2.03	77.1 r	75.6 pq	74.7 o	73.7 lm	77.7 r	75.6 pq	74.5 lm	73.7 jk	76.8 no	74.8 l	73.9 jk	73.2 hi
>2.03	76.6 qr	75.4 p	74.1 mo	73.4 kl	77.3 r	75.4 opq	74.3 klm	73.0 hi	76.4 mn	74.7 l	73.8 ijk	72.8 gh
Bulk rice	71.5 i	68.8 g	66.9 f	65.6 e	74.9 mno	73.4 ij	72.4 gh	71.5 ef	74.9 l	73.4 hij	72.4 g	71.5 f

[a] Each value represents the average of three determinations.
[b] Values within a variety followed by the same letter are not significantly different at $P = 0.05$, using Fisher's method (LSD = 0.62).

the thinnest thickness fraction for Newbonnet resulted in lower bulk rice HRY than those of Millie and Lemont, which had lower mass percentages of the thinnest thickness fraction.

One possible way to improve overall HRY is to remove the thinnest kernels and use this mass fraction for other purposes. The advantage would be that the thinnest kernels could be used for some specialty products, because the thinner kernels in a lot contain a higher protein and vitamin content than does the bulk rice (Matthews et al 1981b). Table X shows the weighted-average HRY computed without the thinnest thickness fraction for the three cultivars. The weighted-average HRYs were computed using Equation 4, with the mass distributions of Table I (Case 3) in which the original mass distributions were adjusted to remove the thinnest thickness fraction. When the thinnest thickness fractions were not included in Equation 4, the weighted-average HRY was greater than that of the bulk rice samples for all cultivars. The ranges of difference in HRY between the weighted-average HRY when the thinnest fraction was not included and that of the bulk rice were 12.3–12.6% (Newbonnet), 1.7–1.8% (Millie), and 0.2–0.5% (Lemont), as shown in Table X.

TABLE V
Head Rice Yields (%) at Different Milling Times (sec) for Newbonnet, Millie, and Lemont Cultivars[a,b]

Thickness Fraction (mm)	Newbonnet				Millie				Lemont			
	15	30	45	60	15	30	45	60	15	30	45	60
<1.83	30.6 b	27.5 a	26.5 a	26.8 a	29.6 b	29.1 b	28.8 ab	27.4 a	36.0 b	34.5 b	32.4 a	32.4 b
1.83–1.88	62.9 i	60.8 h	60.1 gh	58.9 fg	62.9 e	58.0 d	56.5 cd	55.1 c	59.2 ef	57.7 de	57.1 d	54.4 c
1.88–1.93	69.0 mn	67.7 jk	66.7 jk	65.6 j	68.7 ijk	66.6 gh	64.7 f	62.6 e	64.9 jk	63.1 ghi	61.6 g	59.3 f
1.93–1.98	71.1 o	69.6 no	69.1 mno	67.4 kl	72.5 m	70.5 l	69.7 kl	68.0 hij	69.8 o	67.9 n	65.4 jkl	65.1 jk
1.98–2.03	69.8 no	68.5 lmn	67.3 kl	67.5 klm	72.5 m	70.4 l	69.2 jkl	68.3 ijk	69.6 o	66.7 lmn	65.9 klm	65.5 jkl
>2.03	60.0 gh	59.5 gh	59.3 fgh	57.8 ef	69.8 kl	68.0 hij	66.5 gh	64.9 f	67.3 mn	64.0 hij	64.0 hij	61.6 g
Bulk rice	57.2 e	55.4 d	53.9 cd	52.9 c	69.1 jkl	69.7 kl	67.2 hi	65.5 fg	67.2 mn	65.9 klm	64.6 ijk	62.8 gh

[a] Each value represents the average of three determinations.
[b] Values within a variety followed by the same letter are not significantly different at $P = 0.05$, using Fisher's method (LSD = 1.57).

TABLE VI
Degree of Milling (DOM) Values, as Measured by a Satake Milling Meter, at Different Milling Times (sec) for Newbonnet, Millie, and Lemont Cultivars[a,b]

Thickness Fraction (mm)	Newbonnet				Millie				Lemont			
	15	30	45	60	15	30	45	60	15	30	45	60
<1.83	73 de	109 pq	115 q	124 r	0 a	82 ij	89 jklm	95 mno	41 a	94 ij	109 l	108 kl
1.83–1.88	54 a	77 ef	87 ghi	96 klm	0 a	63 def	74 gh	86 ijk	51 bc	80 fg	86 gh	95 ij
1.88–1.93	57 ab	84 fgh	92 ijkl	102 mop	38 b	67 efg	81 hi	92 klmn	51 bc	77 f	91 hi	101 jk
1.93–1.98	63 bc	88 ghij	98 lmo	105 op	48 c	81 hi	94 lmn	102 opq	45 ab	76 f	93 hij	104 kl
1.98–2.03	69 cd	90 hijk	99 lmo	108 pq	56 d	87 ijkl	98 nop	103 pq	57 cd	86 gh	103 kl	103 kl
>2.03	59 ab	81 fg	95 jklm	102 mop	60 de	87 ijkl	97 nop	107 q	68 e	92 hi	103 kl	105 kl
Bulk rice	53 a	78 ef	92 ijkl	102 mop	43 bc	70 f	83 ij	95 mno	59 d	88 hi	101 jk	107 kl

[a] Each value represents the average of three DOM measurements of a single sample.
[b] Values within a variety followed by the same letter are not significantly different at $P = 0.05$, using Fisher's method (LSD = 7.74).

TABLE VII
Coefficients of Linear Regression of Equation 1 for Relating Milled Rice Yields to Degree of Milling for Newbonnet, Millie, and Lemont Cultivars

Thickness Fraction (mm)	Newbonnet			Millie			Lemont		
	Coefficients			Coefficients			Coefficients		
	a_m	b_m	R^2	a_m	b_m	R^2	a_m	b_m	R^2
<1.83	77.861	−0.2004	0.964	55.203	−0.0470	0.731	69.158	−0.1400	0.864
1.83–1.88	82.776	−0.1249	0.988	76.150	−0.0693	0.961	79.952	−0.1113	0.871
1.88–1.93	82.389	−0.0952	0.988	81.587	−0.1028	0.980	80.178	−0.0876	0.987
1.93–1.98	82.855	−0.0873	0.952	81.943	−0.0825	0.996	80.792	−0.0758	0.979
1.98–2.03	82.897	−0.0829	0.971	82.306	−0.0805	0.969	80.784	−0.0700	0.944
>2.03	81.190	−0.0743	0.976	82.849	−0.0893	0.970	82.399	−0.0865	0.922
Bulk rice	77.880	−0.1184	0.940	77.790	−0.0651	0.951	78.994	−0.0668	0.913

TABLE VIII
Coefficients of Linear Regression of Equation 2 for Relating Head Rice Yields to Degree of Milling for Newbonnet, Millie, and Lemont Cultivars

Thickness Fraction (mm)	Newbonnet			Millie			Lemont		
	Coefficients			Coefficients			Coefficients		
	a_h	b_h	R^2	a_h	b_h	R^2	a_h	b_h	R^2
<1.83	37.749	−0.0966	0.887	...	...	...	46.675	−0.1301	0.870
1.83–1.88	67.993	−0.0924	0.843	62.952	−0.0871	0.740	64.449	−0.0968	0.799
1.88–1.93	73.348	−0.0726	0.813	73.149	−0.1077	0.874	70.489	−0.1026	0.826
1.93–1.98	76.206	−0.0779	0.785	76.381	−0.0756	0.914	73.797	−0.0838	0.810
1.98–2.03	74.047	−0.0627	0.826	77.306	−0.0835	0.859	74.075	−0.0819	0.923
>2.03	64.015	−0.0552	0.693	75.954	−0.0986	0.784	77.654	−0.1499	0.817
Bulk rice	61.969	−0.0870	0.948	73.976	−0.0842	0.851	72.384	−0.0815	0.820

Although the weighted-average HRY increases when excluding the thinnest thickness fraction, the total amount of head rice recovered from the thicker fractions would be the same, because the weighted-average HRY percentage would be applied to a rough rice amount that excluded the mass of the thinnest thickness fraction. However, milling rice without the thinnest thickness fraction may offer savings through increased efficiency of milling and separating equipment, as well as improving the size uniformity of milled rice.

CONCLUSIONS

Rough rice kernel thickness and milling time had a significant influence on HRY and DOM. HRY produced by milling various rough rice thickness fractions for various times were linearly, inversely correlated to DOM. This correlation was used to compare HRY from milling various thickness fractions for various durations on an equitable DOM basis.

Compared to the HRY of nonfractionated, bulk rice, the

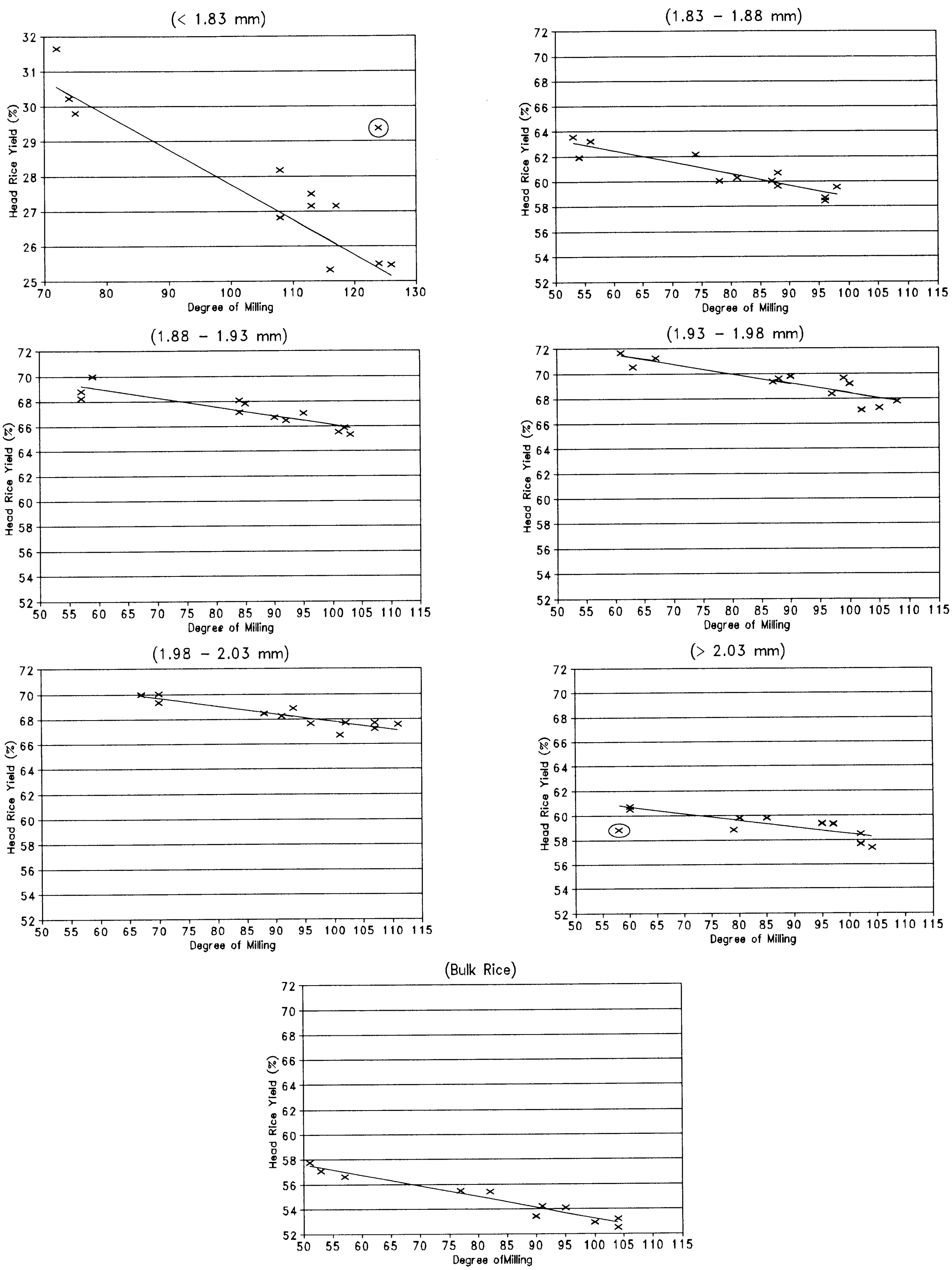

Fig. 4. Relationships of head rice yield to degree of milling for the cultivar Newbonnet in six kernel-thickness fractions and in bulk rice. Each data point represents the average of three milled rice yield determinations. Circled data points considered outliers.

TABLE IX
Milled Rice Yields (MRYs, %) of Fractionated Rice and Bulk Rice Adjusted to the Indicated Degrees of Milling (DOM) by Equation 1 for Newbonnet, Millie, and Lemont Cultivars

Thickness Fraction (mm)	Newbonnet DOM			Millie DOM			Lemont DOM		
	80	90	100	80	90	100	80	90	100
<1.83	62	60	58	51	51	51	58	57	55
1.83–1.88	73	71	70	71	70	69	71	70	69
1.88–1.93	75	74	73	73	72	71	73	72	71
1.93–1.98	76	75	74	75	74	73	75	74	73
1.98–2.03	76	75	75	76	75	74	75	75	74
>2.03	75	75	74	76	75	74	76	75	74
WT_{avg} MRY, %[a]	72.2	71.0	69.8	73.0	72.2	71.3	74.0	73.2	72.4
Bulk rice MRY, %	68.4	67.2	66.0	72.6	71.9	71.3	73.7	73.0	72.3

[a]Weighted average MRY computed using the MRYs of all thickness fractions.

TABLE X
Head Rice Yields (HRYs, %) of Fractionated Rice and Bulk Rice Adjusted to the Indicated Degrees of Milling (DOM) by Equation 2 for Newbonnet, Millie, and Lemont Cultivars

Thickness Fraction (mm)	Newbonnet DOM			Millie DOM			Lemont DOM		
	80	90	100	80	90	100	80	90	100
<1.83	30	29	28	26	26	26	36	35	34
1.83–1.88	61	60	59	56	55	54	57	56	55
1.88–1.93	68	67	66	65	64	62	62	61	60
1.93–1.98	68	67	66	70	70	69	67	66	65
1.98–2.03	69	68	68	71	70	69	68	67	66
>2.03	60	59	59	68	67	66	66	64	63
WT_{avg} HRY, %[a]	58.8	58.0	57.2	65.4	64.7	63.9	64.8	63.8	62.8
WT_{avg} HRY, %[b]	67.3	66.6	65.9	69.0	68.1	67.3	66.4	65.4	64.4
Bulk rice HRY, %	55.0	54.1	53.3	67.3	66.4	65.6	65.9	65.0	64.2

[a]Weighted average HRY computed using the HRYs of all thickness fractions.
[b]Weighted average HRY computed using the HRYs of all but the thinnest thickness fraction.

weighted-average HRY, obtained by separating rough rice into thickness fractions and then milling each size fraction separately, was increased only for the Newbonnet cultivar, but it was increased by as much as 3.8% in this cultivar. We speculate that Newbonnet had a dramatically larger percentage of thin kernels than did Millie or Lemont cultivars. The weighted-average HRY was increased for all three cultivars when the rice in the thinnest thickness fraction was not included in the weighted-average calculation. This largely increased the HRY of Newbonnet, but the HRY of Millie and Lemont were increased only slightly in comparison to the bulk rice control.

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