Effect of Rice Kernel Thickness on Degree of Milling and Associated Optical Measurements

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ABSTRACT

Three cultivars of long-grain rice were milled to three degree of milling (DOM) levels. Inverse linear relationships were established between surface fat concentration (SFC) and Satake milling meter (MM1B) optical DOM measurement values, including whiteness, transparency, and DOM, for the unfractionated head rice within each cultivar. Milled bulk rice for each cultivar was subsequently separated into thickness fractions. Effects of milled rice kernel thickness on SFC and optical DOM measurements were investigated. For a given DOM level, SFC decreased with increasing milled rice kernel thickness up to a thickness of 1.67 mm, after which it remained constant. As the overall DOM level increased, the difference in DOM between thin kernels and thick kernels lessened, implying that thin kernels were milled at a greater bran removal rate than thick kernels. Milled rice kernel thickness significantly (at the 0.05 significance level) affected MM1B whiteness and MM1B transparency in two of the cultivars because of the predominant effects of the thinner kernel fractions. Within each cultivar, MM1B DOM was not significantly influenced by milled rice kernel thickness.

Milling is a mechanical procedure during which brown rice is subjected to abrasive or friction pressure to remove bran layers from the endosperm to yield white rice. Degree of milling (DOM) is a term used to describe the extent to which kernel bran has been removed. Higher DOM levels are generally related to less retention of kernel bran, which is accompanied by a whiter appearance. DOM is important in determining the grade of milled rice as it may affect head rice yield levels (Sun and Siebenmorgen 1993), insect infestation (McGaughey 1970), starch gelatinization (Champagne et al 1990, Marshall 1992), and sensory quality (Piggott et al 1991).

Methods including visual examination, chemical composition analysis, and optical measurements have been developed to indicate the DOM of milled rice. Additionally, the weight percentage of bran removed from brown rice is a technique to express DOM (Wadsworth et al 1991). The USDA Federal Grain Inspection Service (FGIS) standards (USDA 1979) specify that DOM be classified into one of four grades (well-milled, reasonably well-milled, lightly milled, and undermilled) by visual comparison to line samples. Chemical composition analysis typically consists of a measure of surface fat (Hogan and Deobald 1961, Siebenmorgen and Sun 1994), although total fat (Wadsworth et al 1991) or thiamin and phosphorus content (Desikachar 1955) of the milled rice has been used. Optical measurements determine the intensity of the visible or near-infrared light reflected from or transmitted through milled rice (Stermer 1968, Wadsworth et al 1991, Fant et al 1994, Delwiche et al 1996). With an increasing demand for fast, reliable DOM measurements, optical methods have attracted increasing interest. At present, optical DOM measurement systems are commercially available, such as the Satake milling meter (model MM1B), which uses the amounts of reflected and permeated light to calculate DOM. Satake DOM meter readings were found to be strongly correlated to surface fat concentration (SFC) within given cultivars (Siebenmorgen and Sun 1994).

Bulk rice, whether rough, brown, or white, contains kernels of various sizes. The effect of rough rice kernel size on milling quality has been investigated (Matthews and Spadaro 1976, Wadsworth et al 1982, Sun and Siebenmorgen 1993). In this earlier research, bulk rough rice was first separated into several thickness fractions, and each individual kernel fraction was then milled under controlled conditions. Matthews and Spadaro (1976) reported that breakage of milled rice was generally greater for thinner fractions, and the amount of bran (weight of bran per unit brown rice weight) removed in milling increased with decreases in rough rice kernel thickness. Wadsworth et al (1982) found that the amount of removed bran was about the same across the thicker fractions, while for thinner fractions the amount of removed bran increased with decreasing thickness fractions. Sun and Siebenmorgen (1993) showed that head rice yield increased with increasing thickness, reached a maximum, and then decreased. In the rice industry, rice is currently processed and milled as an unfractionated bulk. No research was found quantifying the DOM of milled rice kernels with varying thicknesses milled as an unfractionated bulk.

Limited research has been conducted elucidating the effect of kernel size on optical DOM measurements. For various rough rice thickness fractions, Siebenmorgen and Sun (1994) established linear, inverse relationships between SFC and DOM measured with a Satake MM1B milling meter and found that the relationships differed across cultivars. These varietal differences were speculated to be ultimately due to rough rice kernel size.

The objectives of this research were: 1) to establish general relationships between SFC and optical DOM values, 2) to investigate the effect of milled rice kernel thickness on DOM during unfractionated milling, and 3) to determine the extent that optical DOM measurements are affected by milled rice kernel thickness.

MATERIALS AND METHODS

Sample Preparations

For these experiments, three long-grain rice cultivars, Alan, Newbonnet, and Katy, were procured from farm bins where they had been dried to approximately 11, 12, and 13% moisture content (MC) (expressed on a wet basis), respectively. Each cultivar was first hulled using a commercial-scale Satake husker/paddy separator (model APS-30CX), and then milled in a single pass using a commercial-scale Satake friction mill (model BA-7). Samples were milled to low, medium, and high DOM levels. Head rice was separated from brokens using a Satake test rice grader with a ∅5.2 mm long-grain screen. Using a Carter-Day precision sizer, the head rice samples were separated into five thickness fractions for Alan and Newbonnet and four thickness fractions for Katy. Two

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subsamples of each thickness fraction, as well as the unfractionated head rice samples, were measured for optical DOM values, SFC, and MC as described below.

Optical DOM Measurements

Optical DOM measurements were made using a Satake milling meter (model MM1B). Prior to measurement, the meter was calibrated using white and brown color plates provided with the meter. A MM1B DOM of 0 corresponded to the brown plate and 199 to the white plate. MM1B measurements of whiteness, transparency, and DOM were recorded as the average of three readings from two subsamples of each thickness fraction and the unfractionated bulk. MM1B whiteness was the percentage of light reflected from the sample (instrument range between 15 and 60%), whereas MM1B transparency was the percentage of light permeating the sample (instrument range between 0.00 and 9.99%). The MM1B DOM was calculated using both the MM1B whiteness and the MM1B transparency by a factory-installed algorithm in the microcomputer of the meter.

Surface Fat Concentration Measurements

Surface fat from each sample was extracted using a Soxtec System HT, which consisted of an extraction unit (model 1043) and a service unit (model 1044) (Hogan and Deobald 1961, Siebenmorgen and Sun 1994). A 5-g head rice sample was weighed into a cellulose extraction thimble (∅26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 hr. The thimble with the dried sample was then attached to magnets at the bottom of the condenser of the extraction unit. For surface extraction, the thimble was lowered to immerse the sample in 50 ml of petroleum ether (boiling point 35–60°C) in an extraction cup. The solvent was evaporated by circulating around the extraction cup a hot solution (mixture of 50 mL of mineral oil with 1 L of distilled water) supplied by the service unit. The vapor was condensed into the thimble to extract most of the surface fat from the head rice. This procedure was continued for 30 min. The thimble was then raised above the solvent surface and rinsed for another 30 min by the condensed solvent from the condenser to extract the remaining fat on the surfaces of the kernels. After rinsing, the fluid flow through the condenser was discontinued and the solvent from the thimble was collected for 15 min. The extraction cup was dried at 100°C for 30 min to measure dry matter, which represented the surface fat extracted. The SFC was the mass of the dry matter expressed as a percentage of the original head rice mass (5 g).

Moisture Content Measurements

Two subsamples of 15 g from each milled head rice thickness fraction, as well as each unfractionated sample, were dried in a convection oven at 130°C for 24 hr to determine MC. MC of each subsample was calculated as the percentage mass loss of the original mass (15 g).

RESULTS AND DISCUSSION

Relationships Between SFC and Optical Measurement Values for Unfractionated Samples

Figures 1–3 show the relationships of MM1B whiteness, MM1B transparency, and MM1B DOM versus SFC of the unfractionated samples of Alan, Newbonnet, and Katy cultivars. In each curve, the data point at the highest SFC represented the unfractionated head rice at the lowest DOM level, and vice versa. Inverse relationships existed between SFC and the optical measurement values. These relationships can be described by the following equation: optical measurement values = $A - B \cdot \text{SFC}$ (Eq. 1) where SFC is expressed as a percentage. The coefficients A and B are listed with the associated correlation coefficients (R^2) in Table I.

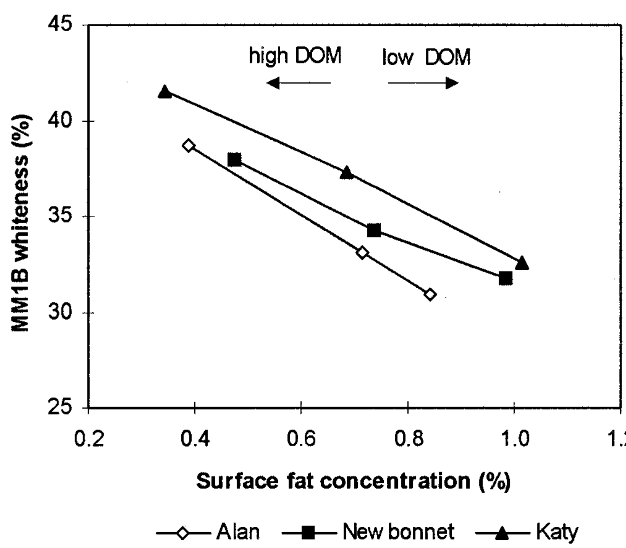

Fig. 1. Whiteness as measured by a Satake MM1B milling meter vs. surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars. Each point represents an average of duplicate measurements.

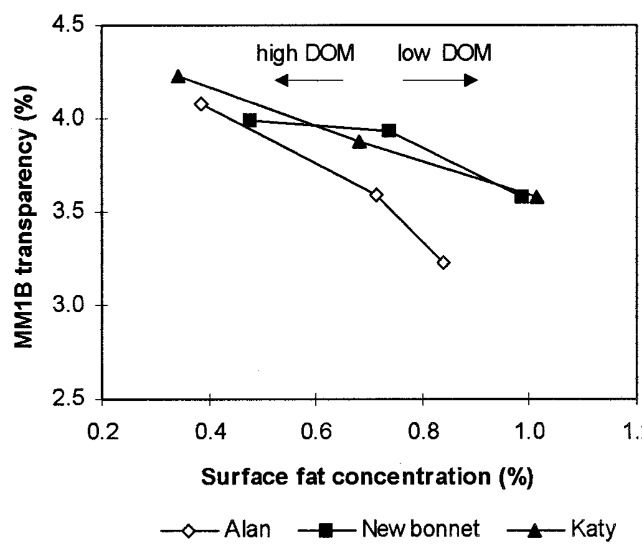

Fig. 2. Transparency as measured by a Satake MM1B milling meter vs. surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars. Each point represents an average of duplicate measurements.

TABLE I
Coefficients of the Linear Regression Models (Eq.1)

	MM1B Whiteness			MM1B Transparency			MM1B DOM		
Cultivar	A	B	R^2	A	B	R^2	A	B	R^2
Alan	45.4	17.2	1.00	4.8	1.6	0.84	132	89.1	1.00
Newbonnet	43.6	12.2	1.00	4.4	0.8	0.83	124	60.9	1.00
Katy	46.1	13.2	1.00	4.6	1.0	1.00	136	66.0	1.00

There was good linearity in all cases except for the MM1B transparency of Newbonnet and Alan. Siebenmorgen and Sun (1994) reported inverse linear relationships only between SFC and MM1B DOM. The results here revealed similar trends relating MM1B whiteness and MM1B transparency to SFC.

To determine whether there were differences in the above relationships, linear regression analysis (Neter and Wasserman 1974) was conducted; Table II shows calculated *F* values. The critical *F* value at the 0.05 significance level was 19. If a calculated *F* value was larger than the critical value, the two lines under comparison were significantly different in either the slope (*B*), the intercept (*A*), or both. Table II indicates that across the three cultivars, the regression lines for MM1B whiteness (Fig. 1) and MM1B DOM (Fig. 3) were significantly different, while there were no statistical differences in the regression lines for MM1B transparency (Fig. 2). This indicates that a given value of MM1B whiteness or MM1B DOM did not represent a fixed SFC across cultivars. This finding concurs with that of Siebenmorgen and Sun (1994), who found that relationships between MM1B DOM and SFC were different across the three long-grain cultivars that they tested.

Figures 1 and 3 indicate that Katy had the highest MM1B whiteness and MM1B DOM and Alan had the lowest values. Taking a SFC of 0.6% as an example, the corresponding MM1B whiteness was 35.1, 36.3, and 38.2% for Alan, Newbonnet, and Katy, respectively, while the corresponding MM1B DOM was 78.5, 87.1, and 96.0.

For MM1B whiteness and MM1B DOM, Alan had the largest slope (*B* value in Table I), whereas Newbonnet had the smallest slope. Thus, Alan changed more in MM1B whiteness and MM1B DOM with SFC than did Newbonnet. Taking a 0.1 percentage point (pp) reduction in SFC as an example, the corresponding increase of MM1B whiteness was 1.7 and 1.2 pp, respectively, for Alan and Newbonnet, while the corresponding MM1B DOM changes were 8.9 and 6.1. Due to the different slopes, differences in MM1B whiteness and MM1B DOM across cultivars diminished at lower SFCs (higher DOMs). At a SFC of 0.8%, the range across the three cultivars was 4.0 pp for MM1B whiteness and 22.1 pp for MM1B DOM, whereas at a SFC of 0.4%, the range was reduced to 2.4 and 12.9 pp, respectively. Thus, with a decrease of SFC or an increase of DOM level, the influence of cultivar on MM1B whiteness and MM1B DOM was reduced.

Effect of Milled Rice Kernel Thickness Fractions on Surface Fat Concentration

Figure 4 illustrates the mass and MC distributions of the head rice for the three cultivars averaged across the three DOM levels, where milled rice kernel thickness values represent the mean value of each milled rice kernel thickness fraction range. Alan and Newbonnet had similar milled rice kernel thickness distribution ranges (1.52–1.77 mm), with the major mass fraction being 1.67 mm (34.6% total mass) and 1.59 mm (48.4%), respectively. The milled rice kernel thickness distribution range for Katy (1.52–1.72 mm) showed the major mass fraction to be 1.59 mm (30.8%). To determine whether MC was related to milled rice kernel thickness, a linear model *t*-test (Neter and Wasserman 1974) was applied to the MC data of Fig. 4. The variation of MC among milled rice kernel thickness fractions was significant at the 0.05 significance level for all three cultivars, with thicker kernels having slightly higher MC.

Figure 5A–C shows the change in SFC across milled rice kernel thickness fractions for each of the three DOM levels for each cultivar. An analysis of variance was conducted, in which milled rice kernel thickness and DOM level were considered as two factors affecting SFC. Statistical *F* values related to milled rice kernel thickness, DOM level, and their interaction, as well as critical *F* values at the 0.05 significance level, are given in Table III. As indicated in Table III, milled rice kernel thickness, DOM level, and the interaction of these variables all had significant effects on SFC.

SFC was inversely and nonlinearly related to milled rice kernel thickness. In general, but much more pronounced at low DOM levels, thinner kernels had higher SFC than thicker kernels. For Alan, the weighted average SFCs at the low and medium DOM levels were 0.89 and 0.74%, respectively, while the SFCs for the thinnest kernels (1.52 mm) at the corresponding DOM levels were 1.11 and 0.94%. The over-retained surface bran on the thinnest kernels may cause this fraction to behave differently in storage and/or subsequent processing operations compared to the predominant thicker kernel fractions.

SFC was also significantly influenced by the interaction between milled rice kernel thickness and DOM level (Table III). The change in SFC with milled rice kernel thickness was greatest at low DOM levels and least at high DOM levels (Fig. 5). For thicker kernels (>1.67 mm), SFC did not change with thickness at a given DOM

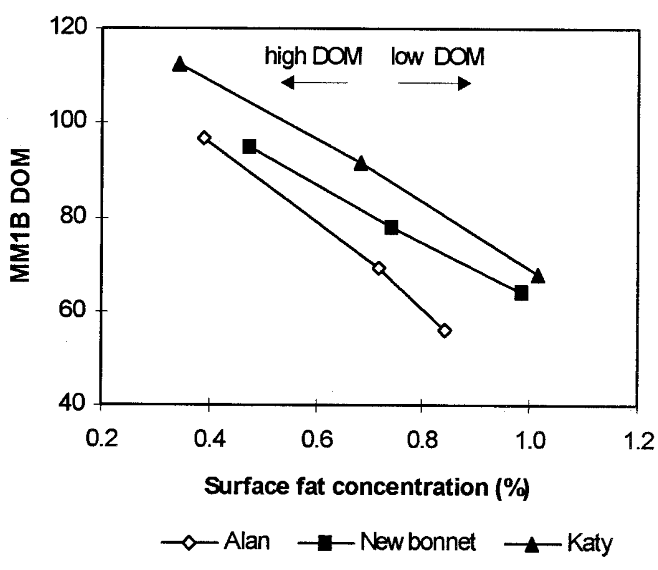

Fig. 3. Degree of milling (DOM) as measured by a Satake MM1B milling meter vs. surface fat concentration of unfractionated head rice for each of the indicated long-grain cultivars. Each point represents an average of duplicate measurements.

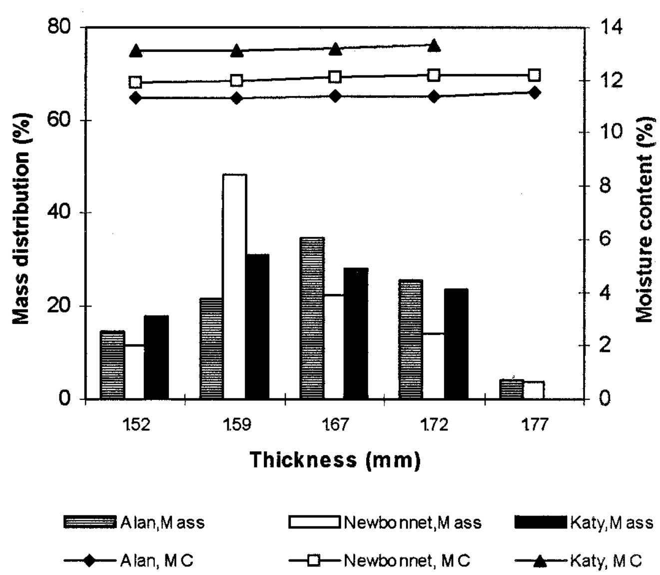

Fig. 4. Distribution of mass and moisture content among milled rice kernel thickness fractions averaged across three degree of milling levels for the indicated cultivars. Each moisture content is the average of six determinations.

level. For thinner kernels (<1.67 mm), SFC increased considerably with decreasing kernel thickness at low DOM levels. This increase diminished with increasing DOM level. It was apparent that, as the milling process progressed, thinner kernels were milled at a greater bran removal rate than thicker kernels, i.e., thinner kernels had a higher percentage of their original bran removed per unit of milling duration than the thicker kernels. By fractionating bulk rough rice into several size fractions, and milling each fraction separately for a given time period, Matthews and Spadaro (1976) and Wadsworth et al (1982) found that thicker rough rice kernels had less bran removed from the kernel surface than thinner rough rice kernels. This agreed with our findings, which were obtained by milling bulk, non-fractionated samples and then thickness fractioning the milled rice.

Effect of Milled Rice Kernel Thickness Fractions on Optical DOM Measurements

Figure 6A–C shows the change in MM1B whiteness, MM1B transparency, and MM1B DOM with SFC across milled rice kernel thickness fractions of Alan. The corresponding relationships for the unfractionated Alan head rice from Fig. 1–3 are also shown in Fig. 6 for comparison. The linear relationships between optical readings and SFC as observed with the unfractionated samples (Figs. 1–3) remained valid for each milled rice kernel thickness fraction. Similar linear relationships were also found to exist for Newbonnet and Katy. For Alan, the 1.52-mm fraction had higher MM1B whiteness, compared to the unfractionated rice; the other four fractions had similar MM1B whiteness (Fig. 6A). All fractions had lower MM1B transparency than the unfractionated head rice (Fig. 6B). There was no difference between the DOM of the unfractionated rice and that of the various milled rice kernel thickness fractions (Fig. 6C).

TABLE II
F Values[a] Calculated from Regression Analysis for Testing the Difference in the Regression Models

Cultivar	MM1B Whiteness	MM1B Transparency	MM1B DOM
Alan vs. Newbonnet	34	3.8	64
Alan vs. Katy	181	2.5	120
Newbonnet vs. Katy	36	0.2	116

[a] Critical F value at the 0.05 significance level is 19.

TABLE III
Calculated F Values (F) and Critical F Values at the 0.05 Significance Level ($F_{0.05}$) Resulting from the Analysis of Variance of Surface Fat Concentration as Affected by Milled Rice Kernel Thickness and DOM Level

Source of Variance	Alan		Newbonnet		Katy	
	F	$F_{0.05}$	F	$F_{0.05}$	F	$F_{0.05}$
Thickness	55[a]	3.1	372[a]	3.1	62[a]	3.5
DOM level	690[a]	3.7	4319[a]	3.7	6487[a]	3.9
Interaction	8.7[a]	2.6	11[a]	2.6	26[a]	3.0

[a] Significant at the 0.05 level.

TABLE IV
Calculated F Values (F) and Critical F Values at the 0.05 Significance Level ($F_{0.05}$) Resulting from the Analysis of Variance of Optical Measurements as Affected by Milled Rice Kernel Thickness

Optical Parameters	Alan		Newbonnet		Katy	
	F	$F_{0.05}$	F	$F_{0.05}$	F	$F_{0.05}$
MM1B whiteness	3.8[a]	3.6	7.4[a]	3.6	0.8	4.4
MM1B transparency	59[a]	3.6	24[a]	3.6	1.4	4.4
MM1B DOM	0.8	3.6	1.4	3.6	0.8	4.4

[a] Significant at the 0.05 level.

To investigate the effect of milled rice kernel thickness on optical DOM measurements, the general linear models procedure of SAS (1987) was used. Table IV shows the calculated F values. Milled rice kernel thickness had significant effects on MM1B whiteness and MM1B transparency for Alan and Newbonnet but not for Katy. Compared to MM1B whiteness, MM1B transparency was much more sensitive to milled rice kernel thickness as illustrated in Fig. 6A and B for Alan. MM1B DOM, being calculated from MM1B whiteness and MM1B transparency, was not significantly affected by milled rice kernel thickness for any of the three cultivars. In Fig. 6A, the thinnest kernel fraction (1.52 mm) of Alan had higher MM1B whiteness than the other four fractions. Linear regression analysis revealed that there was a significant

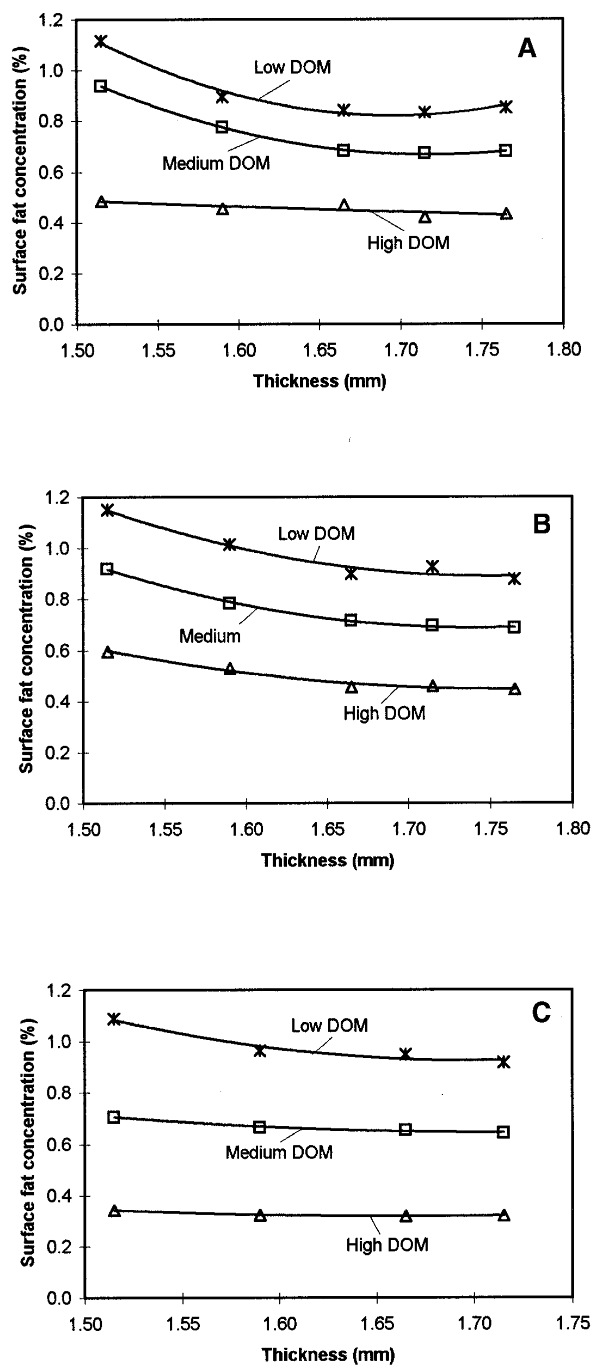

Fig. 5. Surface fat concentration (SFC) of milled rice kernel thickness fractions at three degree of milling (DOM) levels for cultivars Alan (**A**), Newbonnet (**B**), and Katy (**C**) milled as an unfractionated bulk. Each point is an average of two SFC determinations.

difference between the 1.52-mm fraction and the other four fractions, but there were no differences among the other four fractions. In Fig. 6B, for thinner kernels (1.52–1.67 mm), MM1B transparency increased with increasing milled rice kernel thickness, while for thicker kernels (1.67–1.77 mm), MM1B transparency was not significantly affected by milled rice kernel thickness. It was apparent that the statistical significance of milled rice kernel thickness affecting MM1B whiteness and MM1B transparency (Table IV) was primarily due to the thinner kernel fractions.

CONCLUSIONS

Satake optical measurement values, including MM1B whiteness, MM1B transparency, and MM1B DOM in both unfractionated samples and thickness fractionated samples, were linearly and inversely related to SFC. For rice milled as an unfractionated bulk, milled rice kernel thickness did not influence SFC of thicker kernels (>1.67 mm). However, for thinner kernels (<1.67 mm), as milled rice kernel thickness decreased, SFC increased. The amount of SFC change across thickness fractions lessened with increasing DOM levels. As the milling process progressed, thinner kernels were milled at a greater bran removal rate than thicker kernels.

The effect of milled rice kernel thickness on MM1B whiteness and MM1B transparency was significant for Alan and Newbonnet, primarily due to the influence of the thinnest thickness fraction (1.52 mm). At given SFC levels, the thinnest kernel fraction had higher MM1B whiteness than the other four milled rice kernel thickness fractions. Decreasing milled rice kernel thickness caused MM1B transparency to decrease in the thinner kernel fractions (<1.67 mm).

Within each cultivar, MM1B DOM was not influenced by milled rice kernel thickness. However, across the three cultivars, MM1B DOM was significantly different. Apparently there are factors, other than milled rice kernel thickness, that are specific to each cultivar that cause this difference. Because particle size is known to affect optical measurements, other geometric parameters such as kernel length, width, or length to width ratio may explain MM1B DOM differences across cultivars at given SFC levels. Further investigation is required to elucidate these factors.

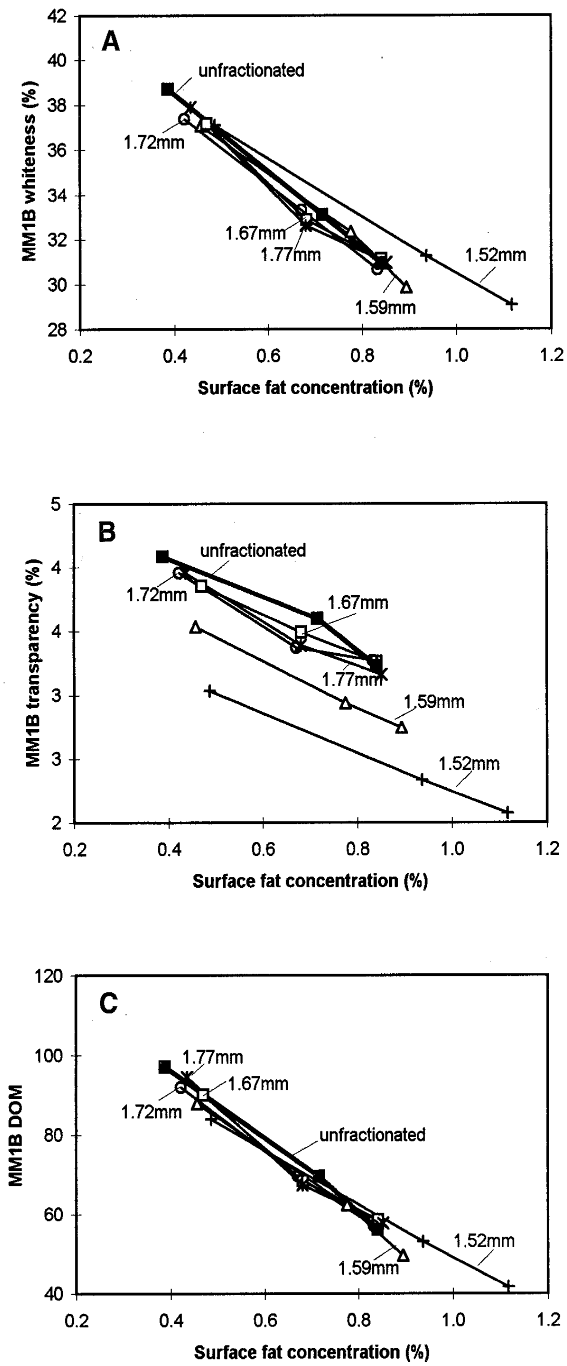

Fig. 6. Whiteness (**A**), transparency (**B**), and degree of milling (DOM) (**C**) as measured by a Satake MM1B milling meter vs. surface fat concentration for unfractionated head rice and various milled rice kernel thickness fractions of Alan.

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