Quality Characteristics of Long-Grain Rice Milled in Two Commercial Systems

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ABSTRACT

Long-grain rice variety Kaybonnet was milled to three degree of milling (DOM) levels in two commercial milling systems (a single-break, friction milling system and a multibreak, abrasion and friction milling system) and separated into five thickness fractions. For both milling systems, the surface lipid content (SLC) and protein content of the milled rice varied significantly across kernel thickness fractions. SLC was influenced by DOM level more than by thickness, while the protein content was influenced by thickness more than by DOM level. Particularly at the low DOM levels, the thinnest kernel fraction (<1.49 mm) had higher SLC than the other kernel fractions. Protein content decreased with increasing kernel thickness to 1.69 mm, after which it remained constant. In both milling systems, thinner kernels were milled at a greater bran removal rate as indicated by SLC differences between the low and high DOM levels. For rice milled to a given DOM level, the multibreak system produced fewer brokens than did the single-break system.

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Brown rice (or hulled rice) is composed of surface bran (6–7% by weight), endosperm (≈90%) and embryo (2–3%) (Lu and Luh, 1991). Of these components, the surface bran is richest in non-starch constituents such as lipids (15.0–19.7%) and protein (11.3–14.9%), whereas the endosperm is richest in starch. Rice milling is a mechanical procedure (abrasion or friction action) to remove surface bran to produce white milled rice. Through the milling operation, lipid and protein contents in brown rice (1.6–2.8% and 7.8–8.3%, respectively) are generally reduced to 0.3–0.5% and 6.3–7.1% in milled rice (Lu and Luh 1991). Despite the high nutritional value of surface bran, most rice consumers prefer well-milled rice for the sake of enhanced conventional quality and flavor. Some studies have indicated that milled rice is significantly different from brown rice not only in cooking quality (Hogan 1969, Bajaj and Sidhu 1989), gelatinization behavior (Marshall 1992), and palatability (Hogan 1969), but also in stability during storage (McGaughey 1970, Wadsworth 1991).

The function of the milling operation is to produce well-milled rice that is essentially free of bran and contains a minimum amount of broken kernels. However, more thorough milling is usually accompanied by increased weight loss (a range of 4–14% of the weight of brown rice) (Wadsworth 1991) and associated head rice yield reduction (Sun and Siebenmorgen 1993). Thus, the performance of commercial systems in terms of milling quality and product uniformity is of great economic importance to the rice industry.

Rough rice comprises kernels of various sizes. Thinner kernels usually contain higher protein, lipids, vitamins, and lower starch contents than thicker kernels (Matthews et al 1981). Several studies (Matthews and Spadaro 1976, Wadsworth et al 1982, Sun and Siebenmorgen 1993) have addressed the effects of kernel size variation on milling performance. In these studies, rough rice was first separated into thickness fractions, and each individual kernel fraction was milled in single-break laboratory mills. Matthews and Spadaro (1976) found that breakage of milled rice was generally greater for thinner kernel fractions. Sun and Siebenmorgen (1993) reported that head rice yield increased with increasing thickness, reached a maximum, and then decreased. Fractionating rough rice before milling was reported by Wadsworth et al (1982) to reduce processing losses and improve milling efficiency. Additionally, Lu and Luh (1991) speculated that the high-protein fraction of rice could be used to develop baby foods.

In the rice industry, rice is typically milled as an unfractionated bulk. Chen and Siebenmorgen (1997) reported that unfractionated milling in a pilot-scale single-break mill (Satake BA-7) produced milled rice in which the surface lipid content (SLC) decreased with increasing kernel thickness to 1.67 mm, after which the SLC remained constant. It was also observed that as the overall degree of milling (DOM) level was increased (i.e., as the milling process progressed, thinner kernels were milled at a greater bran removal rate than thicker kernels).

The previous research mentioned above did not include the use of commercial milling systems. It is yet unknown whether the previous conclusions from laboratory and pilot-scale single-break mills remain valid for commercial single-break milling systems. Additionally, multibreak milling systems have become more popular in the rice industry in recent years. However, no reports were found concerning the milling performance of these systems in terms of effects on kernel to kernel milling uniformity. Clarifying these issues may help rice millers to determine the worth of separating some kernel fractions before or after commercial milling.

Consequently, the objective of this research was to investigate the effects of conventional, unfractionated milling in both single-break and multibreak commercial milling systems on SLC, protein content, and breakage across thickness fractions.

MATERIALS AND METHODS

Commercial Milling Systems

The two milling systems investigated in this research were a single-break milling system and a multibreak milling system, both of which were parts of commercial milling operations. The former consisted of a Satake BA-15 friction mill. The latter comprised a Satake VTA vertical rice whitener and two Satake KB-40 rice polishing machines, configured in series as shown in Fig. 1. In the

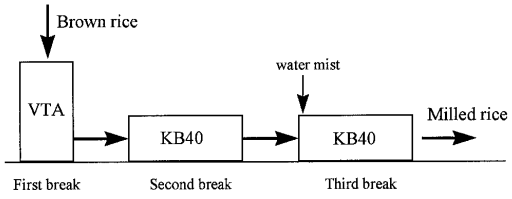

Fig. 1. Configuration of the multibreak milling system comprising a Satake VTA whiteness machine and two Satake KB-40 polishing machines.

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multibreak operation, brown rice was fed into the top of the VTA machine, which applied an abrasive milling action as the rice flowed downward through the mill. The rice from the VTA machine then flowed horizontally in sequence through the two KB-40 machines, which applied a friction milling action to polish the rice. Additionally, in the second KB-40 machine (3rd break), water mist was injected into the air stream just before the air entered the milling chamber.

Sample Procurement and Preparation

A long-grain rice variety, Kaybonnet, from the same lot, with rough rice moisture content (MC) of ≈14% (wet basis), was milled in each of the two commercial milling systems in November 1996. To yield three DOM levels (low, medium, and high), the location of the weight on the mill lever arm was adjusted for the single-break milling system and for each machine of the multibreak milling system. This adjustment allowed for varying milling pressure and duration in the milling chambers. DOM levels were monitored visually by professional milling personnel, and were set according to the color of the milled rice. Samples at each DOM level were collected at the outlet of the two milling systems. Head rice was then separated from brokens using a Satake test rice grader with a ϕ5.2 mm long-grain screen. Using a Carter-Day laboratory precision sizer, the head rice was separated into five thickness fractions (<1.49, 1.49–1.59, 1.59–1.69, 1.69–1.74, >1.74 mm). Each thickness fraction was then measured for SLC and protein content.

Surface Lipid Extraction

Surface lipid content of the milled head rice samples from each thickness fraction was determined using a petroleum ether extraction technique (Hogan and Deobald 1961) in a Soxtec System HT extractor, which consisted of an extraction unit (model 1043) and a service unit (model 1044). Prior to extraction, 5 g of head rice from each thickness fraction was placed in cellulose extraction thimbles (diameter 26 mm, length 60 mm) and dried in a convection oven at 100°C for 1 hr. The thimble with dried sample was attached to the magnets at the bottom of the condenser of the extraction unit. For surface lipid extraction, the thimble was lowered to immerse the sample in 50 mL of petroleum ether (bp 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 lipids from the head rice. This procedure was continued for 30 min to extract most of the surface lipids. 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 lipids on the surface of the kernels. After that, the fluid flow through the condenser was discontinued and the solvent from the thimble was allowed to drain for 15 min. The contents of the extraction cup were dried at 100°C for 30 min to remove the petroleum ether, leaving only the extracted lipids.

The SLC was calculated as the amount of extracted surface lipids expressed as a percentage of the original head rice mass (5 g). This index has been used in previous work for quantifying the DOM (Hogan and Deobald 1961, Sun and Siebenmorgen 1993). It was realized that, for a certain amount (5 g) of head rice, thinner kernel fractions contain more rice kernels and more total kernel surface area (up to 14% by theoretical calculations) than thicker kernels. However, for the purposes of this study, no kernel- or surface area-based SLC correction was used in quantifying DOM level as an index of milling quality evaluation. Rather, the standard calculation method of expressing the amount of extracted surface lipids as a fraction of the original head rice mass was used.

TABLE I
***F* Values from Analysis of Variance of Surface Lipid Content as Affected by Kernel Thickness and Degree of Milling (DOM) Level**

Factors	Single-Break	Multibreak	$F_{0.05}$[a]
Thickness	41.41*[b]	46.25*	3.1
DOM level	865.8*	917.5*	3.7
Thickness × DOM	4.50*	11.50*	2.6

[a] Critical *F* value at 0.05 significance level.
[b] * = significant at *P* = 0.05.

Protein Measurement

Protein content of milled rice samples was measured by means of the Dumas technique (Schmitter and Rihs 1989). Head rice samples from each thickness fraction were ground in a Udy cyclone sample mill with a ϕ0.5-mm screen. For protein measurement, 50 mg of ground sample was placed into a tin capsule and loaded into a Fisons NA-2000 nitrogen/protein analyzer. The sample was melted and converted to combustion gases at 900°C in a combustion reactor. Nitrogen was then separated from the combustion gases and detected by a thermal conductivity detector. Protein content (dry basis) of each sample was calculated (N × 5.95). Duplicate measurements were performed for each sample.

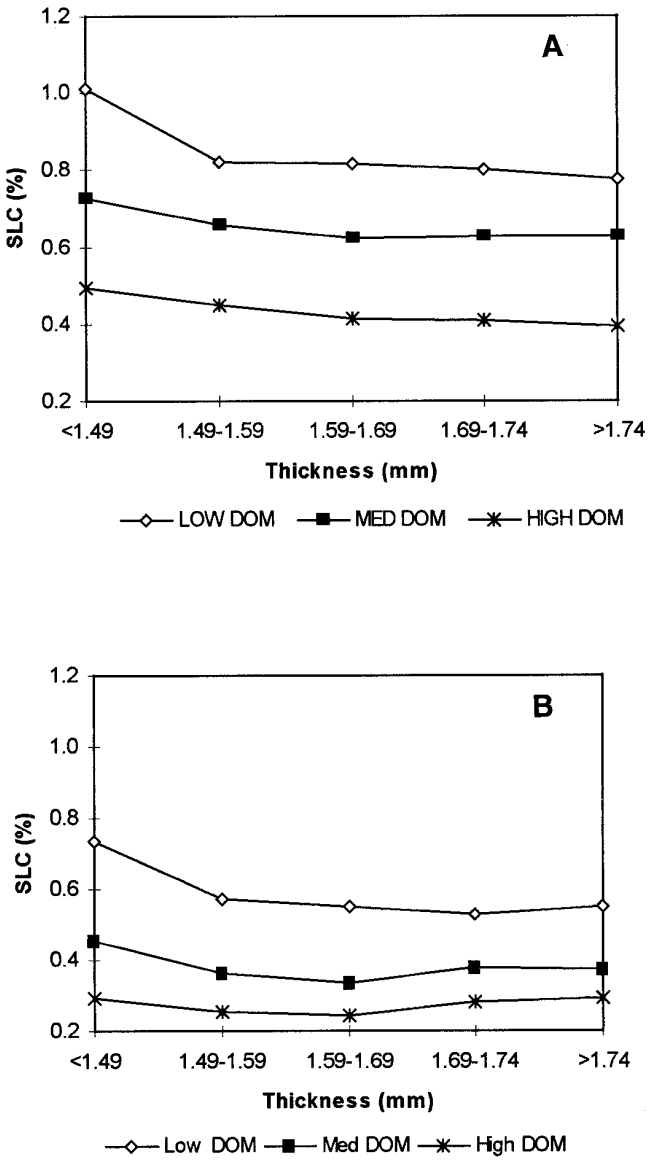

Fig. 2. Surface lipid content (SLC) of kernel thickness fractions from Kaybonnet long-grain rice milled as an unfractionated bulk to three degree of milling (DOM) levels in two commercial systems: single-break milling system (**A**), multibreak milling system (**B**).

RESULTS AND DISCUSSION

SLC

Figure 2 shows the change in SLC across thickness fractions at each of the three DOM levels for unfractionated rice milled in the single-break and multibreak milling systems. To determine the effect of kernel thickness, DOM level, and their interaction on SLC, an analysis of variance was performed, using the GLM procedure of SAS (SAS Institute, Cary, NC). Statistical *F* values (Table I) for both milling systems revealed that kernel thickness, DOM level, and their interaction all had significant effects on SLC. DOM level had a greater effect on SLC than did kernel thickness.

Using Duncan's multiple range test, thickness fractions at each DOM level were grouped according to SLC (Table II). At low and medium DOM levels, the rice milled in the two milling systems had similar trends in the change of SLC across thickness fractions. The thinnest kernel fraction (<1.49 mm) had higher SLC than the other four thickness fractions (Fig. 2 and Table II); the SLC levels among these four fractions were not significantly different. At the high DOM level, the rice milled in the two systems showed a slightly different trend in the change of SLC across thickness fractions. For the rice milled in the single-break system, SLC decreased with increasing kernel thickness to a thickness of 1.69 mm, after which it remained constant. For the rice milled in the multibreak system, SLC decreased with increasing kernel thickness to a thickness of 1.59 mm, remained constant until a thickness of 1.69 mm, and then increased by a small, yet significant amount. All results obtained from the single-break system, as well as the trends at low and medium DOM levels for the multibreak system, agreed with those from similar tests using a pilot-scale single-break milling system (Chen and Siebenmorgen 1997).

The differences between the SLC of the thinnest kernel fraction and the average SLC of the other four thickness fractions were 0.21, 0.09, and 0.08 percentage points (pp), respectively, at low, medium, and high DOM levels for the rice milled in the single-break system (Table II). The corresponding differences were 0.18, 0.09, and 0.02 pp for the rice milled in the multibreak system. This indicates that in both milling systems, increasing milling pressure or duration (changing DOM from a low to high level) caused the thinnest kernel fraction to be milled at a greater bran removal rate than the

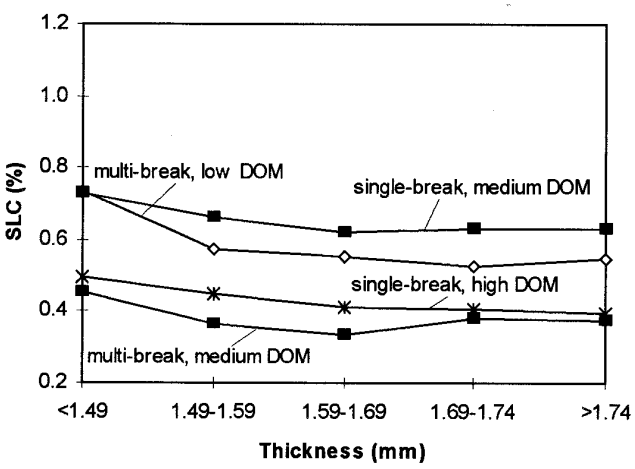

Fig. 3. Surface lipid content (SLC) of kernel thickness fractions at the indicated degree of milling (DOM) levels for Kaybonnet long-grain rice milled in either the single-break or multibreak commercial systems.

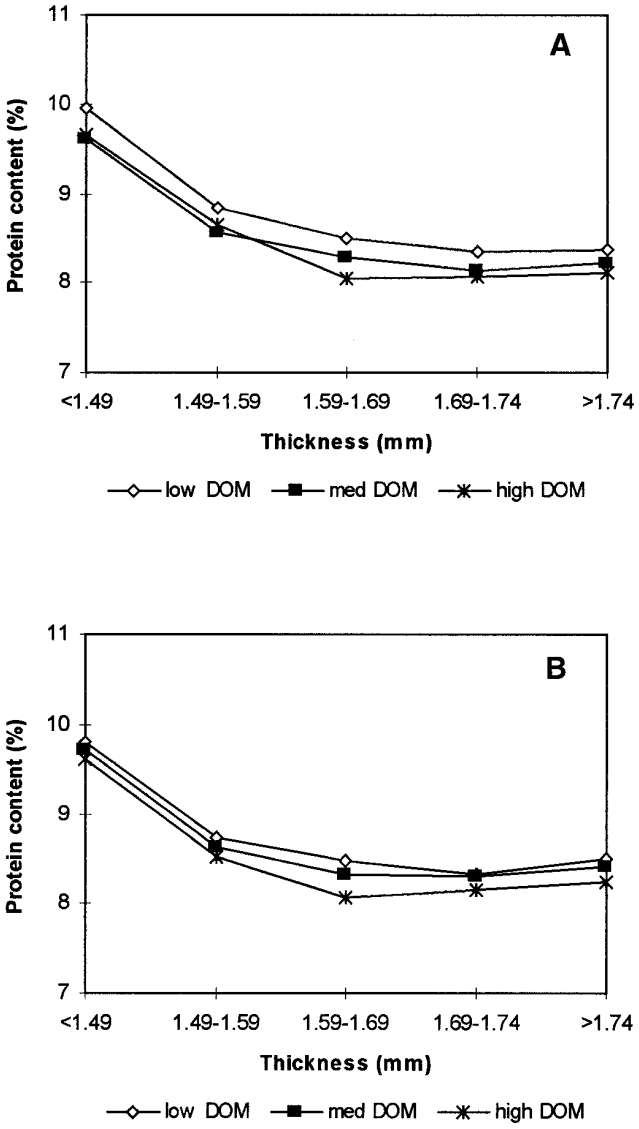

Fig. 4. Protein content of kernel thickness fractions at the indicated degree of milling (DOM) levels for Kaybonnet long-grain rice milled in two commercial systems: single-break milling system (**A**), multibreak milling system (**B**).

TABLE II
Surface Lipid Contents Across Thickness Fractions at Three Degree of Milling (DOM) Levels for the Two Commercial Milling Systems[a]

	Single-Break			Multibreak		
Thickness (mm)	**Low DOM**	**Medium DOM**	**High DOM**	**Low DOM**	**Medium DOM**	**High DOM**
<1.49	1.01a[b]	0.73a	0.49a	0.73a	0.46a	0.29a
1.49–1.59	0.82b	0.66b	0.45b	0.57b	0.37b	0.25b
1.59–1.69	0.81b	0.62b	0.42c	0.55b	0.33b	0.25b
1.69–1.74	0.80b	0.63b	0.41c	0.53b	0.38b	0.28a
>1.74	0.78b	0.63b	0.40c	0.55b	0.37b	0.29a

[a] Values are the mean of duplicate measurements.
[b] Values in each column followed by the same letter are not significantly different at $P = 0.05$, using Duncan's multiple range test.

other kernel fractions. These results agreed with the observations from the pilot-scale single-break milling system tested by Chen and Siebenmorgen (1997).

The thinnest kernel fraction (<1.49 mm) milled to the low DOM level in the multibreak system had an SLC similar to the thinnest fraction milled to the medium DOM level in the single-break system (Fig. 3 and Table II). However, the difference in SLC (0.21 pp) across thickness fractions milled in the multibreak system was larger than the corresponding difference in SLC (0.11 pp) milled in the single-break system. This implies that the multibreak system applied a less aggressive bran removal action to thin kernels relative to the thicker kernels. A similar, yet less striking trend also existed between the rice milled to the medium DOM level in the multibreak system and the rice milled to the high DOM level in the single-break system.

Protein Content

Figure 4 shows the protein content across thickness fractions of the rice milled to each of the three DOM levels in the two commercial milling systems. A statistical analysis similar to that used with the SLC data was performed. Statistical *F* values (Table III) revealed that for rice milled in these two systems, kernel thickness and DOM level had significant effects, but their interaction had no significant effect on protein content.

Table IV exhibits the means of protein content across all thickness fractions for each DOM level from the two commercial systems. For both systems, the rice milled to the low DOM level had the highest protein content, and the rice milled to the high DOM level had the lowest protein content. As more surface bran was removed, the protein content of the milled rice kernels was reduced. The reduction was significant from low to high DOM level. Earlier work (Lu and Luh 1991) showed that milled rice has a lower protein content than brown rice. The results from both systems agreed with and expanded the previous conclusions.

Table V and Fig. 4 show protein content across thickness fractions for rice milled to each of the three DOM levels in the two systems. The rice milled in the two systems had similar trends in the distribution of protein content across thickness fractions. In all cases, for a given DOM level, protein content decreased significantly with increasing kernel thickness to 1.69 mm, after which it remained constant.

Figure 5 shows the relation between protein content and SLC for each thickness fraction of the rice milled in the two commercial systems. For each thickness fraction, the point corresponding to the highest SLC represents low DOM level, and vice versa. At a given SLC, protein content decreased significantly with increasing kernel thickness to 1.69 mm, after which it changed little. This concurs with the conclusion of Matthews et al (1981) that thinner kernels contain higher protein than thicker kernels.

DOM level had less significant effect on protein content than did thickness (Table III). Bran has a slightly higher protein content than the endosperm. By increasing DOM, bran is removed, but essentially no endosperm is removed. Because the mass of the endosperm is much greater than that of the bran, the protein content of the milled rice changed less by DOM level changes than by the inherent protein content differences associated with thickness of kernels (Fig. 5). Furthermore, the interaction of DOM with thickness had no significant effect on protein content (Table III). This suggests that the degree of bran removal resulting from the milling operation did not significantly influence the distribution of protein content across kernel thickness fractions, even though more surface bran was removed from thin kernels than from thick kernels during milling.

Rice Breakage

Rice breakage was quantified by the weight of broken rice expressed as a percentage of the total weight of milled rice. Figure 6 shows the relationship between rice breakage and SLC for the unfractionated rice milled from the two commercial systems. In Fig. 6, points with the least SLC corresponded to the highest

TABLE III
***F* Values[a] from Analysis of Variance of Protein Content as Affected by Kernel Thickness and Degree of Milling (DOM) Level**

Factors	Single-Break	Multibreak	$F_{0.05}$[a]
Thickness	260.14*[b]	318.55*	3.1
DOM level	21.26*	22.32*	3.7
Thickness × DOM	1.66	0.64	2.6

[a] At 0.05 significance level.
[b] * = significant at $P = 0.05$.

TABLE IV
Means of Protein Content Across Thickness Fractions for Degree of Milling (DOM) at Three Levels for Two Commercial Milling Systems

DOM Levels	Single-Break	Multibreak
Low	8.80a[a]	8.77a
Medium	8.56b	8.68b
High	8.53b	8.52c

[a] Values within each column followed by the same letter are not significantly different at $P = 0.05$, using Duncan's multiple range test.

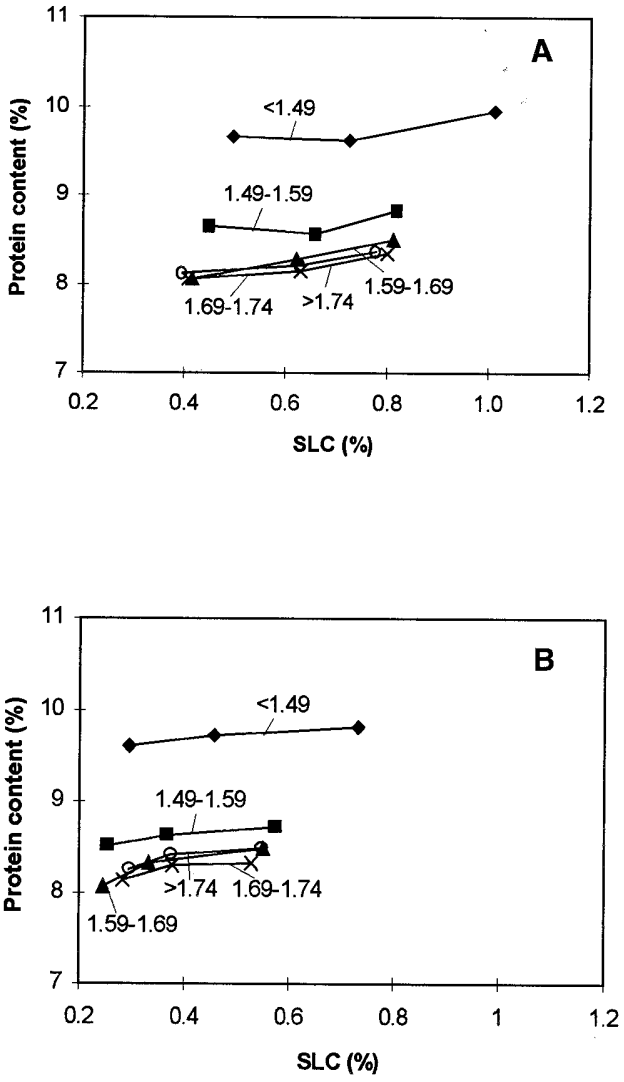

Fig. 5. Protein content versus surface lipid content (SLC) for kernel thickness fractions (mm) from Kaybonnet long-grain rice milled in two commercial systems: single-break milling system (**A**), multibreak milling system (**B**).

TABLE V
Protein Content Across Thickness Fractions for Degree of Milling (DOM) at Three Levels for Two Commercial Milling Systems[a]

	Single-Break			Multibreak		
Thickness (mm)	Low DOM	Medium DOM	High DOM	Low DOM	Medium DOM	High DOM
<1.49	9.95a[b]	9.62a	9.66a	9.81a	9.72a	9.60a
1.49–1.59	8.83b	8.57b	8.64b	8.73b	8.62b	8.51b
1.59–1.69	8.49c	8.28c	8.05c	8.48c	8.32c	8.08c
1.69–1.74	8.35c	8.14c	8.06c	8.32c	8.30c	8.15c
>1.74	8.37c	8.21c	8.12c	8.49c	8.42bc	8.25c

[a] Values are the mean of duplicate measurements.
[b] Values within each column followed by the same letter are not significantly different at $P = 0.05$, using Duncan's multiple range test.

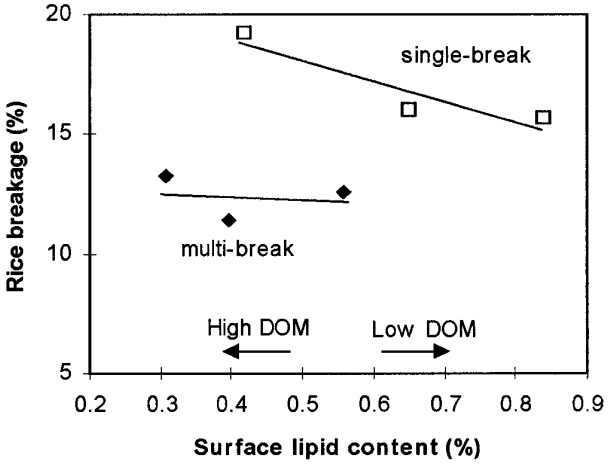

Fig. 6. Relationship between rice breakage and surface lipid content of nonfractionated rice milled in two commercial systems.

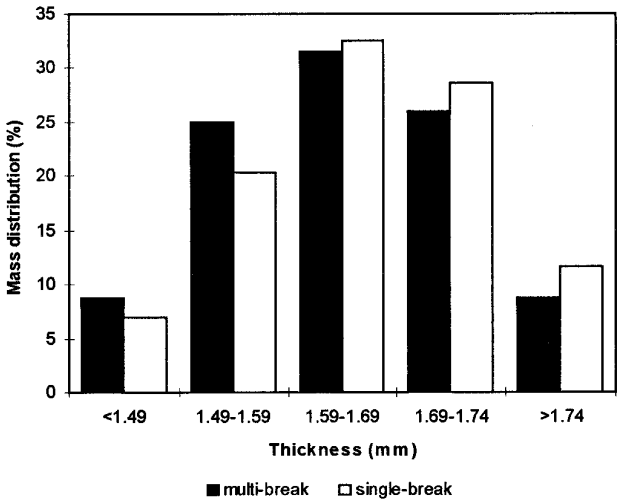

Fig. 7. Mass distribution of the head rice produced from milling Kaybonnet long-grain rice in two commercial systems. Levels shown are the average across DOM levels.

DOM levels, and vice versa. The range for breakage for the three DOM levels was 11.4–13.3% for the rice milled in the multibreak system and 15.7–19.3% for the rice milled in the single-break system. At a representative DOM level of 0.4% SLC, rice breakage in the single-break system was 4–6 pp higher than that in the multibreak system.

The correlation coefficient between breakage and SLC was –0.93 for the rice milled in the single-break system, and –0.20 for the rice milled in the multibreak system. Breakage was highly associated with SLC for the single-break system, implying that as bran was removed, kernels were broken, and thus rice breakage increased as milling progressed. There was a weak relationship between rice breakage and SLC for the multibreak system. In the multibreak milling system, the rice breakage that was observed occurred primarily in the earlier milling stages; as more bran was removed, rice breakage did not increase considerably.

For the milled rice from the two commercial systems, Fig. 7 shows the mass distribution of the head rice across thickness fractions. The rice milled in the single-break system contained fewer thin kernels (<1.59 mm) and more thick kernels (>1.59 mm) than the rice milled in the multibreak milling system. To determine the significance of the difference in the mass distribution of the head rice between these two milling systems, a *t*-test was performed on the means of the mass distribution data for each DOM level of each thickness fraction. Probability values were calculated as 0.01, 0.01, 0.32, 0.16, and 0.04, respectively, from the thinnest kernel fraction to the thickest fraction. Thus, significant differences in mass distribution between the rice milled in the two commercial systems occurred mainly in the thinner kernels (<1.59 mm) and thickest kernels (>1.74 mm). In the single-break system, a higher percentage of thin kernels (<1.59 mm) were broken than in the multibreak system. In the multibreak system, the thickest kernels (>1.74 mm) experienced a higher percentage of brokens than in the single-break system. The results from the single-break system verified the conclusions that breakage of rice was generally greater for thinner fractions when milled in laboratory, single-break systems (Matthews and Spadaro 1976).

CONCLUSIONS

For the Kaybonnet long-grain rice milled in the two commercial milling systems, the thinnest kernel fraction (thickness <1.49 mm) had higher SLC than the other kernel fractions particularly at the low DOM levels. This thinnest fraction amounted to 7–8% of the total weight of the unfractionated head rice. For a given DOM level, protein content decreased with increasing kernel thickness to 1.69 mm, after which it remained constant

As milling progressed from a low to high DOM level in both milling systems, the thin kernels were milled at a greater bran removal rate than were the thicker kernels, as indicated by the amount of surface lipids remaining per unit mass of head rice (SLC). Consequently, the SLC decreased more from thin kernels than from thick kernels. However, because bran contains only a slightly higher protein content than the endosperm, the protein content of the thin kernels relative to that of the thick kernels did not decrease at the same rate as the SLC. Rather, protein content decreased much more uniformly across thickness fractions. Thus, the milling operation had greater effects on SLC than on protein content.

Less rice was broken in the multibreak milling system than in the single-break milling system at any DOM level. Rice breakage progressively occurred as the rice was milled to higher DOM levels in the single-break system, whereas most of the breakage that did occur in the multibreak system appeared to be caused in the early milling stages.

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