Milling Performance and Quality Characteristics of Starbonnet Variety Rice Fractionated by Rough Rice Kernel Thickness[1]

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Cereal Chem. 59(1):50–54

ABSTRACT

Starbonnet variety long-grain rice was used to study the variation of milling and quality factors with kernel thickness. The rough rice was separated by thickness into six fractions, and portions of each fraction were shelled and milled under identical conditions. Milling performance and quality characteristics were evaluated for each fraction. Significant differences among the fractions were found for shelling efficiency, total yield, head yield, processing losses, quantity of chalky kernels, and quantity of damaged kernels. Results indicate that processing the thinner kernels (<1.6 mm) separately offers the potential for producing a new high-protein rice product with excellent protein quality and simultaneously reducing processing losses, improving the quality of the milled rice products, reducing the amount of energy required to dry rice, and increasing the market value of the rice crop.

The thickness of individual kernels of current commercial rice cultivars at harvest varies widely. Previous work with Starbonnet variety rice studied the relationships between the thickness of the kernels and their physical and physicochemical properties (Wadsworth et al 1979b) and chemical composition (Matthews et al 1981). Significant differences in properties and composition were found among the fractions of varying kernel thickness. These differences have implications for practically every phase of research on rice, including cultural practices, breeding, composition, drying, processing, and quality.

This study investigated differences in milling performance and milled rice quality that were related to variation in the thickness of the rice kernels. The areas investigated were shelling efficiency, milling yield, breakage, degree of milling, and the incidences of chalky and damaged kernels. The information provides a more detailed characterization of the rice kernel than has hitherto been available and identifies areas of rice processing in which the potential exists for reducing processing losses and improving quality.

MATERIALS AND METHODS

Rice

The rice used in this study came from the same two lots of Starbonnet variety rice previously used to investigate the relationships between the physical and chemical properties and the kernel thickness (Wadsworth et al 1979b, Matthews et al 1981). The two lots of rice are referred to as lots A and B. The U.S. quality grades of lots A and B were No. 4 and No. 3, respectively.

Processing

The equipment and procedures used to clean, shell, and mill the rice and to separate the rice into fractions by kernel thickness have been reported in detail (Wadsworth et al 1979b). Each lot of rough rice was separated into six thickness fractions with a dockage machine and the five slotted screens listed in Table I. The thickness fractions are referred to by the screen numbers.

Quality Evaluation

Shelling efficiency was determined by hand separating the rough and brown rice after one pass through the sheller with the roll spacing set at 0.483 mm (0.019 in.). The yields of head rice, second heads, and small brokens were determined with a sizing device using a No. 6 sizing plate to remove the small brokens followed by a No. 12 plate to remove the second heads (USDA 1974). The determinations of chalky kernels, damaged kernels, red rice, and weed seeds were made by hand sorting 30-g samples in accordance with the methods set forth in the USDA rice inspection manual (1974). If, because of excessive breakage, the test milling did not provide 30 g of head rice, the entire sample of head rice was used in the determination.

Data Analysis

From two to five replicate samples from each rice lot were processed and evaluated for milling performance and quality characteristics. Values reported are averages of the replicates. Analysis of variance (ANOVA) and Newman-Keul's multiple-range test were applied to determine the significance of differences between the rice lots and among the thickness fractions for the various factors evaluated.

RESULTS AND DISCUSSION

Table I shows the percentages of rough rice retained on each screen, the mean kernel thicknesses, the ranges of kernel thickness, and the moisture contents. For both rice lots, the percentages of rough rice retained on each screen fell within the ranges reported by Matthews and Spadaro (1976) for other lots of long-grain varieties of rice fractionated according to kernel thickness using identical screens.

The moisture content of rice during milling affects the amount of breakage and the degree of milling (Pominski et al 1961, Webb and Calderwood 1977). The moisture contents of the thickness fractions within a lot were not significantly different. However, the moisture contents of the fractions from lot A were approximately 1.5 percentage points higher than those from lot B. We decided not to equilibrate the two lots to the same moisture content before processing because they were not being treated as replicates, but as two samples of Starbonnet variety rice expected to show some differences due to different growing and handling conditions. Also, adjustment of the moisture content might have affected breakage (Kunze 1977). Thus, the differences in moisture contents of the two lots must be taken into consideration when analyzing the milling data.

Shelling

The results of the shelling tests are shown in Table II. ANOVA of the shelling efficiency data indicated significant differences ($P < 0.05$) among the thickness fractions but not between the rice lots. The shelling efficiency decreased from 98% for the thickest fraction to 87% for the thinnest one. Linear regression of efficiency on mean

[1]Presented in part at the 17th Rice Technical Working Group Meeting, College Station, TX, February 13–16, 1978.

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Names of companies or commercial products are given solely for the purpose of providing specific information; their mention does not imply recommendation or endorsement by the USDA over others not mentioned.

TABLE I
Fractionation of Lots A and B of Starbonnet Rough Rice by Kernel Thickness

Screen No.[a]	Slot Size (mm × mm)	Percentage Retained		Mean Thickness (mm)		Range of Thickness (mm)		Moisture Content (% wb)	
		A	B	A	B	A	B	A	B
24	1.98 × 12.70	4.0	1.8	1.94	1.92	1.88–2.06	1.88–2.01	13.0	11.4
23	1.93 × 19.05	13.7	10.0	1.88	1.86	1.83–1.93	1.80–1.93	13.1	11.3
5	1.78 × 12.70	64.8	69.7	1.80	1.79	1.68–1.88	1.70–1.85	12.9	11.4
4	1.63 × 9.53	12.1	14.1	1.65	1.65	1.50–1.75	1.52–1.70	12.9	11.4
22	1.55 × 12.70	2.3	2.4	1.48	1.47	1.32–1.57	1.35–1.57	12.6	11.4
Unders	···	3.1	1.7	1.28	1.31	0.94–1.45	1.09–1.47	12.7	11.1

[a]Screen numbers refer to slotted screens in the Carter Dockage Tester.

TABLE II
Relationship Between Kernel Thickness and Shelling Efficiency and Yield[a]

Screen No.	Shelling Efficiency[b] (%)		Brown Rice Yield[c] (%)		Expected Brown Rice Yield[d] (%)		Rice Lost in Hulls[e] (%)	
	A	B	A	B	A	B	A	B
24	97.3 a	98.1 a	80.4 a	80.2 a	80.5	81.0	0.1 a	1.0 a
23	96.8 a	97.8 a	80.7 a	80.4 a	81.3	81.3	0.7 a	1.1 a
5	95.5 ab	96.6 a	80.7 a	80.7 a	80.5	80.4	−0.2 a	−0.4 a
4	94.6 bc	93.9 b	78.6 b	78.0 b	80.1	80.0	1.9 a	2.5 a
22	92.8 c	89.8 c	75.4 c	71.4 c	79.5	77.0	5.2 b	7.3 b
Unders	87.7 d	86.6 d	58.3 d	55.2 d	76.5	76.4	23.8 c	27.7 c
Unfractionated	95.4	95.9	78.5	79.5	80.4	80.1	2.6	0.8
Recombined[f]	95.3	95.7	79.6	79.4	80.4	80.1	1.0	0.9

[a]Values within a column followed by the same letter are not significantly different at $P = 0.05$.
[b]Percentage of rough rice that had the hulls removed in one pass through the sheller with roll spacing set at 0.483 mm (0.019 in.).
[c]Percentage of brown rice obtained (based on rough minus amount of rough that was not shelled).
[d]Calculated from the mean weights of the rough and brown rice kernels.
[e]Based on expected brown rice yield.
[f]Calculated from a material balance on the thickness fractions.

thickness was highly significant ($P<0.01$). Shelling efficiencies for the unfractionated lots were not significantly different from estimated efficiencies for the recombined thickness fractions as calculated from a material balance. This indicates that shelling kernels of differing thickness together did not affect shelling efficiency.

For a given thickness fraction, separating the unshelled rice from the brown rice after shelling and passing the unshelled rice through the sheller a second time resulted in a second-pass shelling efficiency value that was no different from the efficiency value obtained with the first pass. Increased efficiency for shelling the thinner kernels was attained by decreasing the spacing between the sheller rolls. For example, with rice lot B, fraction 22, decreasing the roll spacing to 0.36 mm (0.014 in.) increased the efficiency from 89.8 to 93.2%.

Also shown in Table II are the actual yields of brown rice obtained from the various thickness fractions, the expected brown rice yields, and the amounts of rice lost in the hulls. ANOVA indicated significant differences among thickness fractions but not between rice lots. Essentially no differences were found in brown rice yield among fractions 24, 23, and 5. However, with the three fractions containing the thinner kernels, the yield of brown rice decreased with decreasing thickness.

Mean kernel weights for the rough, brown, and milled rice from each of the thickness fractions of both of these lots of Starbonnet rice have been reported (Wadsworth et al 1979b). The expected shelling yields of brown rice for the thickness fractions were calculated from the mean weights of rough- and brown-rice kernels, which take into account the proportion of hulls to brown rice. The estimates of rice lost in the hulls were based on the differences between the expected and actual brown rice yields. The amounts of rice lost in the hulls for thickness fractions 24, 23, 5, and 4 are not significantly different from zero (although the higher value for fraction 4 is probably real). The shelling losses for the two thinner-kernel fractions are significant. Sterile florets had been removed when the rough rice was cleaned, so we assumed that the losses were caused by small fragments of caryopsis (resulting from the disintegration of very fragile kernels during shelling) being carried into the hulls by aspiration. Approximately 25% of the brown rice for the under-22 fraction was lost with the hulls.

TABLE III
Relationship Between Kernel Thickness and Milling Yields[a]

Screen No.	Total Yield (% of rough)		Head Yield (% of rough)		Breakage (% of milled)	
	A	B	A	B	A	B
24	73.2 a	71.9 a	65.5 a	61.0 a	10.5 a	15.1 a
23	72.8 a	71.9 a	67.3 a	65.1 b	7.5 b	9.4 b
5	72.6 a	72.8 a	67.1 a	68.2 c	7.6 b	6.3 c
4	68.0 b	66.3 b	45.0 b	50.7 d	33.9 c	23.5 d
22	60.1 c	52.3 c	10.5 c	17.9 e	82.6 d	65.7 e
Unders	24.4 d	30.2 d	2.3 d	4.3 f	90.6 e	85.7 f
Unfractionated	69.1	68.8	60.6	61.4	12.3	10.7
Recombined[b]	70.3	70.8	61.1	62.9	13.1	10.5

[a]Values within a column followed by the same letter are not significantly different at $P = 0.05$.
[b]Calculated from a material balance on the thickness fractions.

Milling

The results of milling tests on the thickness fractions are given in Table III. ANOVA for the total yield, head yield, and breakage data indicated significant differences between rice lots for all three variables. Because the two rice lots were subjected to different growing conditions and were dried to different moisture contents, we had expected that they might perform differently in milling tests (Spadaro et al 1980).

The ANOVA also indicated significant differences among the thickness fractions. Both lots showed similar trends for the relationship between milling yield and kernel thickness. The total yield was essentially constant for the three thicker-kernel fractions (24, 23, and 5) and then decreased with decreasing kernel thickness. Head yield showed an initial increase with decreasing thickness, reached a maximum, and then decreased. The trend in breakage values was approximately opposite that for head yield. Similar relationships between breakage and kernel thickness were reported by Matthews and Spadaro (1976).

The interactions of rice lot with thickness were also significant in the ANOVA. For the total yield results, no simple trend for the interaction effect relating the differences between the lots with the thickness of the kernels was apparent. Essentially no differences were found between the lots for fractions 24, 23, 5, and 4, but lot A had a higher total yield for fraction 22 and lot B was higher for the unders fraction. However, the head yield and breakage data showed trends in the differences between the lots related to kernel thickness. For the fractions containing thicker kernels (24 and 23), the head yields were higher in lot A. The head yields for both lots were approximately equal for fraction 5, and lot A had lower head yields in the three thinner fractions. The differences between the two lots in the breakage results followed a similar but opposite trend. Thus, the effects of kernel thickness on milling quality were greater in lot A than in lot B.

Although the total and head yields for the calculated recombined fractions were higher than those for unfractionated rice, the differences were not great enough to be statistically significant. No attempt was made to adjust the milling conditions to give optimum yields for each thickness fraction.

Table IV compares the amount of bran by-product produced during milling with the actual degree of milling obtained for the head rice. The actual degree of milling was calculated from the mean kernel weights of the brown and milled head rice for each fraction. The differences between the quantity of bran produced and the actual degree of milling are an estimate of the amount of edible rice lost in the bran by-product from the disintegration of fragile kernels. For the three thicker fractions, the losses were about the same and averaged approximately 1%. For the three thinner fractions, the losses increased with decreasing thickness and approached 50% for one sample. The amount of rice recovered from the bran by passing it over a No. 25 sieve (expressed as percent recovered) is also shown in Table IV. No relationship was apparent between the percent recovered and the mean kernel thickness of the fractions, indicating that the particle size distribution of the chits from each fraction was probably similar.

The information contained in Table V was calculated from the experimental data presented in Tables I–IV. Table V shows how 100 g of unfractionated rough rice is distributed into various products according to thickness fractions. Examination of the data in this manner indicates that the two thinner thickness fractions (22 and unders), which together comprise 4–5 g of the rough rice, contributed very little to the head rice yield (0.3–0.6 g) but accounted for approximately half of the total edible rice losses during shelling and milling. In contrast, the three thicker fractions, which together comprise 82–85 g of the rough rice, produced approximately 90% of the head rice and only 25% of edible rice losses. Fraction 4, although contributing approximately 25% of the losses, yielded a significant quantity of head rice (5–7 g).

Table V also shows that if the rough rice were separated by kernel thickness before processing, only 15% of the hulls produced (fractions 4, 22, and under-22) would have to be screened to recover 90% of the edible rice lost in the hulls and only 15–20% of the bran produced (fractions 4, 22, and under-22) would have to be screened to recover 60–70% of the edible rice lost in the bran.

Grading Factors

All thickness fractions were well milled. The milled rice color for

TABLE IV
Comparison Between Quantity of Bran By-Product Produced During Milling and Degree of Milling of Head Rice[a]

	Quantity of Bran By-Product (% of brown)		Degree of Milling[b] (% of brown)		Rice Lost in Bran By-Product[c] (% of brown)		Rice Recovered from Bran[d] (% of rice lost)	
Screen No.	A	B	A	B	A	B	A	B
24	9.0 a	10.3 a	7.0	9.3	2.0	1.0	31.3	66.7
23	9.8 a	10.6 a	8.7	9.7	1.1	0.9	57.3	70.1
5	10.0 a	9.8 a	9.4	8.7	0.6	1.1	70.1	70.3
4	13.5 b	15.0 b	7.3	11.0	6.2	4.0	39.0	59.1
22	20.3 c	26.8 c	11.0	10.6	9.3	15.8	63.3	48.4
Unders	58.1 d	45.3 d	9.1	7.4	49.0	36.2	77.1	58.3
Unfractionated	12.0	13.2	9.0	11.0	3.0	2.2	56.4	62.1
Recombined[e]	11.7	11.4	9.0	9.2	2.7	2.2	61.4	62.5

[a] Values within a column followed by the same letter are not significantly different at $P = 0.05$.
[b] Degree of milling is calculated from the differences in average weights of whole kernels of brown and milled rice.
[c] Calculated by difference.
[d] Chits retained on a 25-mesh screen.
[e] Calculated from a material balance on the thickness fractions.

TABLE V
Distribution of Products from 100 g of Rough Rice Separated by Thickness

					Hull By-Product				Milled Rice						Bran By-Product			
	Rough Rice (g)		Brown Rice (g)		Hulls (g)		Chits (g)		Head Rice (g)		Second Heads (g)		Screenings and Brewer's Rice (g)		Bran (g)		Chits (g)	
Screen No.	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
24	4.0	1.9	3.2	1.5	0.8	0.4	0.0	0.0	2.6	1.2	0.3	0.2	0.0	0.0	0.22	0.14	0.06	0.02
23	13.7	10.0	11.1	8.0	2.6	1.9	0.1	0.1	9.2	6.6	0.7	0.5	0.1	0.1	0.97	0.78	0.12	0.07
5	64.8	69.9	52.3	56.9	12.6	13.7	0.0	0.0	43.7	47.8	2.8	2.6	0.5	0.6	4.92	4.95	0.31	0.63
4	12.1	14.1	9.5	11.0	2.4	2.8	0.2	0.3	5.4	7.2	2.3	1.5	0.5	0.7	0.67	1.21	0.59	0.44
22	2.3	2.4	1.7	1.7	0.5	0.6	0.1	0.1	0.2	0.5	0.7	0.5	0.4	0.3	0.19	0.18	0.16	0.27
Unders	3.1	1.7	1.8	0.9	0.7	0.4	0.4	0.3	0.1	0.1	0.4	0.2	0.3	0.2	0.16	0.07	0.88	0.33
Total	100.0	100.0	79.6	80.0	19.6	19.7	0.8	0.8	61.3	63.3	7.1	5.6	1.9	1.9	7.13	7.33	2.12	1.76

both lots was white to creamy white. Apparent differences in color among the fractions were attributed to differences in the chalkiness of the fractions rather than to differences in the color of the kernels. The quantities of red rice and weed seeds present in these two lots were insignificant. No heat-damaged kernels were detected.

The percentages of chalky kernels in each of the thickness fractions for the milled head rice and second heads are given in Table VI. ANOVA indicated significant differences between rice lots and among thickness fractions. The percentage of chalky kernels increased with decreasing thickness. Head rice in the two thicker fractions had less than 1% chalky kernels (U.S. No. 1 grade). Head-rice chalkiness increased significantly to 3–4% (U.S. No. 3 grade) for the intermediate fraction that contained the bulk of the rice. A very high level of head-rice chalkiness, 12–45% (U.S. No. 6 to sample grade), was found for the three thinner fractions.

Figure 1 shows the effects on chalkiness of separating the rice by kernel thickness into two fractions (thick and thin) for different values of separation thickness. Also indicated on Fig. 1 are the allowable maximum percentages of chalky kernels in head rice for U.S. No. 1 through U.S. No. 4 grades. For rice lot A, a separation into two fractions at a rough rice kernel thickness of 1.73 mm would improve the grade of the bulk of the rice (thick fraction) from a U.S. No. 4 to a U.S. No. 3. Separation at this thickness would remove approximately 15% of the rice as thin kernels. The thin kernels could be blended with other rice lots that have low levels of chalkiness to yield blends that contain the maximum level of chalkiness allowed for a given grade. For rice lot B, removal of the thinner kernels at any reasonable separation thickness would decrease chalkiness but not change the grade rating of the bulk of the rice from the U.S. No. 3 level that it had initially.

The trend for the relationship between chalkiness and kernel thickness for the second heads was similar to that for the head rice. Chalkiness levels were considerably higher for second heads than for head rice, but the higher levels were not unexpected because chalky kernels are fragile and likely to break during milling. Relationships between chalkiness and separation thickness similar to those shown in Fig. 1 for the head rice were also developed for the second heads. Separation of lot A at a thickness of 1.73 mm would improve the grade of the second heads from U.S. sample to U.S. No. 4 while removing approximately 32% of the second heads as thin kernels. For rice lot B, separation at a thickness of 1.63 mm would improve the grade of the second heads from U.S. sample to U.S. No. 4 while removing approximately 13% of the second heads as thin kernels.

The percentage of damaged (discolored) kernels in the head rice and second heads from each of the thickness fractions is shown in Table VI. ANOVA indicated significant differences between lots and among thickness fractions. Unlike that for chalkiness, no trend toward higher percentages of damaged kernels with decreasing thickness was apparent; fractions of intermediate thickness had higher levels of damaged kernels. But these results might not reflect the actual situation. The percentage of damaged kernels that broke in each thickness fraction (based on the information contained in Tables V and VI and the assumption that every broken kernel yielded a second head) were, in order of decreasing thickness, 43, 44, 55, 60, 77, and 95%. The thinner fractions had much higher percentages of damaged kernels broken; possibly the damaged kernels in the thinner fractions were so fragile that they disintegrated into fragments smaller than second heads. Thus the reported values for damaged kernels in the milled rice from the thin fractions might not accurately reflect the quantities present in the rough rice.

The quantities of damaged kernels in the head rice fractions were all below the maximum allowable for U.S. No. 1 grade rice; therefore, separation by thickness had no effect on grade. Distribution by thickness of damaged kernels in the second heads was such that separation by thickness also had no effect on grade.

The Case for Processing Thin Kernels Separately

The thinner kernels (those with a thickness of less than 1.6 mm) accounted for approximately 5% of the Starbonnet rough rice. The milling results indicate that about 50% of the thinner kernels disintegrate during shelling and milling and are lost in the by-products (hulls and bran). Of the remaining thinner kernels, approximately 80% break during milling. Similar results were observed for several other varieties of long-grain rice (Matthews and Spadaro 1976). Most of the thinner kernels that don't break are chalky kernels that are considered quality defects in milled rice. Thus, the thinner kernels contribute relatively little to the economic value of the rice crop and detract from its quality.

The thinner kernels could be used to produce a unique new product. Previous research by Matthews et al (1981) indicated that thinner rice kernels have 20–30% more protein than the bulk of the rice. The protein content of the thinner kernels (11–13%) is comparable to that found in experimental rice varieties genetically bred for high protein (Juliano and Beachell 1975). One of the problems with the high protein varieties has been that the quality of the protein, as indicated by the profile of essential amino acids, is lower than that of conventional rice varieties (Roxas et al 1975). The quality of the protein in the thinner rice kernels was equivalent to that found in the bulk of the rice (Matthews et al 1981). Coffman and Juliano (1979) recently concluded that because of the inherent difficulties of breeding for increased protein content and the urgency of other problems (such as pest resistance and tolerance to various environmental stresses), attempts to increase the protein content cannot be justified as a research priority for rice. The thinner rice kernels are already being produced in substantial

TABLE VI
Distribution of Chalky and Damaged Kernels Among the Thickness Fractions and Milled Rice Products[a]

Screen No.	Chalky Kernels[b] (%)				Damaged Kernels[b] (%)			
	Head Rice		Second Heads		Head Rice		Second Heads	
	A	B	A	B	A	B	A	B
24	0.6 a	0.7 a	1.4 a	2.5 a	0.2 a	0.1 a	1.2 ab	0.6 a
23	0.8 a	0.8 a	3.7 a	2.5 a	0.1 a	0.1 a	1.1 ab	0.9 a
5	3.8 a	3.0 b	6.1 a	7.5 b	0.2 a	0.1 a	3.6 b	2.6 b
4	23.7 b	11.9 c	58.3 b	31.6 c	0.5 b	0.9 c	3.3 ab	4.0 c
22	45.4 c	29.6 d	73.9 c	76.7 d	0.4 b	0.6 b	0.8 a	1.4 a
Unders	45.0 c	36.6 e	87.1 d	81.5 e	0.0 a	0.4 ab	1.3 ab	1.2 a
Unfractionated	5.6	3.6	9.5	19.4	0.2	0.2	3.0	3.3
Recombined[c]	5.2	4.0	33.7	22.7	0.2	0.2	2.8	2.6

[a]Values within a column followed by the same letter are not significantly different at $P = 0.05$.
[b]Expressed as percentage of head rice or percentage of second heads, as appropriate.
[c]Calculated from a material balance on the thickness fractions.

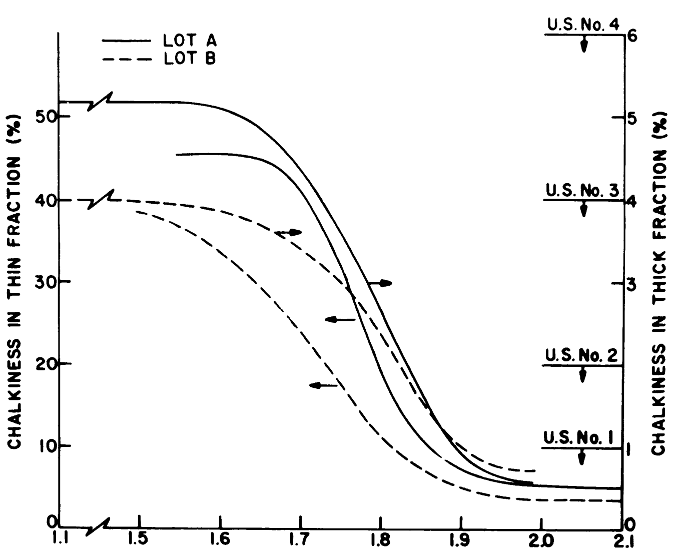

Fig. 1. Effects of fractionation thickness on the distribution of chalky kernels between thick- and thin-kernel fractions of two Starbonnet rice lots.

quantities worldwide (3–5% of the rice crop). No breeding programs or modifications of current agronomic practices are required to produce them. The protein of milled rice contributes 7.4% of its total calories, which meets the nutritional needs of most age groups. The exception is infants (less than 1 yr old), who need protein (with a chemical score of 70) that provides 9.8% of their total calories (Saunders and Betschart 1979). The percentage of calories provided by the protein of the thinner kernels ranges from 12.5 to 14.8%; the thinner kernels could therefore be mechanically isolated from the bulk of rice and processed separately into a brown rice flour for infant feeding.

Handling the thinner kernels separately could also reduce the energy required to dry the rice crop. In freshly harvested rice, the moisture content of the thinner kernels is 6–10 percentage points higher than that of the bulk of the rice.[3] In a typical example, rice harvested at 18% moisture (wb) with a thinner kernel (<1.6 mm) fraction that amounted to 5% of the rough rice (and that had a moisture content of 26%) would normally be dried to 14% moisture. But the thinner kernels could be separated from the bulk of the rice before drying, shelled wet, ground into a flour, and then rapidly dried with ambient air. The reduction in energy needed to dry the bulk of the rice would be approximately 15%.

What economic return could the rice processor expect for modifying his handling procedures to produce a brown rice flour from the thinner kernels? Because this particular type of brown rice flour would be a new product on the market, it does not have an established value. However, the data from Table V and the rice product values published in a recent USDA publication about rice (1980) can be used to estimate a break-even selling price for the new brown rice flour. The estimated break-even price, based on 1979 average prices for head rice ($22.15/cwt), second heads ($10.60/cwt), brewer's rice ($8.85/cwt), and bran ($68.95/ton) is $10.55/cwt. This estimate is calculated assuming that the mills currently recover the rice lost in the hulls and bran, but it does not take into consideration any premium value that might be gained as a result of the improved quality of the milled rice, nor does it consider the value of any energy savings that might accrue. Nevertheless, the price compares favorably with the selling price of New York brewer's corn grits ($10.10/cwt); the new brown rice flour should command a price premium as a food product because it has a higher protein content than corn and superior protein quality. For example, using the data of Hayes et al (1978) and the mathematical procedure of Wadsworth et al (1979a), a corn-soy-milk (CSM) blend was formulated to meet the USDA nutritional specifications (USDA 1977) and a rice-soy-milk blend was formulated for comparison, using brown rice flour prepared from thin rice kernels (Matthews et al 1981) and the same mathematical procedure as that for the CSM blend. The CSM blend contained 55% cornmeal and 21% defatted soy flour and had a protein chemical score of 87 with the sulfur-containing amino acids limiting. The rice blend contained 62% brown rice flour and 16% soy and had a chemical score of 94 with the same limiting amino acids. Based on a cornmeal value of $12.35/cwt and a soy flour value of $27.00/cwt, the equivalent value for the brown rice in this application was $13.13/cwt, a value that does not take into consideration any premium value from the rice blend's higher chemical score. In any case, because chemical score is only an indication of protein quality, studies of protein efficiency ratio, net protein ratio, net protein utilization, nitrogen digestibility, storage stability, and acceptability would have to be made before food blends could be produced using brown rice flour from thin kernels.

[3]J. I. Wadsworth. 1981. Unpublished data.

CONCLUSION

Significant differences in the milling performance and quality characteristics of Starbonnet rice are related to the thickness of the rough rice kernels. Development of innovative procedures for handling the thinner rice kernels (<1.6 mm) offers the potential for producing a new high-protein food-grade rice raw material with excellent protein quality and simultaneously reducing processing losses, improving the quality of the milled rice products, reducing the amount of energy required to dry rice, and increasing the market value of the rice crop.

LITERATURE CITED

COFFMAN, W. R., and JULIANO, B. L. 1979. Seed protein improvement in rice. Page 261 in: Seed Protein Improvement in Cereals and Grain Legumes. Vol. II. IAEA-SM-230/82. Int. Atomic Energy Agency: Vienna.

HAYES, R. E., WADSWORTH, J. I., and SPADARO, J. J. 1978. Corn- and wheat-based blended food formulations with cottonseed or peanut flour. Cereal Foods World 23(9):548–553, 556.

JULIANO, B. O., and BEACHELL, H. M. 1975. Status of rice-protein improvement. Page 457 in: High Quality Protein Maize. Dowden, Hutchinson and Ross, Inc.: Stroudsburg, PA.

KUNZE, O. R. 1977. Moisture adsorption influences on rice. J. Food Process Eng. 1:167–181.

MATTHEWS, J., and SPADARO, J. J. 1976. Breakage of long-grain rice in relation to kernel thickness. Cereal Chem. 53(1):13–19.

MATTHEWS, J., WADSWORTH, J. I., and SPADARO, J. J. 1981. Chemical composition of Starbonnet variety rice fractionated by rough-rice kernel thickness. Cereal Chem. 58:331–334.

POMINSKI, J., WASSERMAN, T., SCHULTZ, E. F., Jr., and SPADARO, J. J. 1961. Increasing laboratory head and total yields of rough rice by milling at low moisture levels. Effects of Bluebonnet 50—A long grain variety. Rice J. 64(10):11–15.

ROXAS, B. V., INTENGAN, C. L., and JULIANO, B. O. 1975. Effect of protein content of milled rice on nitrogen retention of Filipino children fed a rice-fish diet. Nutr. Rep. Int. 11:393–398.

SAUNDERS, R. M., and BETSCHART, A. A. 1979. Rice and rice foods: Chemistry and nutrition. Trop. Foods 1:191–216.

SPADARO, J. J., MATTHEWS, J., and WADSWORTH, J. I. 1980. Milling. Pages 360–420 in: Luh, B. S., ed. Rice: Production and Utilization. AVI: Westport, CT.

USDA. 1974. Inspection Handbook for the Sampling, Inspection, Grading and Certification of Rice. HB 918-11. U.S. Dept. Agric., Agricultural Marketing Service, Grain Division: Washington, DC. 144 pp.

USDA. 1977. Corn/Soya/Milk Announcement CSM-7 with Updating Through Amendment 9. U.S. Dept. Agric., Agricultural Stabilization and Conservation Service: Shawnee Mission, KS.

USDA. 1980. Rice Situation. RS-36. U.S. Dept. Agric., Economics, Statistics, and Cooperative Service: Washington, DC. 20 pp.

WADSWORTH, J. I., HAYES, R. E., and SPADARO, J. J. 1979a. Optimum protein quality food blends. Cereal Foods World 24(7):274–277, 279, 280, 286.

WADSWORTH, J. I., MATTHEWS, J., AND SPADARO, J. J. 1979b. Physical and physicochemical properties of Starbonnet variety rice fractionated by rough rice kernel thickness. Cereal Chem. 56:499–505.

WEBB, B. D., and CALDERWOOD, D. L. 1977. Relationship of moisture content to degree of milling in rice. Cereal Foods World 22:484.

[Received June 12, 1981. Accepted September 1, 1981]