Physical and Physicochemical Properties of Starbonnet Variety Rice Fractionated by Rough Rice Kernel Thickness[1]

J. I. WADSWORTH, J. MATTHEWS, and J. J. SPADARO, Southern Regional Research Center,[2] P.O. Box 19687, New Orleans, LA 70179

ABSTRACT

Cereal Chem. 56(6):499-505

Two lots of Starbonnet variety long-grain rice were used to study the variation of kernel properties with kernel thickness. The rough rice was separated by thickness into six fractions. Portions of each fraction were shelled and milled under identical conditions. For each fraction of rough and brown rice, the mean kernel thickness, length, width, moisture content, weight, volume, density, and porosity were determined. For the milled rice fractions, densities, water uptake values, and alkali spreading values were determined. Flours prepared from the milled rice fractions were used to measure peak and setback viscosities and gelatinization temperatures. The densities of the hulls from the various fractions were also determined. Mathematical relationships between the various properties were developed.

Considerable information has been published on the variations in the physical, chemical, and physicochemical properties of a rice kernel while it matures in the field (International Rice Commission 1967, Juliano 1972, Kester et al 1963).[3] As the caryopsis develops, it attains its maximum length and width before it attains its maximum thickness (Del Rosario et al 1968). In current rice cultivars, the thickness of individual kernels at harvest varies widely. The effect of variation of kernel thickness in harvested rice is a little-studied aspect of rice research, although it has implications for many phases of rice investigation, including cultural practices, breeding, drying, processing, quality, and composition. Matthews and Spadaro's research on rice milling (1976) involved the range of thickness of individual kernels in harvested rice; that research showed significant differences in milling quality related to thickness.

This study investigated the relationships between the thickness of the rice kernel and the kernel length, width, moisture, weight, volume, density, porosity, water uptake value, alkali spreading value, gelatinization temperature, and Brabender amylograph curve. Mathematical relationships between the various properties were developed. The information derived gives a much more detailed characterization of the rice kernel than has hitherto been available.

MATERIALS AND METHODS

Rice

Two lots of Starbonnet variety long-grain rice, grown in southwestern Louisiana in 1975 and 1977, were used to study the variation of physical and physicochemical properties with kernel thickness. Both rice lots were dried by commercial drying facilities and handled with identical cleaning, fractionating, shelling, and milling procedures.

Cleaning

Rough rice was cleaned with a Carter Dockage Tester with an air flow setting of 9 to remove low density material such as sterile florets and with a No. 28 sieve in the top position and a No. 25 sieve in the middle position to remove straw and large weed seeds. A second pass was made with the No. 000 riddle to remove small weed seeds and broken brown rice.

Fractionating

The cleaned rough rice was then separated by kernel thickness into six fractions with the Dockage Tester and five slotted screens. The thickest kernels were removed first on a Carter No. 24 screen, which has a slot width of 1.98 mm. Then subsequent fractions were separated by screens with progressively smaller slots (1.93, 1.78, 1.63, and 1.55 mm). The screens were in the top sieve position of the Dockage Tester (which has vertical motion) rather than in the middle or bottom sieve positions (which have horizontal motion), because the rough rice had less tendency to stick in the slots of the screens. The rice was passed over each screen three times to assure complete separation.

Shelling

A portion of each thickness fraction of rough rice was shelled in a McGill sheller according to directions in the USDA Inspection Handbook (1974). Clearance between the rollers was standard for long-grain rice (0.019 in.) for all samples.

Milling

A portion of brown rice from each rough rice thickness fraction was milled in a No. 2 McGill mill. For each sample, 140 g of brown rice was milled for 60 sec with the weight and weight holder set 5.25 in. from the end of the lever arm. These conditions produced a well-milled rice for all fractions.

Length, Width, and Thickness

Lengths and widths of the rough and brown rice kernels for each fraction were determined by the method described by Wratten et al (1969). A platform type dial-micrometer was used to measure the thickness of each of 100 kernels randomly selected from each rough and brown rice fraction. Frequency distribution curves for kernel thickness were determined with approximately 1,000 kernels randomly selected from the unfractionated rice.

Weight, Volume, and Density

The mean kernel weight for each thickness fraction was determined by weighing 500 randomly selected kernels. The volume of the same 500 kernels was measured with a Beckman air comparison pycnometer. Densities were calculated. Three replicates were run for each of the rough, brown, and milled rice fractions. Densities of the hulls from each fraction were also determined with the pycnometer.

To determine in greater detail the relationship between thickness and weight, 100 rough rice kernels were arbitrarily selected so that their thicknesses uniformly spanned the range of thickness for the unfractionated rice. The thickness of each rough rice kernel was individually measured by micrometer and the kernel weighed. The

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[1] Presented in part at the 17th Rice Technical Working Group Meeting, College Station, TX February 14–16, 1978.

[2] One of the facilities of the Southern Region, Science and Education Administration, U.S. Department of Agriculture.

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.

[3] Also reported by N.N. Chau and O.R. Kunze. Moisture contents of the driest and wettest rice grains in a field during the harvesting season. Presented at the Seventeenth Rice Technical Working Group Meeting, Texas A & M University, College Station, TX, February 14–16, 1978.

kernel was then hand shelled and its caryopsis similarly measured and weighed. Individual kernel volumes were not measured because the pycnometer cannot precisely determine the volume of a single kernel.

Moisture

The moisture content for each rough rice thickness fraction was determined by AOAC Methods 13.058 and 13.004.

Physicochemical Properties

Water uptake values and alkali spreading values for milled rice from each fraction were determined by standard methods (Simpson et al 1965). Brabender amylographs were run with a 1,000 cm-g cartridge. The procedure used to measure the peak and setback viscosities of each sample was described by Halick and Kelly (1959). The values reported as "setback" are viscosities after cooling to 50° C and not the difference from the peak viscosity after cooling. Gelatinization temperatures were estimated from the amylograph curves and the birefringence end point temperature.

Data Analysis

Two-way analysis of variance and Newman-Keul's multiple range test (Chew 1976) were applied to determine the significance of differences among the thickness fractions and between the rice lots for the various rice properties. Empirical relationships based on linear regression models were calculated by standard techniques. Nonlinear least squares models were developed with the Nelder and Mead flexible simplex approach (1964) to evaluate the coefficients in the equations.

RESULTS AND DISCUSSION

The rice lots grown in 1975 and 1977 are referred to as A and B, respectively. The frequency distribution of kernel thickness for lot A of Starbonnet rough rice is shown in Fig. 1. The curve is very skewed toward lower thicknesses and practically devoid of a tail toward greater thicknesses. The general shape resembles a Pearson's Type III distribution (Fry 1928). Fitting a Pearson Type III formula to the experimental data by nonlinear least squares procedure yields the equation

$$f = (1.95 \times 10^{-6})\,(1.91 - T_r)^{0.69}\,[\exp(12.1T_r)] \quad r^2 = 0.892$$

where f = frequency (%), T_r= rough rice thickness (mm), and r^2= fraction of total sum of squares explained by regression. The distribution of brown rice thickness is very similar in shape to the rough rice distribution but with the peak thickness shifted approximately 0.23 mm. Cumulative frequency distributions for the rough and brown rice thickness (Fig. 2) are essentially parallel. The difference between the two curves is approximately 0.20 mm for the thicker kernels and 0.25 mm for the thinner ones.

The frequency distribution curves of rice lots B and A were very similar. The main differences were that the peak thickness of B was 0.03 mm less than that of A and that no kernels thinner than 1.1 mm were found in lot B.

The relationship between thickness of rough rice and of brown rice for 100 hand-shelled kernels from lot A is shown in Fig. 3. The linear regression equation that describes the relationship over the range of the data is

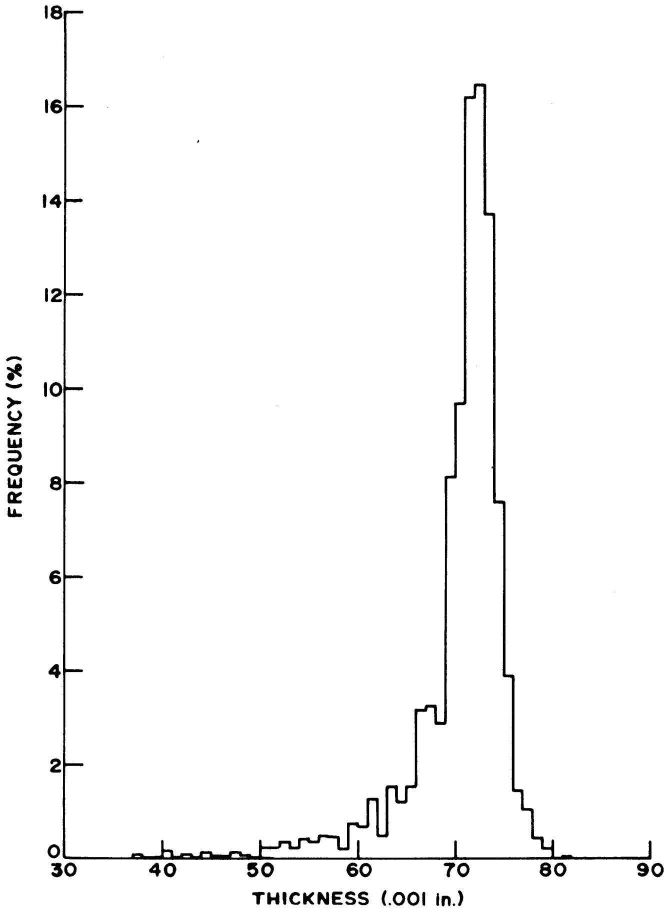

Fig. 1. Frequency distribution for rough rice kernel thickness in a harvested lot of Starbonnet variety long-grain rice.

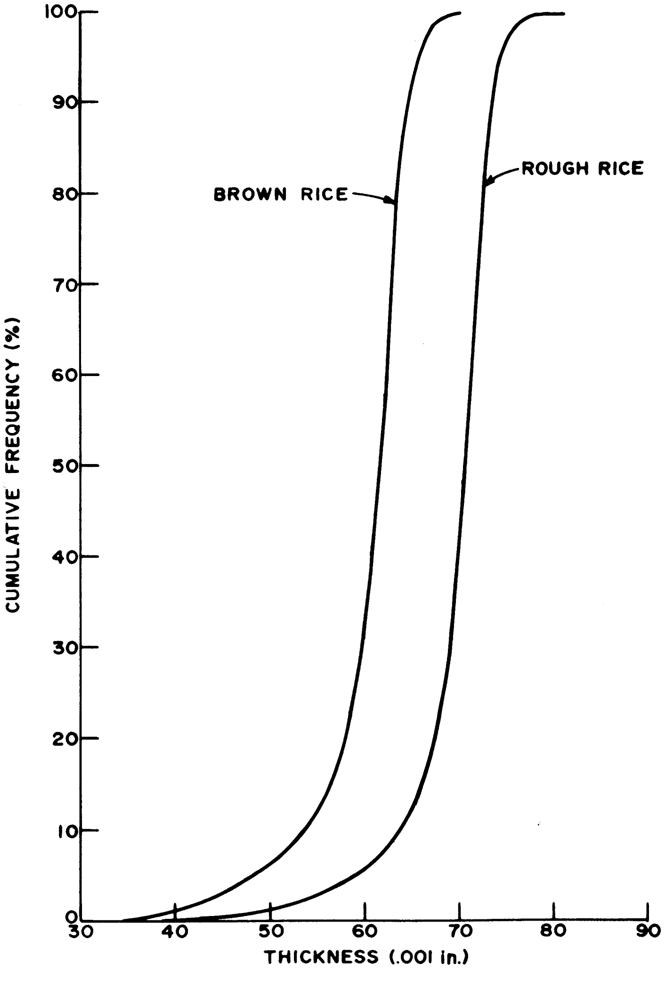

Fig. 2. Cumulative frequency distribution curves for rough rice and brown rice kernel thicknesses in a Starbonnet variety long-grain rice.

$$T_b = 1.16\ T_r - 0.50 \quad r^2 = 0.980$$

where T_b = brown rice thickness (mm). The regression is highly significant ($P < 0.001$). However, the data may be starting to deviate from linearity with the thinnest kernels. The comparable regression equation for lot B is

$$T_b = 1.13\ T_r - 0.45 \quad r^2 = 0.981$$

The two lots of rough rice were each separated by thickness into six fractions with the Carter Dockage Tester and the five slotted screens. For any given screen, separation efficiency for one pass through the Dockage Tester was 90% and for two passes, 99%. Table I shows for each fraction the percentages of rough rice retained, the mean kernel thicknesses, and the ranges of kernel thickness. Two-way analysis of variance indicated significant differences among the thickness fractions but not between the rice lots. Rough rice kernels compressed slightly under the constant force applied by the sensing arm of the platform-type micrometer used to measure thickness. Thus the measured thickness of the thinnest kernels retained on a screen was approximately 0.1 mm less than the slot size of that screen. For both lots of rice, the percentages of rough rice retained in each fraction fell within the ranges reported by Matthews and Spadaro (1976) for other lots of long-grain rice fractionated by thickness with similarly sized screens.

Physical and physicochemical property data are presented for both rice lots A and B. The general trends for changes in properties with thickness are very similar for both lots. Therefore the discussion that follows is based mainly on the variation in the properties of A with thickness, and only the differences between A and B are pointed out.

The unfractionated rice was dried by a commercial drying facility before it was shipped. The moisture contents of rice lots A and B as received at the laboratory were 12.5 and 11.4% (wb), respectively. Differences were not significant among the moisture contents of the various thickness fractions, indicating that the moisture equilibrium does not vary with the thickness of the kernel. One question, not answered, is whether or not moisture contents differed among the fractions before drying.

Table II shows mean physical dimensions for the rough rice kernels in each thickness fraction and for brown rice kernels derived from each thickness fraction of rough rice. Physical dimensions of milled rice kernels were not obtained because these depend on the degree of milling and are not inherent properties of the grain.

For both rough and brown rice, mean thicknesses of the various fractions are all significantly different. The thinner rough and brown rice kernels have significantly shorter lengths than the thicker rough and brown rice kernels, respectively. The linear equations for the regression of mean length on mean thickness for both rough and brown rice from lot A are

$$L_r = 1.50\ T_r + 6.40 \quad r^2 = 0.817$$
$$L_b = 2.05\ T_b + 4.06 \quad r^2 = 0.978$$

where L = length (mm). The linear regressions of rough rice length and brown rice length on thickness are both significant ($P < 0.05$ and $P < 0.01$, respectively). Analysis of the residuals from the regression of rough rice length on thickness indicates a possibility of curvature in the relationship.

For rough rice lot A, the mean widths of the various fractions did not differ significantly. Although the precision of the data was such that the regression of width on thickness was not significant, the trend in the data is toward smaller widths for thinner kernels. For lot B the thinner rough rice kernels had significantly smaller widths.

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

Screen No.	Screen Size (mm)	Percentage Retained A (%)	Percentage Retained B (%)	Mean Thickness A (mm)	Mean Thickness B (mm)	Range of Thickness A (mm)	Range of Thickness B (mm)
24	1.98	4.0	1.8	1.94	1.92	1.88–2.06	1.88–2.01
23	1.93	13.7	10.0	1.88	1.86	1.83–1.93	1.80–1.93
5	1.78	64.8	69.7	1.80	1.79	1.68–1.88	1.70–1.85
4	1.63	12.1	14.1	1.65	1.65	1.50–1.75	1.52–1.70
22	1.55	2.3	2.4	1.48	1.47	1.32–1.57	1.35–1.57
Unders	···	3.1	1.7	1.28	1.31	0.94–1.45	1.09–1.47

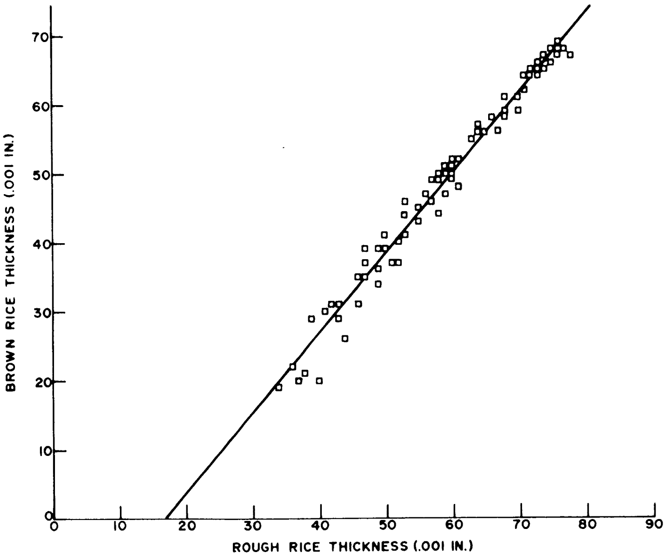

Fig. 3. Relationship between the thickness of a brown rice kernel and that of the rough rice kernel from which it was obtained.

TABLE II
Physical Dimensions of Rough and Brown Rice from Rough Rice Thickness Fractions[a]

Screen No.	Rough Rice Kernels: Mean Thickness A (mm)	Rough Mean Thickness B (mm)	Rough Mean Length A (mm)	Rough Mean Length B (mm)	Rough Mean Width A (mm)	Rough Mean Width B (mm)	Brown Rice Kernels: Mean Thickness A (mm)	Brown Mean Thickness B (mm)	Brown Mean Length A (mm)	Brown Mean Length B (mm)	Brown Mean Width A (mm)	Brown Mean Width B (mm)
24	1.94 a	1.92 a	9.55 a	9.35 a	2.62 a	2.58 a	1.71 a	1.70 a	7.52 a	7.49 a	2.26 a	2.23 a
23	1.88 b	1.86 b	9.30 b	9.04 b	2.64 a	2.51 a	1.65 b	1.66 b	7.57 a	7.21 b	2.24 ab	2.12 b
5	1.80 c	1.79 c	8.94 c	8.79 c	2.54 a	2.41 b	1.57 c	1.57 c	7.26 a	6.81 c	2.20 ab	2.07 b
4	1.65 d	1.65 d	8.69 d	8.33 d	2.54 a	2.37 bc	1.41 d	1.42 d	6.91 b	6.53 d	2.13 b	1.97 c
22	1.48 e	1.47 e	8.56 d	8.33 d	2.46 a	2.33 c	1.24 e	1.25 e	6.53 c	6.27 e	1.93 c	1.84 d
Unders	1.28 f	1.31 f	8.51 d	8.28 d	2.50 a	2.36 bc	1.09 f	1.12 f	6.38 c	6.07 f	1.78 d	1.70 e

[a] The same letter within a column indicates no significant difference between means at $P = 0.05$ (Newman-Keul's multiple range test).

The thinner kernels have significantly smaller widths for brown rice of both rice lots. The linear regression equation (significant at $P < 0.01$) that describes the data for lot A is

$$W_b = 0.792\ T_b + 0.94 \quad r^2 = 0.951$$

where W = width (mm).

Two-way analyses of variance indicate that both the rough and brown rice kernels in lot B have significantly ($P < 0.05$) smaller lengths and widths than do the kernels in A.

Table III shows mean kernel weights and volumes for rough and brown rice from the various thickness fractions. Analysis of residuals from linear regressions of kernel weight and kernel volume on thickness for both rough and brown rice indicates that the relationships are nonlinear. The relationship between kernel weight and kernel thickness for 100 rough rice kernels is shown in Fig. 4. The relationship for 100 brown rice kernels is shown in Fig. 5. In these graphs, the curvature in the relationships becomes obvious. Nonlinear least squares regression was used to fit hyperbolic functions with three coefficients to the weight-thickness data. The derived equations for rough and brown rice for lot A are

$$M_r = 79.8\ [(0.165 + 0.0655\ T_r{}^{3.16})^{.317} - 0.562] \quad r^2 = 0.978$$
$$M_b = 41.3\ [(0.656 + 0.362\ T_b{}^{2.48})^{.404} - 0.843] \quad r^2 = 0.962$$

where M = weight (mg).

The nonlinear relationship between kernel volume and thickness is not unexpected because high correlations between thickness and length and between thickness and width were previously shown. Figure 6 shows the relationship between kernel volume and the product of kernel length, width, and thickness for both rough and brown rice. In this figure, a dashed line represents the volume of an elipsoid as a function of the product of its three axes. The equation for the elipsoid and the linear regression equations for volume on the product of length, width, and thickness for lot A are

$$V_{\text{elipsoid}} = 0.524\ (L)\ (W)\ (T)$$
$$V_r = 0.530\ (L_r)\ (W_r)\ (T_r) - 0.00668 \quad r^2 = 0.999$$
$$V_b = 0.526\ (L_b)\ (W_b)\ (T_b) - 0.00094 \quad r^2 = 0.996$$

where V = volume (cc). The volume of a brown rice kernel is very closely approximated by an elipsoid. The volume of a rough rice kernel deviates considerably from an elipsoid with equivalent length, width, and thickness.

Two-way analyses of variance indicate that the rough and brown rice kernels in lot B have significantly ($P < 0.05$) smaller weights and volumes than do the kernels in A.

Webb and Stermer (1972) indicate that density might be a better criteria of rice quality than are some of the measurements currently used. Densities of rough, brown, and milled rice, as well as rice hulls from the various thickness fractions, are shown in Table IV.

The differences in rough rice densities among the various fractions are significant. This is not surprising because the density of the caryopsis is greater than the density of the hull, and the ratio of caryopsis weight to hull weight (calculated from the relationships between kernel weight and thickness) is changing.

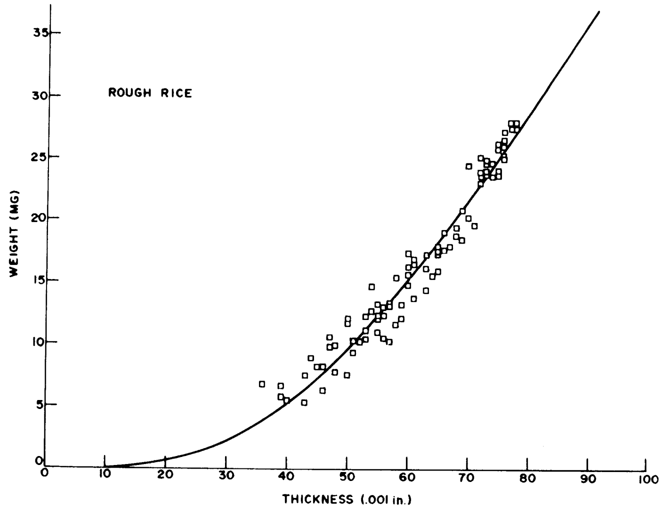

Fig. 4. Relationship between the weight and thickness of rough rice kernels.

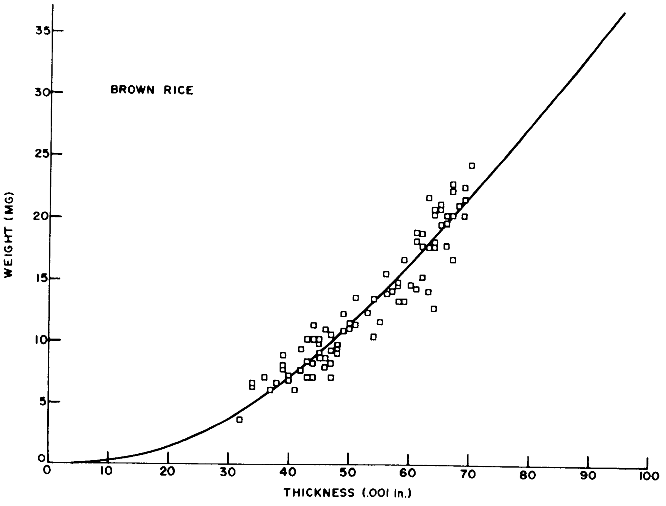

Fig. 5. Relationship between the weight and thickness of brown rice kernels.

TABLE III
Weight and Volume of Rough and Brown Rice Kernels from Rough Rice Thickness Fractions[a]

Screen No.	Rough Rice Kernels				Brown Rice Kernels			
	Mean Weight		Mean Volume		Mean Weight		Mean Volume	
	A (mg)	B (mg)	A (cc)	B (cc)	A (mg)	B (mg)	A (cc)	B (cc)
24	26.1	25.3	0.0186	0.0180	21.0	20.5	0.0145	0.0143
23	24.6	24.0	0.0176	0.0170	20.0	19.5	0.0139	0.0133
5	22.1	21.4	0.0159	0.0152	17.8	17.2	0.0124	0.0118
4	17.1	17.0	0.0126	0.0123	13.7	13.6	0.0096	0.0094
22	13.2	13.5	0.0100	0.0099	10.5	10.4	0.0074	0.0072
Unders	9.8	10.6	0.0076	0.0079	8.0	8.1	0.0057	0.0056

[a] All means within a column are significantly different at $P = 0.05$ (Newman-Keul's multiple range test).

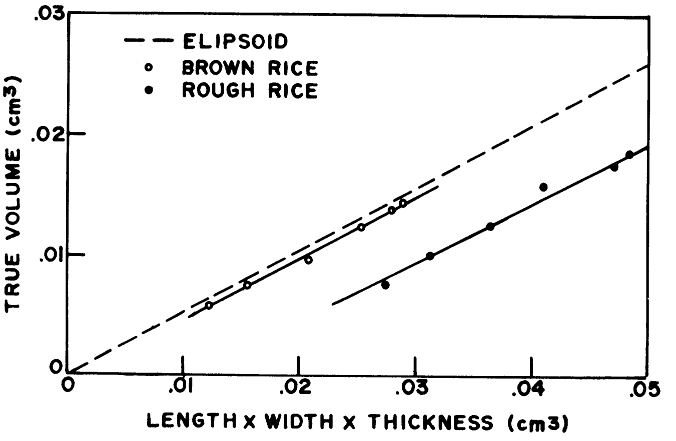

Fig. 6. Relationships between kernel volume and the product of length × width × thickness for rough and brown rice kernels. The broken line is the relationship for the volume of an elipsoid with the product of its three axes.

The measured rough rice densities were compared with the densities calculated from the relative quantities of hull and caryopsis. The measured densities were all lower, indicating that the rough rice kernel must contain internal voids from which air is not readily transferred. If air were free to move into or out of these voids, then the air comparison pycnometer would not have recorded them. The mean porosities (volume of voids/volume of mass) for the rough rice kernels from the various thickness fractions in order of decreasing thickness are 0.014, 0.014, 0.019, 0.036, 0.054, and 0.078 in lot A and 0.005, 0.001, 0.004, 0.029, 0.018, and 0.043 in lot B.

For brown rice and milled rice, kernels in the thinner fractions are significantly less dense than those in the thicker fractions. This result was not anticipated. Whether these differences in density are due to differences in composition or to some other factor such as chalkiness is not yet clear. Wratten et al (1969) reported on the effect of moisture content on density. However, because no significant differences exist among the moisture contents of the various fractions, they could not contribute to the density differences. The density of chalky kernels was slightly less than the density of nonchalky kernels of the same thickness. Because the amount of chalkiness is considerably higher in the thinner fractions, it is probably a factor in the differences in density for both brown and milled rice. Variation in bran/endosperm ratio in the brown rice fractions probably contributes to the variation in brown rice density. However, neither chalkiness nor the bran/endosperm ratio have been sufficiently quantified to determine their effects on density conclusively.

The linear regression equations for density on thickness for lot A are

$$D_r = 0.1796\ T_r + 1.062 \qquad r^2 = 0.994$$
$$D_b = 0.0679\ T_b + 1.329 \qquad r^2 = 0.996$$
$$D_m = 0.0349\ T_b + 1.403 \qquad r^2 = 0.937$$

where D = density (g/cc) and D_m = milled rice density (g/cc). The regressions are significant at $P < 0.01$.

Densities of rice hulls from the six thickness fractions did not differ significantly. The mean density of hulls was 1.339 g/cc. This value is approximately double the 0.735 g/cc reported (Fieger et al 1947, Houston 1972). Other tests showed that rice hulls settled in water as adhering air bubbles were expelled; therefore the value of 1.339 g/cc is probably closer to their true density.

The three-way analysis of variance (ANOVA) of the density data is shown in Table V. The three-way ANOVA indicates significant differences in density among the thickness fractions, among the kernel types, and between the rice lots. Two-way ANOVA's indicate significant differences between the rice lots for rough and brown rice densities but not for milled rice density.

The physicochemical properties of milled rice derived from the various thickness fractions and from the unfractionated lots are shown in Table VI. The properties, which are generally recognized as tests of cooking quality, include Brabender amylograph peak and setback viscosities, gelatinization temperature, alkali spreading value, and water uptake value. Peak viscosity decreased with decreasing thickness. Peak viscosities were considerably lower in the three thinnest fractions than in the three thicker fractions. This might be due to differences in starch content rather than to differences in the starch itself. The unfractionated rice from lot A had a Brabender peak viscosity of 545 Brabender units (BU). The value for unfractionated rice calculated from the values for the six fractions is 538 BU, indicating that the effects of the various fractions are additive. The Brabender setback viscosities are quite interesting. The three thicker fractions have small differences between peak and setback viscosities (−2 to 65 BU). For each of the three thinner fractions, however, the setback viscosities are significantly higher (104–176 BU) than the peak viscosities. Setback viscosity for the unfractionated rice calculated from the values for the six fractions is not significantly different from the

TABLE IV
Densities of Rough, Brown, and Milled Rice Kernels and Rice Hulls from Rough Rice Thickness Fractions[a]

Screen No.	Density: Rough Rice A (g/cc)	Rough Rice B (g/cc)	Brown Rice A (g/cc)	Brown Rice B (g/cc)	Milled Rice A (g/cc)	Milled Rice B (g/cc)	Rice Hulls A (g/cc)	Rice Hulls B (g/cc)
24	1.404 a	1.409 a	1.445 a	1.432 a	1.460 a	1.461 a	1.35 a	1.33 a
23	1.401 a	1.412 a	1.440 ab	1.433 a	1.461 a	1.463 a	1.35 a	1.35 a
5	1.390 b	1.410 a	1.437 b	1.434 a	1.460 a	1.460 a	1.34 a	1.34 a
4	1.359 c	1.388 b	1.426 c	1.424 b	1.452 ab	1.452 b	1.32 a	1.33 a
22	1.325 d	1.366 c	1.411 d	1.404 c	1.443 b	1.447 bc	1.33 a	1.33 a
Unders	1.291 e	1.348 d	1.404 e	1.391 d	1.442 b	1.442 c	1.34 a	1.35 a

[a] The same letter within a column indicates no significant difference between means at $P = 0.05$ (Newman-Keul's multiple range test).

TABLE V
Summary of Analysis of Variance of Density Data

Source	Degrees of Freedom	Sums of Squares	Mean Squares	F-Value
A[a]	1	0.130×10^{-2}	0.130×10^{-2}	220**[b]
B[c]	2	0.113	0.565×10^{-1}	9535**
C[d]	5	0.384×10^{-1}	0.768×10^{-2}	1297**
AB	2	0.572×10^{-2}	0.286×10^{-2}	483**
AC	5	0.101×10^{-2}	0.201×10^{-3}	34**
BC	10	0.286×10^{-1}	0.286×10^{-2}	205**
ABC	10	0.197×10^{-2}	0.197×10^{-2}	33**
Error	72	0.427×10^{-3}	0.593×10^{-5}	
Total	107	0.173		

[a] A = Rice lots.
[b] ** = Significant at $P = 0.01$.
[c] B = Type of rice (rough, brown, or milled).
[d] C = Kernel thickness.

TABLE VI
Physicochemical Properties of Milled Rice from Rough Rice Thickness Fractions and Unfractionated Rice[a]

Screen No.	Vicosity (BU)[b] Peak A	Peak B	Setback A	Setback B	Gelatinization Temperature (°C) A	B	Alkali Spreading Value A	B	Water Uptake Value (ml/100 g) A	B
24	563 a	567 a	583 a	619 a	74–76	75–78	3.8 a	4.1 a	45 a	63 a
23	575 a	545 a	573 a	610 ab	74–76	76–78	3.5 ab	4.2 a	45 a	60 a
5	550 a	544 a	575 a	596 b	74–76	75–78	3.3 b	3.8 ab	43 a	60 a
4	438 b	451 b	545 b	555 c	74–76	75–78	3.3 b	3.5 ab	75 b	85 b
22	400 c	399 c	510 c	519 d	74–76	76–78	3.0 bc	3.6 b	120 c	170 c
Unders	383 c	249 d	495 c	525 d	74–76	75–78	2.9 c	3.0 c	147 d	198 d
Unfractionated	545	536	575	585	74–76	75–78	3.3	3.8	48	65

[a] The same letter within a column indicates no significant difference between means at $P = 0.05$ (Newman-Keul's multiple range test).
[b] Brabender units, measured with a 1,000 cm-g cartridge.

measured value. This also indicates that the effects of the six fractions on viscosity are additive.

No significant differences were found in the gelatinization temperatures of the starch from the six thickness fractions by either Brabender Viscograph data or by birefringence end point temperature. The gelatinization temperatures of 74–76° C for lot A and 75–78° C for lot B are typical of a long-grain variety and are at the high end of what is classified as an intermediate gelatinization temperature range (Webb and Stermer 1972).

Alkali spreading values for the various thickness fractions decreased with decreasing thickness. The linear regressions of alkali spreading on thickness are highly significant (r^2 values are 0.857 and 0.859 for A and B, respectively). The alkali spreading values, which range from 2.9 to 4.2, are typical of a long-grain rice with intermediate gelatinization temperature (Webb and Stermer 1972). Highly significant negative correlations between alkali spreading values and gelatinization temperatures for different rice varieties and grain types have been reported (Simpson et al 1965). Because the observed gelatinization temperatures for the various fractions were not significantly different, however, no correlations between alkali spreading and gelatinization temperature exist for these data.

Mean water uptake values for the three thicker fractions are not significantly different, but water uptake values increased significantly for the thinner fractions. The water uptake value for the unfractionated rice A, calculated from the values for the various fractions, was 52 ml/100 g. The observed value for unfractionated rice A was 48 ml/100 g, which is not significantly different from the calculated value, indicating that water uptake behavior of a kernel is independent of the behavior of other kernels in its environment.

Highly significant *positive* correlations between water uptake values and alkali spreading values for various rice varieties and grain types have been reported (Simpson et al 1965). For the data in Table VI, the correlations between water uptake and alkali spreading are significant *negative* correlations. Thus the relationship among the kernel thickness fractions within this variety is the reverse of the relationship among varieties. Water uptake value is a measure of the rate and degree of hydration of the kernel. Alkali spreading is considered to be related to the textural characteristics or structural integrity of the kernel. A kernel that absorbs water more rapidly could reasonably be expected to disintegrate more rapidly in an alkali solution. The results apparently contradict this expectation.

Additional information is gained by analyzing water uptake values on a "per kernel" basis rather than a "per 100 g" basis. The water uptake value for the thinnest fraction was approximately 3.2 times greater than the value for the thickest fraction. Based on mean kernel weights for the two fractions, 100 g of the thinnest fraction contains approximately 2.8 times as many rice kernels as 100 g of the thickest fraction. The amounts of water absorbed per kernel for the various fractions in order of decreasing thickness were 8.5, 8.1, 6.9, 9.8, 11.2, and 9.9 μl for lot A and 11.8, 10.6, 9.4, 10.4, 15.4, and 14.3 μl for lot B. The measured amount of water absorbed per kernel is still greater for the thinner kernels, but the differences are not significant. The smaller kernels have less mass and less surface area; the rate and quantity of water absorbed by kernels from the various thickness fractions must therefore be due to structural or compositional differences in the endosperm. Chalkiness could be a factor. Further study of the thickness fractions is needed to fully explain these observations.

Two-way analyses of variance indicate that rice lot B has significantly higher setback viscosities, alkali spreading values, and water uptake values than does lot A.

Maturity and Thickness

One question to be answered is whether or not thinner kernels are simply immature kernels that would eventually mature fully if allowed to grow for additional time. Del Rosario et al (1968) reported that the rice caryopsis attains its full length approximately four days after flowering, its maximum width 14 days after flowering, and its maximum thickness 21 days after flowering. If thickness were a function of kernel maturity only, then no significant correlations between thickness and length or width should be seen. However, we have shown highly significant correlations of brown rice thickness with length and width (correlation coefficients of 0.989 and 0.975, respectively). Ebata and Nagato (1967) and Del Rosario et al (1968) reported on the change in weight of rice kernels while they were maturing in the field. Their data, taking moisture changes into consideration, produced a curve for kernel weight vs days after flowering (maturity) that showed a negative second derivative. The hyperbolic functions that describe the weight-thickness relationship for the data we report have positive second derivatives.

Briones et al (1968) reported that the gelatinization temperature of the rice starch decreases as the grain matures, and Kester et al (1963) concluded that stage of maturity has no influence on gelatinization temperature. The results of our study indicate no change in gelatinization temperature with kernel thickness.

Kester et al (1963) reported that peak viscosity and water uptake value both decrease as the rice matures to its optimum harvest condition. For this study, the trend in water uptake value with increasing kernel thickness is similar to that of a maturing kernel; however, the magnitudes of the changes are considerably different. The trend in the changes in peak viscosity with increasing kernel thickness is opposite that of a maturing kernel. Briones et al (1968) and Kester et al (1963) reported that the amylose content of rice starch increased as the kernel matured. Halick and Kelly (1959) reported that high amylose starches would show maximal increases in setback viscosities. In this study, the thicker kernels show small changes between peak and setback viscosities, whereas the thinner kernels show large increases in setback viscosity over peak viscosity (indicative of higher amylose in the thinner kernels). The differences in peak and setback viscosities might also be due to differences in starch concentration (Bhattacharya and Sowbhagya 1978).

CONCLUSIONS

No strong similarities appear to exist between the changes in the physical and physicochemical properties of rice kernels as they mature and in those of kernels of increasing thickness from harvested Starbonnet variety rice. Also the significant correlations between thickness and length and the differences in shape of the weight-thickness curve compared with the weight-maturity curves indicate that the spread in thickness of harvested rive is not related solely to a range in maturity of the kernels. This indicates the need for additional basic research to explain the differences in properties of rice kernels of differing thickness.

ACKNOWLEDGMENT

We wish to express appreciation to John D. Tallant for assistance with the statistical analyses.

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[Received October 24, 1978. Accepted May 11, 1979]