Bulk Density of Long- and Medium-Grain Rice Varieties as Affected by Harvest and Conditioned Moisture Contents[1]

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ABSTRACT

The effect of harvest and conditioned moisture contents (MC) on bulk density (BD) of rough, brown, and white rice was determined for several long- and medium-grain rice varieties harvested from different Arkansas locations. The results indicated that harvest MC (HMC) significantly affected the BD of freshly harvested and conditioned rough rice. Higher HMC levels resulted in lower BD levels for rough rice over the conditioned MC range from 11 to 29% (wb). There was a strong linear relationship between rough rice BD and conditioned MC for a given HMC. The harvest location had a more pronounced effect on rough rice BD of long-grain varieties than of medium-grain varieties. The BD of brown and white rice was less dependent on harvest location and conditioned MC than the BD of rough rice. Rice harvested at low MC level (≈13%) gave a higher BD for both brown and white rice than that harvested at higher MC levels. Medium-grain varieties showed a higher BD for brown and white rice than did long-grain varieties.

Bulk density (BD) is an important physical property of rough and milled rice. The BD of rice is dependent on grain type (long-, medium-, or short-grain), moisture content (MC), kernel density, and additional physical properties such as kernel shape and dimensional characteristics. Wratten et al (1969) studied the physical dimensions and BD of long- and medium-grain rice varieties conditioned to various MC levels. They found that the rough rice length, width, thickness, and BD were linear, direct functions of MC. This trend was also observed by Morita and Singh (1979), who studied the BD of short-grain rough rice. In a related investigation of physical properties of rough and milled rice, Bhattacharya et al (1972) reported that as MC increased, kernel density and BD of rough rice increased, whereas that of brown rice decreased. They noted that BD is related to the kernel shape (i.e., length-to-width ratio); the more round the kernel, the greater the BD and the lower the porosity.

Shrinkage of rough, brown, and white short-grain rice associated with air-drying was determined by Steffe and Singh (1980). Using an air-comparison pycnometer, they observed that as rough rice was dried from 30 to 15% (db), the volumetric reductions for white, brown, and rough rice were 12.4, 13.7, and 10.7%, respectively. In addition, Arora (1991) and Muthukumarappan et al (1992) studied the volumetric changes of rice kernels with MC. Muthukumarappan et al (1992) reported that the coefficients of linear and cubical hygroscopic expansion for rough, brown, and milled rice were higher during adsorption than during desorption.

Harvest MC (HMC) is an issue concerning rice producers because it greatly affects rice quality and the associated economic return (Kocher et al 1990). Bal and Ojha (1975) showed that the MC of paddy grain decreased linearly in a period of 16 to 46 days after flowering. They suggested that the optimum HMC, in terms of maximum grain yield as well as milling quality, would be from 22 to 24%. Other research has shown that rice properties, particularly kernel MC distribution, change with HMC levels. Kocher et al (1990) and Siebenmorgen et al (1992) showed that kernel MC variability greatly increased as the HMC increased.

Changes in rice BD with conditioned MC have been reported in the literature, particularly for short- and medium-grain rice. However, little has been reported on the dependence of BD on the MC at which rice is harvested, or the effects of such variables as harvest location or variety, and the role that these variables play in the BD of rice conditioned to various MC levels. Also, there is limited reported data quantifying the relationships between BD and conditioned MC of long-grain rough, brown, and white rice. The objective of this study was to determine the BD of rough, brown, and white rice of various long- and medium-grain varieties harvested from Arkansas locations over a range of HMC levels and dried to a range of conditioned MC levels.

MATERIALS AND METHODS

Harvesting and Conditioning

Rice was harvested from the Rice Research and Extension Center at Stuttgart, AR, and the Northeast Research and Extension Center at Keiser, AR, in 1995. The rice were grown under the recommended management procedures provided by the Arkansas Cooperative Extension Service. The soil at the Stuttgart location was a Crowley silt loam, whereas the soil at Keiser was a Sharkey silt clay. Long-grain varieties Cypress, Kaybonnet, and Newbonnet, and medium-grain varieties Bengal and Orion were harvested from production-scale fields with plot combines. The experimental plan was to harvest a given variety at high (>24%), medium (18–22%), and low (12–16%) MC levels (unless otherwise specified, moisture content is expressed on a wet basis), from the same location in a field at Stuttgart. To elucidate location effects, only medium HMC rices were harvested at Keiser. The actual HMC levels for each variety at each location are given in Table I.

The harvest procedure consisted of cutting ≈180 kg of a variety with a plot combine and bagging in paper sacks. The rice was then transported to the University of Arkansas Rice Processing Laboratory on the day of harvest and cleaned using a dockage tester (Carter-Day Co., Minneapolis, MN). Top and middle screen sizes used for both long- and medium-grain varieties were no. 28 and 25, respectively, while the bottom screen used for the long- and medium-grain varieties were no. 22 and 4, respectively. Cleaned rice from each variety harvested at a given MC was then spread on a tarp in a laboratory maintained at 21°C to allow slow drying. During the drying process, the rice was stirred periodically to minimize MC gradients within the bulk.

As the rice dried, a 2.2-kg sample of rough rice was collected using a Boerner divider (Seedburo Equipment Co., Chicago, IL) at intervals of ≈1 MC percentage point. The BD of the rough rice was measured immediately after the sample was collected. Once the rice on the tarp reached ≈16% MC, 4.5-kg samples of rough rice were selected at intervals of ≈1 MC percentage point, from which BD measurements of rough, brown, and white rice were made. This procedure was repeated until the conditioned MC reached ≈11%.

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Bulk Density Measurement

The BD of rough, brown, and milled rice was measured using a Seedburo bulk density weight test apparatus consisting of a filling funnel with a quart cup placed beneath the funnel. From each sample of rough rice at a given MC level, a subsample was selected and poured into the funnel. After the valve at the bottom of the funnel was tripped, the rice flowed into the quart cup placed under the funnel. The rice was leveled off at the top of the cup using a straight-edge. The BD was calculated by dividing the weight of rice in the cup by the cup volume, taken as a standard dry quart. This procedure was repeated three times with the same subsample to obtain an estimate of the measurement error. The deviation of BD values for each subsample was <0.2%. Two additional subsamples were then measured for BD in triplicate, as with the first subsample. The mean of the nine BD measurements were reported as the BD for a sample.

The rough rice <16% MC was hulled using a paddy husker (model APS-30CX, Satake Engineering Co., Tokyo). White rice was obtained by milling portions (120 g) of the brown rice samples for 30 sec using a McGill No. 2 laboratory mill (Rapsco, Brookshire, TX). BD measurements on the brown and white fractions were made using only whole kernels. Head rice was separated from brokens using a Seedburo sizing machine. Degree of milling (DOM) of the head rice was measured using a milling meter (model MM-1B, Satake). BD tests were conducted on the brown and white rice samples using the same procedure described above for rough rice. MC measurements of rough, brown, and milled rice components were determined by oven-drying ≈15-g samples at 130°C for 24 hr in a convection oven.

Statistical Analysis

The REG procedure (SAS Institute Inc., Cary, NC) was used to investigate the relationship between rough, brown, and milled rice BD and conditioned MC. The statistical analysis for the comparison of two regression lines (Neter and Wasserman 1974) was performed to determine differences between BD and conditioned MC relationships across HMC levels, harvest location, and variety.

TABLE I
Harvest Locations with Corresponding Harvest Moisture Content (HMC) Levels of Rice Varieties

	HMC (%, wb)		
Location and Variety	High (>24%)	Medium (18–22%)	Low (12–16%)
Stuttgart, AR			
Bengal	· · ·	20.9	12.9
Cypress	29.1	20.6	14.5
Kaybonnet	· · ·	18.9	12.5
Keiser, AR			
Bengal	· · ·	21.7	· · ·
Orion	· · ·	17.2	· · ·
Cypress	· · ·	21.0	· · ·
Newbonnet	· · ·	21.1	· · ·

RESULTS AND DISCUSSION

The BD of freshly harvested rough rice with different HMC levels and harvest locations is given in Table II. Values of rough rice BD measured at the HMC varied with rice variety, HMC, and harvest location. Figure 1 illustrates the changes in BD of long-grain Cypress rough rice with conditioned MC for different HMC levels and locations. BD decreased linearly with decreasing conditioned MC for each HMC. The linear decrease in rough rice BD with decreasing conditioned MC is consistent with the observations reported by Bhattacharya et al (1972) and Arora (1991). This trend can be explained in terms of the presence of an air space between the brown rice kernel and hull (Steffe and Singh 1980). It is speculated that as water leaves the kernel, the inner brown rice kernel shrinks in volume at a faster rate than does the overall rough rice kernel, thus increasing the air space between the brown rice kernel and hull layers. Accordingly, the moisture loss causes kernel mass loss but is not associated with corresponding reductions in overall rough rice kernel volume. This results in decreasing BD with decreasing conditioned MC.

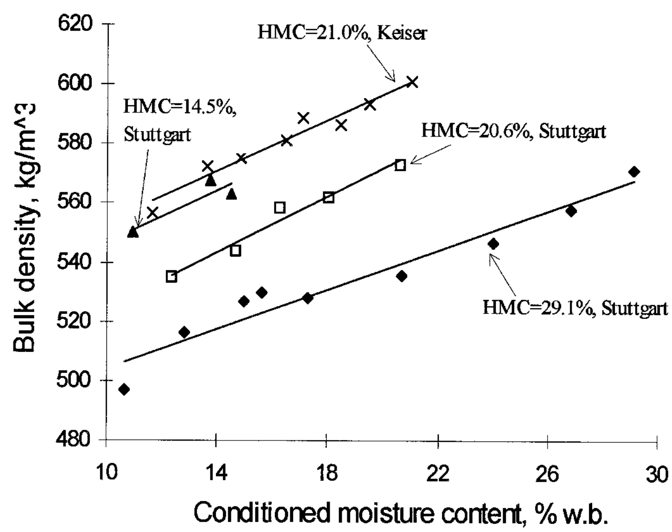

Fig. 1. Dependence of rough rice bulk density on conditioned moisture content of long-grain variety Cypress harvested at either Keiser or Stuttgart, AR, at the indicated harvest moisture content (HMC) levels.

TABLE II
Dependence of Bulk Density (BD) of Rough Rice on Harvest and Conditioned Moisture Content (MC)

Location and Variety	Harvest MC (% wb)	BD at Harvest MC (kg/m^3)	BD at 13% MC (kg/m^3)[a]	Range of Conditioned MC (% wb)	Linear Regression Equations[b]
Stuttgart, AR					
Bengal (medium-grain)	20.9	601	562	14–21	$y = 4.44x + 504.7$ ($R^2 = 0.94$)**[c]
Bengal (medium-grain)	12.9	568	· · ·	· · ·	na[d]
Cypress (long-grain)	29.1	572	514	11–29	$y = 3.36x + 470.3$ ($R^2 = 0.94$)***
Cypress (long-grain)	20.6	573	539	12–21	$y = 4.74x + 477.1$ ($R^2 = 0.97$)**
Cypress (long-grain)	14.5	563	560	11–15	$y = 4.38x + 503.2$ ($R^2 = 0.79$)*
Kaybonnet (long-grain)	18.9	601	582	11–19	$y = 3.47x + 536.7$ ($R^2 = 0.97$)*
Kaybonnet (long-grain)	12.5	616	· · ·	· · ·	na
Keiser, AR					
Bengal (medium-grain)	21.7	615	566	11–22	$y = 5.12x + 499.5$ ($R^2 = 0.96$)**
Orion (medium-grain)	17.2	585	563	13–17	$y = 5.80x + 487.8$ ($R^2 = 0.92$)*
Cypress (long-grain)	21.0	601	566	12–21	$y = 4.32x + 510.3$ ($R^2 = 0.95$)***
Newbonnet (long-grain)	21.1	603	573	11–21	$y = 3.58x + 526.7$ ($R^2 = 0.91$)***

[a] BD calculated using linear regression equations for rough rice.
[b] Where y = BD of rough rice (kg/m^3) and x = conditioned moisture content (% wb).
[c] *, **, *** are significant at $P = 0.05$, 0.01, and 0.001, respectively.
[d] Not applicable.

Figure 1 further indicates that the MC at which Cypress rice was harvested significantly affected the rough rice BD value at a given conditioned MC level ($P < 0.05$). Higher HMC levels produced successively lower conditioned rough rice BD levels over the conditioned MC ranges. For example, at a conditioned MC of 13.0%, the BD values of Cypress rough rice harvested at 29.1, 20.6, and 14.5% MC at Stuttgart were 514, 539, and 560 kg/m^3, respectively (Table II). The lower BD values for rough rice harvested at high MC levels can be explained by the presence of immature kernels (Bal and Ojha 1975, Kocher et al 1990). Immature kernels would be expected to have less mass per unit volume than fully matured kernels. Conditioning rough rice by drying did not change the kernel immaturity effect, with the result that the higher HMC rice had the lower BD over all conditioned MC levels. The results in Table II also indicate that Kaybonnet harvested at a fairly high MC (18.9%) produced much lower rough rice BD at a conditioned MC of 13% (582 kg/m^3) than did Kaybonnet harvested at an MC level of 12.5% (616 kg/m^3). However, for medium-grain Bengal harvested at 20.9% MC at Stuttgart, the rough rice BD at 13% conditioned MC was 562 kg/m^3, which was only 6 kg/m^3 less than Bengal harvested at 12.9% MC.

Harvest location affected the BD levels of Cypress rough rice at the time of harvest and after conditioning (Fig. 1). Cypress harvested from Keiser had a much higher BD than that from Stuttgart with a similar HMC. Factors influencing the BD at different harvest locations could include climatic conditions, soil type, and production practices. The possible influence of these factors on the BD of rice needs further verification.

Figure 2 shows the conditioned MC effect on the BD of medium-grain varieties Bengal and Orion with a medium HMC. There was not a great difference in BD at any given conditioned MC for these medium-grain lots. However, the statistical analysis for the comparison of two regression lines (Neter and Wasserman 1974) indicated that the linear regressions for Bengal from Stuttgart and Keiser were significantly different ($P < 0.05$). The harvest location difference in BD values for Bengal (medium-grain) (Fig. 2) was much less than for Cypress (long-grain) (Fig. 1). There was no significant difference in the BD relationship between Orion and Bengal harvested from the same location (Keiser).

A significant difference ($P < 0.05$) in the BD value and conditioned MC relationship was observed between the long-grain varieties (Newbonnet, Cypress, Kaybonnet) harvested at medium MC (Fig. 3). Kaybonnet from Stuttgart gave the highest BD over the conditioned MC range, although it had a slightly lower HMC that may have caused slightly higher BD values. Newbonnet and Cypress from Keiser exhibited similar BD relationships, yet statistically different ($P < 0.05$), over the conditioned MC range. Cypress from Stuttgart had the lowest BD of all long-grain varieties harvested at the medium HMC level.

The statistical analysis using the procedures developed by Neter and Wasserman (1974) indicated that there were no significant differences between the slopes of all the regression lines in Figs. 1–3 ($P < 0.05$). This means that the differences between the regression lines discussed above resulted only from the differences in the intercepts of the lines. Thus, the slopes of all the linear regression lines was averaged to give a value of 4.4. With this average slope, one can predict BD of rough rice at any conditioned MC level from the BD at harvest MC.

Tables III and IV show the BD and MC of brown and white rice milled from rough rice at conditioned MC <17%. The paired comparison *t*-test indicated that there were significant differences in MC between rough, brown, and white rice ($P < 0.001$). Brown rice MC was higher than rough rice MC by a mean value of 0.5 percentage points, indicating that the hulls contain less moisture than the rice caryopsis (Lu and Siebenmorgen 1992). Milling of the brown rice resulted in a decrease in MC by an average of 0.3 percentage points.

A comparison of Tables II, III, and IV indicates that BD increased as rough rice was processed to brown and then white rice. In general, the BD differences between brown and white rice decreased with decreasing MC of the rice. For a given rice lot, the BD for brown and white rice was affected by the conditioned MC. However, the changes in BD for brown or white rice with conditioned MC were relatively small when compared to the changes in rough rice BD with conditioned MC. Bhattacharya et al (1972) soaked brown rice in water and then slowly dried it to give various MC levels. They found that the BD of the brown rice linearly increased as MC decreased from 27 to 15%. Our results did not indicate a significant correlation between brown or white rice BD and conditioned MC. However, there were limited data points over the conditioned MC range for each BD and conditioned MC relationship. The level of conditioned MC also affects rate of bran removal during milling and thus the degree of milling (Bennett et al 1993), which could have possibly affected BD. Our measurements indicated that, as conditioned MC decreased from 16.7 to 12.8%, the DOM of Cypress head rice decreased from 105 to 87 as measured with the Satake milling meter.

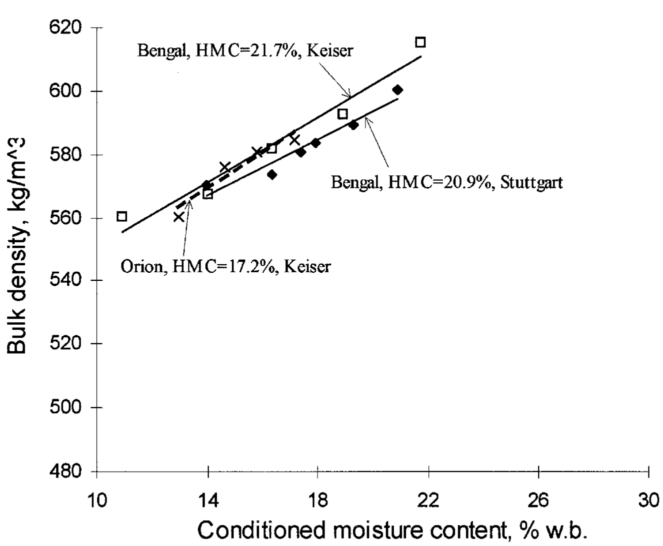

Fig. 2. Dependence of rough rice bulk density on conditioned moisture content of medium-grain varieties Orion and Bengal harvested at either Stuttgart or Keiser, AR, at the indicated harvest moisture content (HMC) levels.

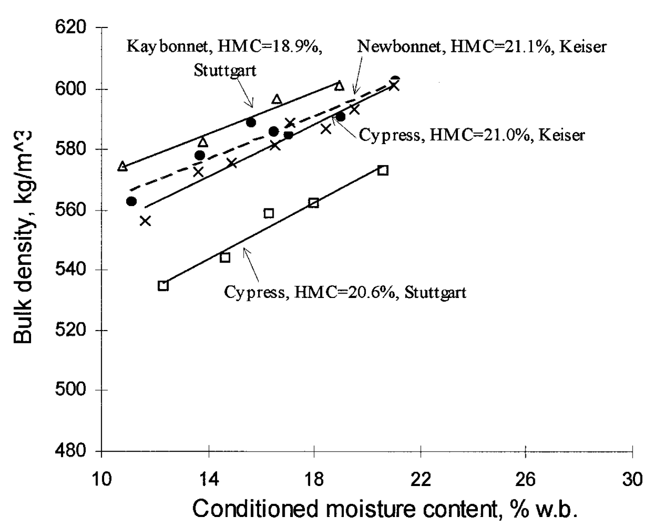

Fig. 3. Dependence of rough rice bulk density on conditioned moisture content of long-grain varieties Cypress, Kaybonnet, and Newbonnet harvested at either Stuttgart or Keiser, AR, at the indicated similar harvest moisture content (HMC) levels.

For comparison, the BD for brown and white rice at a conditioned MC of 13% was calculated from a linear regression of BD against the corresponding conditioned MC levels for brown or white rice for each rice lot. The results are given in Tables III and IV. Similar to the trend of rough rice BD and HMC, rice harvested at a lower MC gave a higher BD for both brown and white rice than that harvested at higher MC levels.

Cypress harvested at 21% MC from Keiser had lower white rice BD than any of the Cypress from Stuttgart, even though the rough rice BD was greater. For Bengal harvested at a medium MC (≈21%), location had no effect on brown rice BD at conditioned MC of 13% but had small effect on the BD of white rice at a conditioned MC of 13% (i.e., the white rice BD for Stuttgart showed only a 6 kg/m^3 higher BD than that for Keiser).

Grain type (long- vs. medium-grain) had a great effect on brown and white rice BD. The BD for brown and white medium-grain rice at a conditioned MC of 13% ranged from 761 to 814 kg/m^3 and from 793 to 845 kg/m^3 respectively, whereas the range of BD for brown and white long-grain rice at a conditioned MC of 13% was 717–778 kg/m^3 and 742–800 kg/m^3, respectively.

CONCLUSIONS

Rice variety, HMC and location, and conditioned MC had significant effects on the BD of rough rice. High HMC levels resulted in low BD values for rough rice over the conditioned MC range from 11 to 29%. Harvest location had a more pronounced effect on rough rice BD of long-grain than medium-grain varieties. Cypress (long-grain) harvested from Keiser had a much higher BD than that from Stuttgart with a similar HMC. However, the harvest location effect on BD for Bengal (medium-grain) from the same locations was much less. There was a strong linear relationship between rough rice BD and conditioned MC for a given HMC.

The BD increased as rough rice was processed to brown and then white rice. The BD for brown and white rice was also affected by the conditioned rough rice MC, but the changes in BD values for brown or white rice with conditioned MC were relatively small when compared to the changes of rough rice BD with conditioned MC. Rice harvested at a lower MC gave higher BD values for both brown and white rice than that harvested at higher

TABLE III
Bulk Density (BD) and Conditioned Moisture Content (MC) of Brown and White Long-Grain Rice Harvested at Two Locations

Location and Variety	Harvest MC (% wb)	Rough Rice Conditioned MC (% wb)	Brown Rice Conditioned MC (% wb)	Brown Rice BD (kg/m^3)	Brown Rice BD at 13% MC (kg/m^3)[a]	White Rice Conditioned MC (% wb)	White Rice BD (kg/m^3)	White Rice BD at 13% MC (kg/m^3)[a]
Stuttgart, AR								
Cypress	29.1	15.0	15.5	710	717	14.6	768	761
	29.1	12.8	14.0	717		13.7	759	
	29.1	10.7	11.2	720		11.4	758	
	20.6	16.3	16.9	710	724	16.4	763	763
	20.6	14.7	14.9	715		14.6	763	
	20.6	12.3	12.8	726		12.9	763	
	14.5	14.5	15.2	722	725	15.0	765	764
	14.5	13.7	14.2	725		13.6	768	
	14.5	10.9	11.6	726		11.7	760	
Kaybonnet	18.8	13.8	14.2	734	731	14.1	764	760
	18.8	10.8	11.4	727		11.6	755	
	12.5	12.5	13.2	778		13.4	800	. . .
Keiser, AR								
Cypress	21.0	16.5	16.7	718	732	16.1	761	752
	21.0	14.9	15.3	722		15.1	757	
	21.0	13.6	14.6	728		14.3	756	
	21.0	11.6	12.3	734		12.3	750	
Newbonnet	21.1	16.5	16.1	731	731	15.3	755	742
	21.1	15.6	15.7	730		15.3	753	
	21.1	13.7	14.3	724		14.2	748	
	21.1	11.2	11.9	734		11.8	735	

[a] Calculation based on linear regression of brown or white rice BD against conditioned MC for each rice lot.

TABLE IV
Bulk Density (BD) and Conditioned Moisture Content (MC) of Brown and White Medium-Grain Rice Harvested at Two Locations

Location and Variety	Harvest MC (% wb)	Rough Rice Conditioned MC (% wb)	Brown Rice Conditioned MC (% wb)	Brown Rice BD (kg/m^3)	Brown Rice BD at 13% MC (kg/m^3)[a]	White Rice Conditioned MC (% wb)	White Rice BD (kg/m^3)	White Rice BD at 13% MC (kg/m^3)[a]
Stuttgart, AR								
Bengal	20.9	17.4	17.6	754	773	16.9	783	807
	20.9	16.4	16.7	762		16.0	792	
	20.9	14.0	14.7	766		14.2	799	
	12.9	12.9	13.4	814	814	13.5	845	845
	12.9	11.3	12.1	813		12.3	844	
Keiser, AR								
Bengal	21.7	16.3	17.0	760	773	16.3	790	801
	21.7	14.0	14.5	774		14.3	805	
	21.7	11.0	11.7	775		11.8	800	
Orion	17.2	17.2	17.7	755	761	16.5	779	793
	17.2	15.8	16.2	763		15.7	784	
	17.2	14.6	15.1	753		14.7	791	
	17.2	13.0	13.6	763		13.6	787	

[a] Calculation based on linear regression of brown or white rice BD against conditioned MC for each rice lot.

MC levels. Harvest location had a small effect on the BD of brown and white rice. Medium-grain varieties showed a higher BD for brown and white rice than for long-grain varieties.

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