Grinding Methods: Their Impact on Rice Flour Properties

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ABSTRACT

California medium grain broken white rice was reduced to flour by grinding on seven different mills. The resulting flour particle size and functional properties were affected by the type of grinder used. Burr and blade mills gave coarse flours; the roller mill, an intermediate flour; and pin, hammer, and turbo mills, fine flours. The latter two mills also heated the flour more than the others. Coarser flours had less damaged starch and functioned better in 100% rice flour breads, whereas finer flours with more damaged starch were preferred for composite flour breads containing 30% rice. Water absorption capacity was greater for fine flours. The initial increase in amylograph viscosity started at a lower temperature for fine flours than for coarser ones. Differential scanning calorimetry of six rice flours of differing particle sizes gave different endotherms (T_{max}) that paralleled microscopic gelatinization temperatures. Enthalpies determined by differential scanning calorimetry were lower for flours with a higher degree of damaged starch. Mill selection and processing procedures are therefore important considerations in the production of rice flours for different end-product uses.

In the wheat industry, flour is produced by "milling." Terminology differs in the rice industry; rice flour is produced by "grinding" broken milled white rice on various types of mills or grinders. Rice flour is a specialty by-product manufactured by rice millers to meet specific needs. It is used as a dusting or anticaking agent for refrigerated biscuit doughs or as an ingredient in extruded products, pancake and waffle mixes, and baby foods. The only specifications for rice flour are those set by rice flour users.

Problems have occasionally occurred in commercial applications using rice flour in breads for allergy diets or as thickeners for baby foods. Not enough is known about the quality factors of rice flours to resolve these problems. Rice has been shown to vary widely in its cooking and eating quality, depending on variety and type of rice, amylose content, and gelatinization behavior (Halick and Kelly 1959, Juliano et al 1965, Perez and Juliano 1979, Williams et al 1958). Rice flour should reflect the same characteristics as shown by the rice from which it was ground. Varietal differences in amylose content alter the quality of fermented rice cake (puto) made in the Philippines (Perdon and Juliano 1975, Sanchez 1975). Varietal differences in amylose content and gelatinization temperature also affect the texture of 100% rice flour bread (Nishita and Bean 1979). In addition, Halick and Kelly (1959) noted that particle size greatly influenced the pasting characteristics of rice flour. Cagampang et al (1973) reported that gel consistency of cooked rice pastes was influenced by particle size. Yamazaki et al (1971) obtained softer, more palatable rice flour butter cakes when finer particles (less than 120-mesh) were used.

Besides differences due to variety, the state of the flour particles also contributes to the behavior of rice flour. Therefore, consideration of the type of grinding equipment used to prepare rice flour seems important. A search of the literature for commercial rice flour production methods was unsuccessful. To gain some insight into the impact of grinding technique on rice flour properties, seven different mills were used to grind second-head rice. The differences in physicochemical and functional properties of the resulting rice flours were examined.

MATERIALS AND METHODS

Rice

A single lot of California medium-grain second-head rice from the 1977 crop was obtained from the Rice Growers Association of California (Sacramento, CA 95804). It was approximately one year old when received and therefore had undergone aging changes. It was stored until needed at −23°C in 5-gal friction-lid cans lined with plastic bags. Proximate composition was 12.9% moisture, 1.14% nitrogen, 0.60% fat, 0.28% fiber, and 0.34% ash.

Mills

Burr Mills. Two burr mills were used—a coffee mill (Laboratory Construction Co., Kansas City, MO), set at 10, and a Bauer disc mill (No. 148-2-8, Bauer Bros. Co., Springfield, OH) with plate No. 8114x.

Knife or Blade Mill. Successive passes were made through 2.0-, 1.0-, and 0.5-mm screens of a Wiley mill No. 1 (Arthur H. Thomas Co., Philadelphia, PA).

Roller Mill. The Brabender Quadrumat Jr. (C. W. Brabender Instruments, Inc., So. Hackensack, NJ) was used with a No. 64 gritz gauze reel sifter.

Hammer Mill. This was a Mikro pulverizer, type CF (U.S. Filter Corporation, Summit, NJ) with the feed auger set at 24 rpm and using a 0.039 in. screen.

Pin Mill. An Alpine Augsburg type 160Z (Alpine American Corporation, Natick, MA) was used with the varidrive set at 6 (14,000 rpm). Two flours were prepared: 1) pin mill 1×, one pass, and 2) pin mill 2×, two passes.

Turbo (High-Speed Impact) Mill. A hurricane turbo-grinder (Pillsbury Mills, Minneapolis, MN) was set at 10,000 rpm and used on second-head rice previously passed through the coffee mill.

Analytical Methods

Particle size distribution was determined by shaking 100 g of rice flour through 50-, 70-, 100-, 120-, 140-, and 200-mesh screens (U.S. Standard sieve series) on a Ro-Tap Sieve Shaker for 10 min. The median particle size (PS50) was determined as the estimated sieve size through which 50% of the sample (by weight) would pass.

Flour color was determined with a Hunter Color/Difference Meter D25-2, using Hunterlab Tile Standard No. C2-5518 (L = +95.1; a = −0.6; b = +0.9).

Amylograph results were obtained by the method of Halick and Kelly (1959) under conditions described by Nishita and Bean (1979). Birefringence end point temperature (BEPT) at 98% extinction was obtained by the method of Schoch and Maywald (1956). Differential scanning calorimetry (DSC) results were obtained on a DuPont model 990 according to Donovan (1979). Six flours (2 mg each) were heated with 15 μl of water at a rate of 5°C/min.

Damaged starch was determined by the method of Thivend et al (1972), except that readings were taken after 1 and 2 hr and extrapolated back to zero time. Because glucoamylase was used to hydrolyze the starch, the results are reported as "percent glucose" of the flour. Water retention capacity was measured by Yamazaki's alkaline water retention capacity (AWRC) test (1953).

[1]Reference to a company or product name does not imply approval or recommendation of the product by the USDA to the exclusion of others that may be suitable.

Rice breads were prepared by the method of Nishita et al (1976) and composite flour breads, by the method of Bean et al (1976), using 30% rice flour replacement, 3.0% shortening, and optimum water.

Three replications were made in determining particle size distribution, BEPT, DSC, and AWRC. Duplicate tests were made for damaged starch and baking quality. A single determination was made for color and for amylograph behavior.

RESULTS AND DISCUSSION

Particle Size Distribution

Depending on the mill used, a wide range of rice flour particle size distributions was obtained with the Ro-Tap (Fig. 1). The PS50 measurements for each flour are given in Table I. These data show that hammer-milled and pin-milled 1× and 2× flours had the finest granulations, with PS50 of approximately 117, 111, and 88 μm, respectively. Burr-milled (coffee mill) flour was the coarsest, estimated at 630 μm. The distribution curve for turbo-milled flour coincides with that for the roller-milled, which would appear to indicate that these flours had similar size distribution. However, scanning electron microscopic examination showed turbo-milled flour to have the finest size of all the flours. These differences highlight the limitation of sieve-size analyses for such a fine particle material as that obtained on a turbo mill. Ro-Tap sieving for 30 min shifted more turbo-milled flour to the finer screens but did not change roller-milled flour data. Examination of screens showed that fine turbo-milled particles would clump on the screens during sieving rather than passing through. These were easily disrupted by hand. Temperature rise during grinding was highest for the turbo- and hammer-milled flours, intermediate for the blade-milled flour, and noticeably less for the pin-, roller-, and burr-milled flours. Both pin-milled flours had the same temperature rise, so any changes in properties by pin-milling twice should be attributable to changes in particle size rather than to heat damage. In general, particle size had a major influence on functional properties of the rice flours.

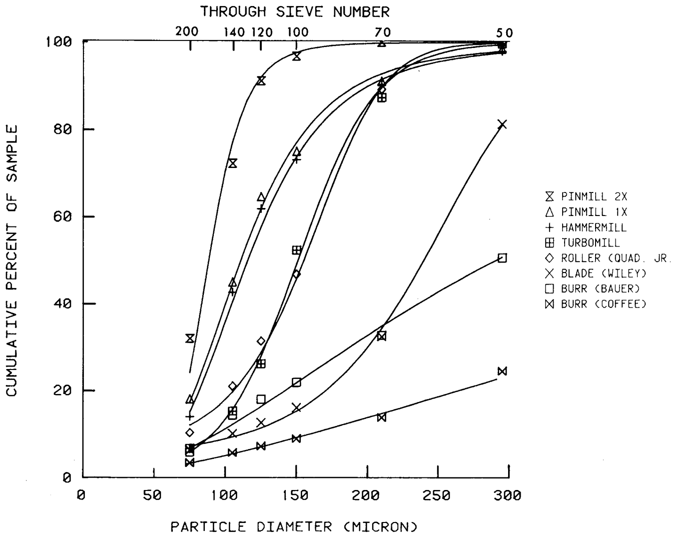

Fig. 1. Cumulative particle size distribution by weight for rice flours ground on various mills.

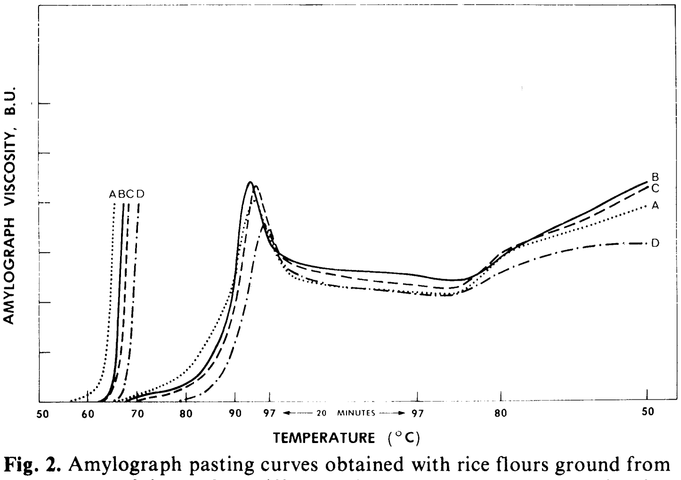

Fig. 2. Amylograph pasting curves obtained with rice flours ground from the same lot of rice on four different mills. Short curves, 20% slurries; full curves, 10% slurries. Flours: **A** = turbo-milled, **B** = roller-milled, **C** = pin mill 1×, **D** = burr-milled (Bauer).

Color

Hunter Color/Difference Meter data (Table II) indicated that the finer flours were brighter and whiter. Turbo-, hammer-, pin-, and roller-milled flours gave the highest "L" values for whiteness. The "a" values were unchanged, but "b" values indicated a tendency toward decreasing yellowness as the particles became finer.

Gelatinization Characteristics

Amylograph gelatinization histories are presented in Fig. 2 for four flours, selected to show the range of performance obtained. The short curves on the left show viscosity increases of 20% rice flour slurries immediately upon swelling of the starch. Those on the right give full gelatinization histories of 10% slurries on the same four flours. In the 10% slurries, the initial onset of swelling of the starch is not measurable as viscosity, but subsequent swelling, starch breakdown, and setbacks are recorded. For the flours shown, heating to 97° C, holding at 97° C, and cooling to 50° C gave essentially similar paste viscosities, except for burr-milled rice flour (curve D). This flour and the other coarse burr-milled flour (not shown) gave initial viscosity increases at a higher temperature and lower viscosities at the peak and upon cooling to 50° C than the flours from the other mills. This property may have practical application when rice flour is used as a thickener. Coarsely ground flours produced on the burr mills may not have the thickening power of more finely ground flours. Control of particle size for

TABLE I
Rice Flour: Median Particle Size by Weight (PS50)[a] and Flour Temperature

Mill	PS50 (μm)	Flour Temperature (°C)
Turbo	151[b]	88
Hammer	117	75
Pin		
2×	88	38
1×	111	38
Roller	155	30
Blade	239	50
Burr		
Bauer	290	32
Coffee	630	36

[a] PS50 = estimated sieve size through which 50% of the sample would pass.
[b] Determined by scanning electron microscopy to be the finest flour in the study.

TABLE II
Hunter Color/Difference Meter Readings[a] of Rice Flours

Mill[b]	L	a	b
Turbo	+93.9	−0.7	+3.4
Hammer	+92.2	−0.8	+5.8
Pin			
2×	+92.5	−0.8	+4.9
1×	+91.3	−1.0	+6.4
Roller	+90.6	−0.9	+7.4
Blade	+84.0	−1.0	+6.3
Burr			
Bauer	+88.4	−1.0	+8.9
Coffee	+86.0	−0.8	+10.2

[a] L: 100 = white, 0 = black; a: − = green, + = red; b: − = blue, + = yellow.
[b] Mills producing finer particle sizes are listed first.

assessing gelatinization and pasting characteristics was stressed by Halick and Kelly (1959). Data shown in Fig. 2 add support to their findings.

Short curves, such as those on the left, using more concentrated rice flour slurries normally indicate initial onset of gelatinization of the starch and have been shown to correlate with the loss of birefringence determined microscopically (Halick et al 1960). The temperature of 20% slurries at initial viscosity increase has been shown to depend on rice variety (Halick and Kelly 1959, Nishita and Bean 1979). In data shown here, however, all flours were milled from the same lot of second-head rice, so differences are attributable not to variety but to grinding method. These four curves show initial viscosity increases at 55.5, 61.0, 62.5, and 66.0°C. The other flours (not shown) gave increases between 59.5 and 65.0°C. This indicates a 10.5°C spread estimated for initial gelatinization temperature between the very fine and very coarse flours from the same parent rice. More exacting measurements by microscopic and calorimetric determinations discussed below indicated a much narrower range.

BEPT determinations showed 98% extinction for all flours between 65.2 and 66.8°C, a range of 1.6°C (Table III). DSC results for six flours gave maximum temperatures from 65.9 to 67.4°C, a range of 1.5°C. The variation in temperatures, even though slight for the more precise BEPT and DSC methods, shows the importance of grinding method in preparation of samples for studying rice flour properties.

For all three measurements of gelatinization temperature, the finest flours had the earliest temperature of onset and the coarse flours, the latest. In spite of the lack of precision for scientific purposes, the amylograph viscosity data may have the most practical value for the rice flour user who needs to know the temperature range at which his rice flour product will increase in viscosity.

Determinations by DSC also gave enthalpy of gelatinization, a measure of the heat necessary to gelatinize starch. Enthalpy changes calculated from areas of the gelatinization endotherm were less for the finer flours (turbo-, hammer-, and pin-milled) than for roller- and burr-milled flours. Stevens and Elton (1971) have attributed these differences in enthalpy to differences in the amount of damaged starch in the flours. The results for the six flours examined in the DSC thus indicate greatest damage to starch in the hammer- and turbo-milled flours, less in the two pin-milled flours, and least in the roller- and burr-milled flours. Except for the roller-milled flour, these results met predictions reasonably well.

Damaged Starch

Analytical determinations of damaged starch (Table III) showed turbo- and hammer-milled flours to have the most damaged starch, 24 and 20% glucose, respectively. The pin-milled flours had appreciable starch damage. The second grinding on the pin mill increased damaged starch, although slightly less than suggested by enthalpy changes. Roller-milled flour showed the least damaged starch; burr-milled had slightly more, and blade-milled, slightly more yet.

Water Retention Capacity

In practical applications, damaged starch affects water retention capacity of the flour. Table III gives results for AWRC and for the same procedure using distilled water. The trends were similar. The turbo-milled and hammer-milled flours, two of the three finest flours, showed the highest water retention, as might be expected from the high damaged-starch value. Pin mill 2× flour showed higher retention value than pin mill 1× flour. The two burr-milled flours, with the coarsest particle size distributions, had the lowest water-retention capacities. Values for roller-milled flour were intermediate and not in agreement with trends for enthalpy and damaged starch; they may reflect other properties. The roller-milled flour received the least heat during milling (Table I). How heat may influence other data reported is not clear.

Baking Tests

Rice Bread. The formula for yeast-leavened, 100% rice flour bread developed for people with allergy to wheat is a useful tool for showing differences among rice varieties (Nishita and Bean 1979). The sensitivity of this formulation was also useful for differentiating among grinding methods used to prepare rice flours for baking applications. Rice breads with the largest volumes (650–660 cc) were obtained with roller-, blade-, and both burr-milled flours (Table III). Bread from pin mill 1× flour had a slightly lower but acceptable loaf volume, whereas bread from pin mill 2× flour was very dense and unacceptable. Pin milling a second time did not appreciably change temperature or damaged starch; thus, the differences in baking properties were most likely the result of differences in particle size (PS50 of 111 μm for pin mill 1× flour compared with 88 μm for pin mill 2× flour). Turbo-milled and hammer-milled flours also produced dense loaves that did not rise during fermentation. To compensate for the increased water absorption capacity, the dough water was increased for turbo-milled, hammer-milled, and pin mill 2× flours. Dough consistency was softened, as expected, and loaf volume improved as the absorption was increased, but the quality of the breads never approached that of the acceptable loaves made with the other five flours.

Composite Flour Bread. The finer flours that performed poorly in 100% rice breads proved superior in composite flour bread tested at 10–30% replacement levels for wheat. They produced breads similar in texture to wheat bread. In contrast, coarse burr-milled flours gave harsh textures to composite flour breads. In all cases, loaf volumes of composite flour breads at 30% replacement were lower than those for 100% wheat bread.

TABLE III
Effects of Grinding Methods on Some Rice Flour Properties

Mill[a]	Birefringence End Point Temperature (°C)	Differential Scanning Calorimetry[b]: Maximum Temperature (°C)	Differential Scanning Calorimetry[b]: Enthalpy of Gelatinization (cal/g)	Damaged Starch (% glucose)	Water Retention Capacity: Distilled	Water Retention Capacity: Alkaline	Loaf Volume[c] (cc)
Turbo	65.2	65.9 ± 0.2	2.00 ± 0.13	24.2	140	134	205
Hammer	65.5	66.4 ± 0.1	1.79 ± 0.08	20.4	142	138	220
Pin							
2×	66.7	66.8 ± 0.1	2.15 ± 0.23	16.0	123	118	255
1×	66.8	66.8 ± 0.1	2.39 ± 0.10	15.1	110	104	615
Roller	66.3	67.0 ± 0.4	2.52 ± 0.14	1.2	121	118	650
Blade	66.1	···	···	10.4	108	103	660
Burr							
Bauer	66.5	67.4 ± 0.2	2.60 ± 0.17	6.4	103	99	660
Coffee	66.7	···	···	6.4	100	97	650

[a] Mills producing finer particle sizes are listed first.
[b] Mean ± standard deviation.
[c] Bread from 100% rice flour.

General Considerations

Results reported here are based on flours prepared from one lot of second-head rice on mills adjusted to specified settings. Other rices and mill settings may produce flours with a different array of characteristics. Desired functional properties apparently can be achieved by controlling particle size distribution and damaged starch. Heat exposure of the rice during grinding to flour also may be important. Some mills apparently cause heating sufficient to change functional properties; the extent of this alteration was not assessed in this study. Additional studies on rice flour properties probably have potential for upgrading a useful by-product of rice milling. In summary, proper mill selection and processing procedures are important considerations in the production of rice flours for specific end-product use.

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