Effects of Milling on the Physicochemical Characteristics of Waxy Rice in Taiwan[1]

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ABSTRACT

Three types of mills and six milling methods were employed to mill two waxy rice varieties (TCSW1, long grain; TCW70, short grain), and the physicochemical and functional properties of rice flour were examined. The results showed that dry-milling maintained a higher level of the chemical components than other milling methods. Wet-milling slightly increased solubility as test temperatures increased, and significantly increased swelling power at 75 and 85°C for TCSW1 and TCW70, respectively. Hammer and semi-dry hammer milling gave higher percentages of coarse particles (100–300 μm); cyclone and turbo milling led to a more even particle-size distribution, and the wet-milling gave the finest particles (10–30 μm). Dry hammer-milled rice had higher gelatinization and pasting temperatures, and semi-dry grinding milling resulted in the lowest pasting temperature, setback viscosity, and enthalpy value among the mills. The final quality of the two waxy rice varieties was profoundly affected by the mill type and milling method.

Waxy rice (*Oryza sativa* L.), also called glutinous, sweet, or *mochi* rice, is characterized chiefly by very low amounts of amylose in the starch. It can be classified as indica and japonica types which are commonly used for food in Taiwan (Chang 1990). Besides inherent preprocessing starch properties and storage history, different types of mills or grinders profoundly affect the physicochemical and functional properties of rice flour (Nishita and Bean 1982, Bean and Nishita 1985, Lu and Lii 1989, Arisaka et al 1992, Yang 1994, Chen 1995). However, wetting encourages uniform cooking instead of starchy, gummy cooking, and the steeped preparation results in a smoother differential scanning calorimetry (DSC) scan than does dry milling (Chen 1995, Kohlwey et al 1995).

In some Asian countries, rice is milled to flour or to a coarse meal as part of the process for making traditional rice-based baked or steamed products (Juliano and Sakurai 1985, Chen 1988). Wet-milled rice flour usually produces better texture than dry milling. However, part of the water-soluble vitamins, albumin, sugars, and some lipids are lost during wet-milling (Chen 1988, Yang 1994, Chen 1995, Juliano and Hicks 1996). Because of high costs and environmental concerns, dry or semi-dry methods have been used to produce quality similar to that obtained from wet-milling (Lu and Lii 1989, Chen 1995).

In this study, two waxy rice varieties were milled to flour using six milling methods. Changes in the resulting chemical compounds and physicochemical characteristics of the waxy rice flour were observed.

MATERIALS AND METHODS

Materials

Two waxy type rice varieties, japonica type (Taichung Waxy 70, TCW70) and indica type (Taichung Sen Waxy 1, TCSW1) were obtained from the Taichung District Experimental Station, Chang-Haw county, Taiwan, in 1994, and packed in laminated polyethylene film bags and then stored in a cold room at 4°C before milling process. The rice was milled using turbo (made in Taiwan), cyclone (Udy Corp., Boulder, CO), hammer (Culatti, type MDCI, Swiss), plate (Straub Co., Philadelphia, PA), or stone (made in Taiwan) mills.

For dry-milled flour, polished rice kernels were ground with turbo, cyclone, or hammer mills. For semi-dry milled flour, rice samples (30% mc) were steeped for 1 hr and then centrifuged for ≈1 min (2,000 rpm) to remove water. The rice was then ground with the hammer or plate mill, and dried in a hot air oven at 40°C for 12 hr to reduce the moisture to 13%. For wet-milled flour, the rice kernels were steeped for 1 hr and then ground with four times its weight in water with a double-disk stone mill. The slurry was poured into a thick cloth bag and centrifuged (2,000 rpm) to remove the free water. The wet-milled flour was then dried in a hot-air oven at 40°C for 12 hr to reduce the moisture to 13%.

Methods

The moisture, crude protein, crude lipid, and ash for all the rice flours were determined using Approved Methods 44-15A, 46-11A, 30-10, and 08-01 (AACC 1995). The conversion factor (N × 5.95) was applied to convert nitrogen to crude protein content. The color of the waxy rice flours was determined by a ∑80 Color System (Nippon Deshoku Industry Co., Japan). The *L, a, b* scale was used as the light to dark, red to blue, and yellow to green indices.

The particle-size distribution was measured with a Galai CIS-1 system (Galai Production Ltd., Israel). Sample (≈100 mg) was mixed with 400 mL of ethanol, and the particle-size distribution was expressed as a percentage (%) of the waxy rice flour. The median particle size (PS50) was determined as the estimated sieve size through which 50% of the sample would pass.

Swelling power and solubility were determined at a test temperature range of 65–95°C according to Schoch (1964) with minor modifications (Lii et al 1986).

Starch-pasting properties were measured with a Rapid Visco-Analyser (RVA model 3D, Newport Scientific Pty., Ltd., Narrabeen, Australia). Rice flour (3 g, 14% mb) was weighed directly into an aluminum RVA canister. Distilled water was added to a total of 28 g. Sample was held at 50°C for 1.5 min, heated to 95°C in 3.7 min, held at 95°C for 2 min, cooled to 50°C in 3.7 min, and then held at 50°C for 6.1 min. Apparent viscosity was recorded in Rapid Visco-Analyser units (1 RVU = ≈10 cps) (Welsh et al 1991).

Differential scanning calorimetry (DSC) was performed with a Setaram DSC 121 (Setaram Co., France). The heating rate was 5°C/min from 20–150°C. Samples (110–120 mg) were premixed with water (2:3, w/w) and kept at 4°C overnight to allow a uniform distribution of water in the flours. These samples were placed in stainless crucibles and reweighed before the DSC analysis. Onset (T_o) and peak (T_p) transition temperatures were determined for each endothermic by a computerized system developed by the Setaram Co. The transition enthalpies (Δ*H*) were determined from the peak area of the endothermic and expressed as joules per gram of dry matter (Huang et al 1994).

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Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) to detect any differences in mean values from replicate runs of each treatment (SAS Institute, Cary NC). Duncan's new multiple range test ($\alpha = 0.05$) was used for the comparison of sample means. Pearson's correlation procedure was used to examine the degree of association between variables.

RESULTS AND DISCUSSION

Effects of Milling on Chemical Composition and Color

The two waxy rice cultivars, TCW70 and TCSW1, contained 4.91–8.03% protein, 0.19–0.93% ash, and 0.30–2.50% lipids (Table I). Dry-milling resulted in higher contents of protein, lipid, and ash than did wet-milling ($P < 0.05$). When soaked rice kernels are processed by wet-milling, some soluble protein, sugars, and nonstarch bound lipids are washed out (Medcalf and Lund 1985, Chen 1988, Yang 1994, Chen 1995, Juliano and Hicks 1996).

Color measurement showed that the finer the flours, the brighter and whiter their color (Table I). Stone-milled flour gave the highest *L* value for whiteness and the lowest *a* and *b* values. The *b* value indicated a tendency toward decreasing yellows as the particles became finer. The correlation coefficient showed a significance between PS50 and *L* and *b* as well as white index (WI) of –0.77, 0.86, and –0.75, respectively ($P < 0.01$). The results indicate that the sample particle size affected the color, and that the smaller flour particles resulted in a smoother surface. Since the samples were different in particle size, the surface texture reflected from

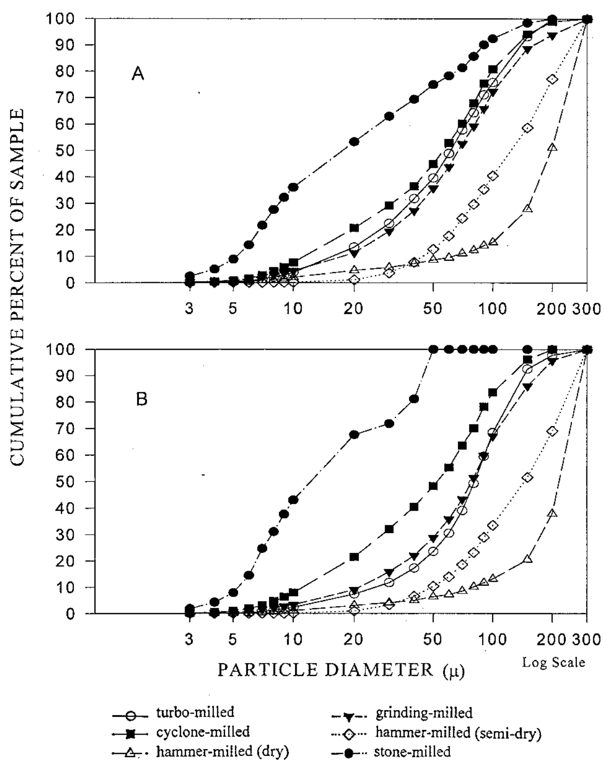

Fig. 1. Effect of milling methods on the particle-size distribution of TCW70 (**A**) and TCSW1 (**B**) rice flours.

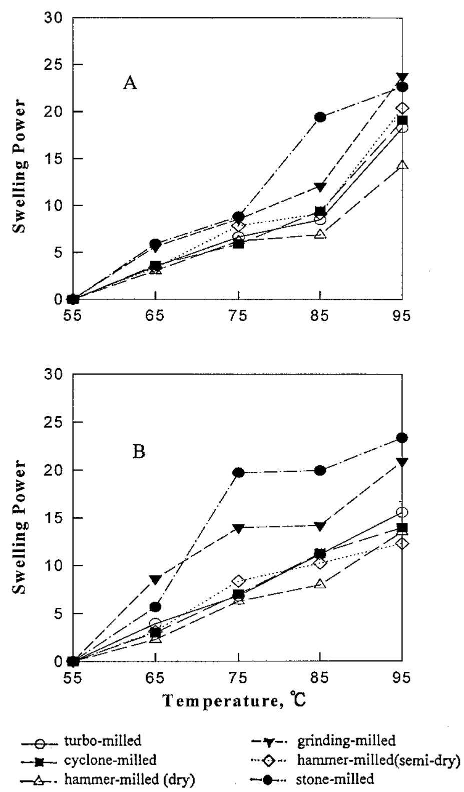

Fig. 2. Effect of milling methods on the swelling power of TCW70 (**A**) and TCSW1 (**B**) rice flours.

TABLE I
Effect of Milling Type on Chemical Composition (%) and Color of Rice Flours[a,b]

Rice and Milling Method[c]	Moisture	Protein	Ash	Lipid	Color *L*	Color *a*	Color *b*	WI[d]	Median Particle Size (μm)
TCW70									
A	12.69±0.10a	7.05±0.06a	0.89±0.07a	2.20±0.06a	93.11±0.19d	–0.12±0.18d	1.11±0.08c	93.03±0.10b	62.2
B	11.27±0.24b	6.86±0.06a	0.76±0.05b	1.69±0.42b	93.93±0.07c	–0.25±0.15bc	0.15±0.07d	93.92±0.12c	56.9
C	12.45±0.41a	6.85±0.04a	0.72±0.03b	1.53±0.03bc	89.23±0.05e	–0.01±0.18b	3.84±0.09a	88.56±0.12c	197.3
D	9.05±0.06d	6.35±0.36b	0.47±0.02cd	1.23±0.04c	93.75±0.20b	–0.05±0.13a	–0.11±0.12e	93.74±0.10a	66.7
E	10.50±0.28c	6.20±0.11b	0.50±0.03c	1.17±0.07c	93.07±0.36d	–0.16±0.11c	1.31±0.07b	92.95±0.18d	126.6
F	9.12±0.05d	5.71±0.30c	0.42±0.02d	0.57±0.08d	96.49±0.19a	–0.00±0.10a	–3.96±0.19f	94.74±0.19a	17.0
TCSW1									
A	12.62±0.08a	7.88±0.04b	0.62±0.06b	2.54±0.15a	87.33±0.14d	–2.86±0.08d	3.54±0.07c	86.53±0.07b	88.6
B	10.91±0.09c	7.92±0.08b	0.68±0.06a	2.04±0.06b	88.66±0.14c	–2.56±0.16bc	2.36±0.08d	88.13±0.11c	52.5
C	12.26±0.24b	8.05±0.07a	0.61±0.07b	1.96±0.11b	82.76±0.22e	–2.38±0.11b	6.42±0.04a	81.44±0.10c	215.1
D	8.92±0.15e	7.40±0.14c	0.39±0.07c	0.83±0.07c	93.68±0.23b	–0.30±0.17a	–0.13±0.08e	93.70±0.14a	77.9
E	9.42±0.10d	7.14±0.14d	0.31±0.03d	0.68±0.05c	87.20±0.10d	–2.63±0.20c	4.32±0.08b	86.23±0.18d	145.4
F	12.21±0.20b	4.97±0.12e	0.19±0.05e	0.30±0.10d	96.72±0.50a	–0.19±0.10a	–3.59±0.12f	95.12±0.28a	12.3

[a] Means of triplicates ± standard deviation.
[b] Means within row with different letters are different significantly at $P < 0.05$.
[c] Milling types A–F: turbo; cyclone; hammer; grinding; semi-dry hammer; wet stone, respectively.
[d] White index = $100 - \sqrt{(100 - L)^2 + a^2 + b^2}$.

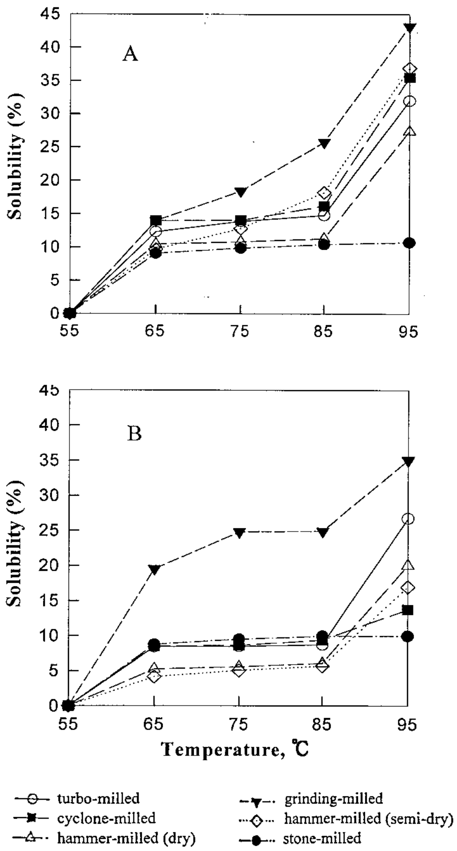

Fig. 3. Effect of milling methods on solubility of TCW70 (**A**) and TCSW1 (**B**) rice flours.

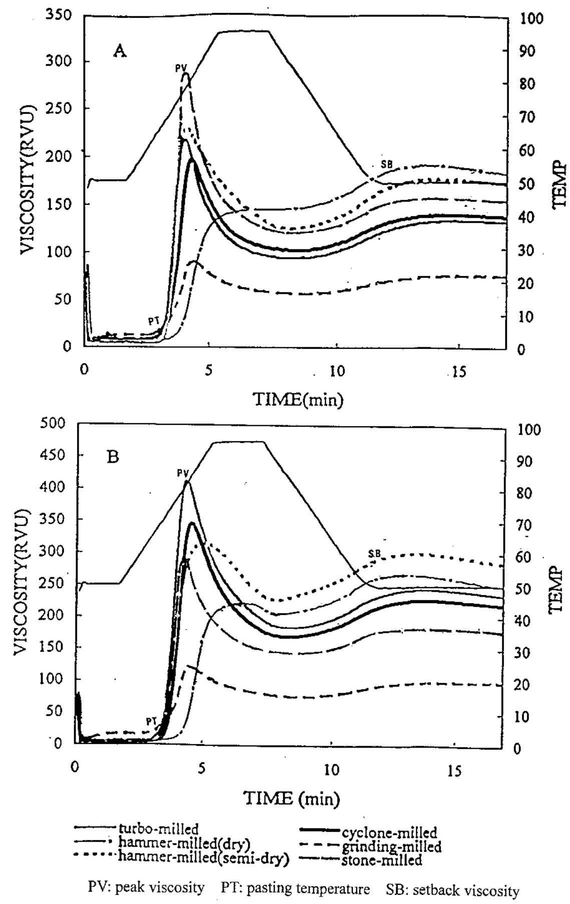

Fig. 4. Effect of milling methods on the pasting characteristics of TCW70 (**A**) and TCSW1 (**B**) rice flours.

the sample would vary among samples (Bean 1986, Kurimoto and Shelton 1988).

Distribution of Particle Size

Dry and semi-dry hammer milled flours were coarser for both rice varieties, and the semi-dry hammer milled flour was finer than dry hammer-milled rice flour at 100–300 μm. Cyclone- and turbo-milled flours had more even distributions, and stone-milled had more finer flour (10–30 μm), ≈62.92 and 71.84% for TCW70 and TCSW1, respectively (Fig. 1). The PS50 of all samples ranged from 12.3 to 215.1 μm (Table I), indicating that all samples were significantly different from each other ($P < 0.05$). The turbo-mill heated the sample to 50°C, the hammer mill also reached 42°C during milling, but the stone-milled samples stayed at room temperature. Scanning electron microscopy showed that dry-milled rice flour has clump starch granules, but the starch granules from wet-milled samples were separated (Arisaka et al 1992).

Swelling Power and Solubility

The resulting data on swelling power and solubility for the different milling methods are shown in Figs. 2 and 3. For wet-milling, solubility increased slightly as the test temperature increased (Fig. 3), but the swelling power increased significantly at 75 and 85°C for TCSW1 and TCW70, respectively (Fig. 2). The grinding-milled rice flour had higher solubility than the others. Possibly, the differences were caused by damaged starch produced during the grinding process (Arisaka et al 1992, Chen 1995). The waxy type starch granules unrestricted the swelling and resulted in the absence of a network structure from amylose molecules that can hold the starch molecules together (Tester and Morrison 1990).

Pasting Behavior Determined by RVA

Pasting properties for the rice flours as measured by the RVA are shown in Fig. 4. Milling method and cultivar affected all parameters, including peak viscosity (PV), maximum setback viscosity (SB), and pasting temperature (PT). There were no systematic differences in PV, SB, and PT for rice varieties. However, the angle and the sharpness of slope from initiation of viscosity to the peak viscosity were clearly different between the two samples. Dry hammer-milled flour showed the highest pasting temperature, and the semi-dry grinding milled flour had the lowest pasting temperature and setback viscosity. The pasting curve for dry hammer-milled flours showed negligible viscosity breakdown during a heating-hold cycle and higher viscosity during the cooling cycle, indicating that retrogradation is rapid. In the relationship between particle size and pasting temperature, the finest flours had the lowest initial onset temperature, while the coarse flours had the highest. The breakdown value (BD) decreased as PS50 increased significantly ($r = -0.67$, $P < 0.05$). However, the wet-milled rice flour from TCW70 had higher peak (306 ± 20 RVU) and breakdown (178 ± 14 RVU) viscosity than those from TCSW1. This is probably because the flour with larger particles could not hydrate or expand as rapidly and was inhibited by the starch on the particle surface (Jomduang and Mohamed 1994). Nishita and Bean (1982) reported that the absence of peak viscosity is due to delayed swelling of the starch granules that are embedded in the relatively large endosperm chunks in coarse flours.

Pasting Behavior Determined by DSC

Semi-dry plate milled flour showed the lowest ΔH value. TCSW1 rice flour had higher T_o and T_p values than TCW70, but a nonsignificant difference in ΔH (Table II). The T_o value decreased as PS50 decreased significantly ($r = 0.59$, $P < 0.05$). The lowest ΔH value came from the semi-dry plate milled flour, which compared with highest ΔH value obtained from the wet-milled flour. It reflects the considerable disruption of the native crystalline structure

TABLE II
Effect of Milling Type on Thermal Behavior of Rice Flours Determined by Differential Scanning Calorimetry[a,b]

Rice and Milling Method[c]	Onset T_o (°C)	Peak T_p (°C)	Enthalpy ΔH (J/g)
TCW70			
A	59.83±0.64c	71.21±0.89c	11.08±0.03b
B	61.11±0.27b	72.62±0.69a–c	10.31±0.69b
C	62.06±0.15a	72.90±0.78ba	12.43±0.48a
D	60.95±0.10b	73.30±1.04a	4.75±0.47c
E	58.81±0.31d	71.71±0.48bc	12.75±0.33a
F	58.17±0.14e	69.64±0.64d	12.80±0.25a
TCSW1			
A	62.10±0.49d	72.53±0.48b	10.39±0.80b
B	65.09±0.18a	74.37±0.74a	10.50±0.68b
C	64.19±0.18b	74.61±0.47a	11.87±0.60a
D	63.28±0.54c	72.63±0.61b	4.11±0.17c
E	62.07±0.53d	73.97±0.07a	11.63±1.72a
F	59.24±0.28a	71.88±0.28b	11.74±0.41a

[a] Means of triplicates ± standard deviation.
[b] Means within row with different letters are different significantly at $P < 0.05$.
[c] Milling types A–F: turbo; cyclone; hammer; grinding; semi-dry hammer; wet stone, respectively.

occurred during the grinding process. The mechanical force caused starch damage during milling, with a lower ΔH value in rice flour (Bean and Nishita 1985, Park et al 1988, Lu and Lii 1989, Carpio and Aco 1990, Arisaka et al 1992, Jomduang and Mohamed 1994, Yang 1994, Chen 1995). Marshall (1992) reported that a reduction in particle size caused a large decrease in T_p, T_c, and ΔH, but only a modest decrease in T_o. The cooking quality is affected by moistening or steeping the rice flour, which also produces a smoother DSC scan (Kohlwey et al 1995).

CONCLUSIONS

In this study, we found that waxy rice variety, mill type, and milling process profoundly affected the physicochemical characteristics of rice flours. The differences in milling parameters resulted in changes in functional properties. Thus, rice variety and milling method are two major factors affecting the quality of rice flours.

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