Some Physicochemical and Food Application Characteristics of California Waxy Rice Varieties[1]

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ABSTRACT

Three waxy rice varieties are currently available in the United States. All are grown in California. Mochigome, the oldest variety, is preferred over the more recently developed varieties, Ampec and Calmochi-202, for making *mochi*, a traditional rice product. Physicochemical characteristics of the three varieties show small differences between Mochigome and the newer varieties. Additional testing is indicated to determine factors that may account for the subtle differences in *mochi* quality. All three varieties had short, bold, chalky grains, low gelatinization temperatures, low amylograph viscosities, soft gel consistency, and high hydration capacity. These properties are characteristic of the short-grain, japonica types of rice. All three varieties contained negligible amounts of amylose and had the expected freeze-thaw characteristics, which show their potential for improving textures of sauces and baked products subjected to freeze-thaw cycles. These varieties appear to offer a suitable set for studies on the fine structure of amylopectin and other rice components to account for varietal differences.

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Waxy rice (*Oryza sativa*), also called glutinous, sweet, or *mochi* rice, is characterized chiefly by its lack of amylose in the starch. It is generally derived from japonica (short or medium) rices. In the United States, the milled kernel is short, bold, and chalky white. In some countries, waxy varieties derived from indica rices have long kernel lengths. For all waxy rices, the cooked kernels are sticky and adhere to one another, providing a product with a decidedly different texture than that obtained from amylose-containing rices (short, medium, or long grains).

Several years ago, Hanson et al (1951, 1953) reported on some useful characteristics of waxy rice flour for stabilizing sauces, gravies, and puddings against separation/degradation during freeze-thaw cycles encountered in frozen foods. Since that time, frozen food items have expanded to include many baked products. Modified starches and starch-complexing agents were developed to provide more economical freeze-thaw stability to frozen foods. Thus, the use of waxy rice did not increase with the increase in production of frozen foods.

Consumption of waxy rice in the United States generally has been limited to specialty foods traditionally used by Asian cultures, eg, *mochi* and *manju* by Japanese and a variety of dessert items by Chinese and Filipinos. Until recently, one variety, Mochigome, grown in California, fulfilled the market demand for these products. Increased immigration from other Asian countries and increased export demand has motivated development of additional varieties. Currently, three waxy varieties are available in California, and each gives slightly different eating-quality characteristics to the traditional products. No known commercial production is available from other states.

This article describes the results of several physicochemical measurements made in an effort to find distinguishing criteria to explain differences in eating quality noted for *mochi* made with the three commercial waxy rice varieties grown in the United States. We also discuss possible applications designed to exploit the freeze-thaw stability afforded by waxy rice flour in frozen products.

[1]Mention of firm names or trade products does not imply that they are endorsed or recommended by the U.S. Department of Agriculture over other firms or similar products not mentioned.
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MATERIALS AND METHODS

Initial studies were conducted on flours and second head rice from 1981 crops. The major part of this study is concerned with three waxy rice varieties obtained as milled white rice from the 1982 crops grown in California. They were Ampec from Pacific International Rice Mills, Inc. (PIRMI), Woodland, CA; Calmochi-202 from Butte County Rice Cooperative, Richvale, CA; and Mochigome from Koda Brothers, South Dos Palos, CA. Ampec is a proprietary variety released by Rice Researchers, Inc., Glenn, CA, in 1974. Calmochi-202 was developed at the Rice Experiment Station at Biggs, CA (Carnahan et al 1981). Mochigome is an old variety introduced into California from Japan in the mid-1930s and privately developed. It was the only variety available until recent years and is the preferred waxy variety for traditional *mochi* cakes.

Length and width of 20 milled rice kernels were measured according to ARS (1973), using a Nikon SMZ-10 microscope with reflected light at 8 × magnification. Length is the distance between the most distant tips of the kernel; width is the distance across the kernel at the widest point (ARS 1973). The 1,000-grain weight was obtained by averaging the weights of two random samples of 100 kernels and multiplying by 10.

Flours were obtained from the milled rice, using a Brabender Quadrumat Junior Mill No. 46 fitted with a Brabender reel sifter No. 64 grit gauze. Particle-size distribution of the flours was made according to the Ro-tap method of Nishita and Bean (1982). Protein was determined by AACC method 46-11 (1983). Amylose was determined by the method of BeMiller (1964), a procedure suitable for trace amounts of amylose in the presence of amylopectin.

Gel-consistency determinations were made by the method of Cagampang et al (1973). Sample weight increased from 100 to 200 mg to aid differentiation of the extremely soft waxy rices.

Pasting characteristics were determined in a Brabender Visco/amylo/Graph using a 700 cm-g sensitivity cartridge. Freshly milled flours and flours aged 12 weeks at room temperature were suspended with all but 100 ml of total water in a 1,000-ml Erlenmeyer flask and shaken 50 times in 30 sec. After transferring to the amylograph bowl, the remaining 100 ml of water was used to rinse the flask. The very low pasting viscosity of the waxy flours obtained with the 10% slurry (50 g/450 ml) necessitated use of 20% slurries (100 g/400 ml) to fully evaluate pasting history. This is twice the quantity used with nonwaxy rices (Halick and Kelly 1959). Slurries were heated from 30 to 97°C, held at 97° C for 20 min, then cooled to 50°C. Heating and cooling rates were 1.5°C/min. A 30% slurry concentration (165 g/385 ml) was used to estimate the apparent gelatinization temperature at the 20-

Brabender unit (BU) intercept of the viscosity increase curve. This slurry was mixed with a stirring rod in a 1,000-ml beaker to facilitate dispersion.

Loss of birefringence was determined on a 1% slurry on a polarizing microscope equipped with a Kofler hot stage at a heating rate of 5° C/min. Birefringence endpoint temperature (BEPT) was determined at 95% extinction. Differential scanning calorimetry (DSC) was obtained on a 1981 flour at a heating rate of 5° C/min, essentially as described by Donovan et al (1983). Alkali spreading values were determined in duplicate by the method of Little et al (1958), using 1.7% KOH, and also using 1.3% KOH as recommended by Palmiano and Juliano (1972) for waxy rice.

Moisture content of rice flours was determined by AACC method 44-40 (1983). For water uptake during *mochi* preparation, moisture was determined on raw, soaked, steamed, and kneaded (*mochi*) rice by the modified two-stage air-oven method: AACC method 44-18 followed by method 44-19 (1983).

Mochi cakes were made in an electric *mochi* maker (National, SD-1801, Matsushita Electric Trading Co., Ltd., Central Osaka, Japan). According to the manufacturer's directions, 1 kg of rice was soaked in excess water for more than 8–12 hr (17 hr in our case) at ambient temperature (22–24° C), drained, and placed in the *mochi* maker, which steamed the rice in 23 min and kneaded it to a smooth paste (*mochi*) in 7 min. Water (348 ml) was used in the steam tank for the cooking process. This *mochi* maker combines an automatic rice cooker/steamer and a central impeller, which performs a kneading action on dough by pulling it into the central pin as it rotates. The sticky rice easily forms a cohesive film. (Traditionally, the steamed rice was pounded to a paste with a wooden mallet.) Water uptake was determined during the process by measuring moisture content of the rice at several stages in the preparation. Moisture content is reported as a percentage of the combined weight of rice and water.

Water uptake of the raw milled rices was determined according to Yanase et al (1982a) by soaking 20 g of rice (12% mb) in 100 ml of distilled water for periods up to 16 hr at ambient temperature (22–24° C), carefully draining the soaked rice to remove water, and weighing the drained, soaked rice. The increase in weight is calculated and reported as the percentage absorbed by the 20 g of rice.

RESULTS AND DISCUSSION

Physicochemical Properties.

Table I gives some physicochemical properties of the 1982 crop of waxy rices that are pertinent to this study. Some values from literature are shown for other rice types for comparison. The length and length/width (L/W) ratio classifies these waxy rices as short grain (ARS 1973). The L/W ratio also suggests a bold shape designation by IRRI classification (Khush et al 1979). The 1,000-grain weight shows minor differences among the waxy varieties, and all three were within the range reported for medium-grain, white milled rice. These samples were obtained as milled rices, and different degrees of milling may account for slightly different 1,000-grain weights.

Protein contents of the waxy rices are similar and slightly higher than those of short-grain rice. Amylose contents are almost negligible, resulting in very soft gel consistencies—essentially no gel. However, other rices also give similarly soft gel consistencies while containing amylose. This gel consistency test is used widely for screening among rices with very different cooking characteristics, eg, dry and flaky versus soft and sticky, but it is not sensitive to differences that may exist among the three waxy rices of our study. Independent tests[5] gave similar gel consistency values for these three samples, but higher gel viscosity values for Mochigome when a Wells-Brookfield viscometer was used on the gel consistency samples.

Particle-size determinations on the flours milled from the white kernels (Table II) showed no significant differences in size-distribution characteristics among the three varieties when roller milled. The size distribution and PS50 values indicated that they were somewhat coarser than a roller-milled, California medium-grain rice (Nishita and Bean 1982). In Asian countries, commercial rice flours are available in a range of particle sizes appropriate to different applications. Commercial use in the United States has not yet developed a need for a wide range of specific flour characteristics, especially for waxy rices.

Gelatinization Characteristics

Figure 1 shows amylograph pasting curves for one variety (Mochigome) for 10 and 20% slurry concentrations of freshly milled flour and the same flour after aging at room temperature for 12 weeks. A 30% slurry curve for the same flour held in frozen storage after milling is included to provide an estimate for the onset of gelatinization temperature. Selected data points from amylograph curves are summarized in Table III for all three varieties.

All samples gave higher viscosities for flours held at room temperature (22–24° C) for 12 weeks (Fig. 1 and Table III). Although minor, these changes may indicate that the aging phenomenon had not been completed when the samples were received as milled rices approximately six months after harvest. Before that, they had been in commercial storage at room temperature, first as paddy (rough), then as milled rice. The time interval at each stage is unknown. Villareal et al (1976) has shown that aging changes, demonstrated by amylography, occurred in rough and milled rices stored at 29° C for six months. They also showed viscosity increases for stored starches isolated from fresh rice before storage. Perez and Juliano (1981) have shown viscosity changes (increases) to be most rapid in the first three months after

[5] B. O. Juliano. 1984. Personal communication.

TABLE I
Some Physicochemical Properties of U.S. Waxy Rices Compared with Literature Values for Nonwaxy Rices

	Average Length (mm)	Average Length/Width Ratio	Average 1,000-Grain Wt (g)	Protein[a] (N × 5.95, %)	Amylose[b] (%)	Gel Consistency[c] (mm)
Waxy rices						
Ampec	4.52	1.61:1	18.3	6.9	0.78	88.5
Calmochi-202	4.46	1.64:1	18.7	7.0	0.85	83.5
Mochigome	4.68	1.66:1	19.4	7.0	0.23	93.0
Typical U.S. commercial rices[d]						
Short	5.2–5.4	1.7:1–2.0:1	20–23	6–6.5	18–20	
Medium	5.5–5.8	2.1:1–2.3:1	17–21	6–7	15–20	64–88
Long	6.7–7.0	3.4:1–3.6:1	15–18	6–7.5	23–26	45–87

[a] Waxy rice protein reported on 11% moisture basis to facilitate comparison with published commercial rice values.
[b] Percent of starch, dry basis.
[c] Two hundred milligrams of waxy rice flour. Others, 100 mg of rice flour.
[d] Gel consistency from Nishita and Bean (1979). All others, from B.D. Webb (1980).

harvest for milled rices stored at 28–30° C. Little or no change was observed in stored flours obtained from milled rice "well aged" for four to six months (Juliano 1984).

Viscosity changes upon storage have been suggested to be due to changes in components other than starch (eg, lipids and cell wall polysaccharides) that, in turn, affect starch gelatinization behavior (Barber 1972, Shibuya and Iwasaki 1982). Starches isolated by Shibuya et al (1977) from fresh and stored rices did not show differences in their amylograph viscosities. This contrasts with findings of Villareal et al (1976), who stored starches isolated from fresh rice and found differences noted above.

Such changes on storage of rice and of flours indicate the need for caution when comparing values from several samples. It is probably best to "age" the flour for a few months or to use freshly milled flour from well-aged rice to improve interpretation and comparison of data.

Flour from Mochigome variety gave lower amylograph viscosities than Ampec or Calmochi, which were similar throughout pasting (Table III). Although slight, the lower viscosity exhibited for the Mochigome flour was consistent for all amylograph runs (some not shown) and may indicate a varietal characteristic worth pursuing. However, caution must be taken in arriving at such a conclusion because these are single samples from one crop year and because the aging history of these samples is undocumented. Slight varietal differences are discussed later in relation to other gelatinization characteristics.

TABLE II
Particle-Size Distribution of Roller-milled Rice Flours

	Cumulative Percentage Through Sieve No.						PS50[a] (μm)
	200	140	120	100	70	50	
Waxy							
Ampec	5.2	10.7	16.2	24.2	50.4	86.9	208
Calmochi-202	4.8	9.0	13.6	20.3	42.9	84.2	219
Mochigome	4.7	9.9	15.0	22.2	47.0	85.3	213
Medium[b]	10.3	21.0	31.3	46.8	89.1	100.0	155

[a]PS50 = estimated sieve size through which 50% of the sample would pass.
[b]Adapted from Nishita and Bean (1982).

A major difference in gelatinization behavior of the waxy rices compared with nonwaxy rices and other cereal grains is the low temperature (65–66° C) at which the peak viscosity occurs (Table III). This follows soon after the temperature range of the loss of birefringence. Microscopic examination during heating shows that the granules swell to double or triple the original diameter by 65° C, then immediately collapse. This behavior contrasts with that for amylose-containing cereal starches, which swell upon loss of birefringence but remain as swollen entities until a second swelling followed by bursting and collapsing, usually above 80° C when the major viscosity increase occurs. This was shown pictorially by Miller et al (1973). The two-stage viscosity increase is evident in amylographs containing carboxymethylcellulose (CMC) (Sandstedt and Abbott 1964, Juliano and Perdon 1975). We could not demonstrate it with our waxy rice flours (data not shown). Only the first peak occurred, delayed until 75° C in a 1% CMC solution.

Table IV shows some additional gelatinization characteristics of the waxy rices. The low viscosities obtained with these flours necessitated the use of a 30% slurry (instead of 20%) to estimate the temperature of onset of gelatinization and swelling. Such low

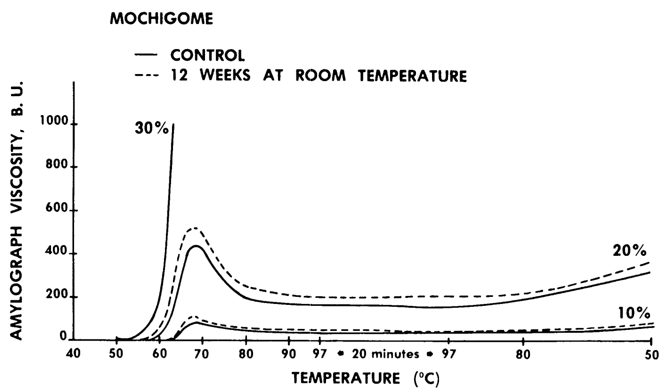

Fig. 1. Amylograph pasting curves for Mochigome waxy rice flour: Control, 10 and 20% slurries tested within 24 hr of milling; 30% slurries tested on flours stored at −23° C.

TABLE III
Amylograph Characteristics of Fresh Roller-milled and Stored[a] U.S. Commercial Waxy Rices

	Viscosity (BU)			Temperature (° C)	
Slurries	Peak	Hold 20 Min	Cool to 50° C	First increase (20 BU)	Peak
10%					
Ampec					
Fresh	135	50	80	62.5	66.5
Stored	155	57	100	63	67
Calmochi-202					
Fresh	145	50	90	63	66.5
Stored	160	55	98	63	67
Mochigome					
Fresh	95	40	75	63.5	67
Stored	110	45	80	64	68
20%					
Ampec					
Fresh	535	185	340	58	66.5
Stored	650	235	417	58.5	67.5
Calmochi-202					
Fresh	555	200	365	59	67
Stored	670	238	408	58.5	66.5
Mochigome					
Fresh	435	160	315	59	68.5
Stored	515	210	370	58.5	67
30%[b]					
Ampec	2,530	630	1,275	53	65
Calmochi-202	2,610	630	1,230	53.5	66
Mochigome	2,190	555	1,115	54	66

[a]Ten and 20% slurries run within 24 hr of milling and after 12 weeks at room temperature.
[b]Stored at 23° C until tested.

viscosity values for waxy rices relative to their nonwaxy counterparts is consistently noted in studies from many countries, irrespective of grain length of the waxy variety (Bhattacharya and Sowbhagya 1979, Villareal et al 1976). When the slurry concentration was increased to 30% to obtain an estimate of the onset of swelling and gelatinization, all three flours showed the initial viscosity increase between 53 and 54°C (Table IV). A viscosity peak was obtained at 65–66°C in these 30% slurries. Microscopic determination of BEPT showed all three varieties lost 95% of birefringence by 61–62°C. All birefringence had disappeared by 65–66°C.

Table IV also shows alkali spreading values for the waxy rices. This test using 1.7% KOH has proved useful in studying commercial and breeder samples of rices having a wide range of starch-gelatinization temperatures (Kongseree 1979, Webb 1980, Bhattacharya et al 1972, Khush et al 1979). The spreading values indicating degree of degradation by alkali have an inverse relationship with gelatinization temperature (Juliano et al 1964). Short-grain waxy rices tend to have low gelatinization temperatures, indicated by the high alkali spreading values. The samples shown here all gave the maximum spreading and clearing values using 1.7% KOH. When the alkali concentration was lowered to 1.3%, as recommended by Palmiano and Juliano (1972), the three waxy rice varieties showed some differences. The lower value (5.6) for Mochigome is consistent with its tendency toward a slightly higher temperature of initial viscosity increase of a 30% slurry and the final BEPT values from Kofler hot-stage determination (Table IV). The general trends with these different tests were similar; the small differences observed among the rices may be worthy of further study of samples from future crop years.

Differential Scanning Calorimetry

Differential scanning calorimetry (Fig. 2) on flour from the 1981 crop of Mochigome gave a temperature of gelatinization (T_{max}) of 67.1°C. This is in the same temperature range as the peak viscosity temperature exhibited by its 1982 counterpart (Table III). Several other waxy rice flours (not shown) gave T_{max} within 1°C of this sample. Waxy flours do not exhibit a phase transition between 90 and 100°C. This transition was identified as the melting of an amylose-lipid complex by Kugimiya et al (1980). Its relationship to rice starch was recently studied by Russell and Juliano (1983).

TABLE IV
Gelatinization Properties

	Amylograph Viscosity[a] Initial Viscosity Rise to 20 BU (°C)	Amylograph Viscosity[a] Peak Viscosity Temperature (°C)	Final BEPT[b] (°C)	Alkali Spreading KOH 1.7%	Alkali Spreading KOH 1.3%
Ampec	53.0	65	61.0	7.0	6.0
Calmochi-202	53.5	66	61.8	7.0	6.6
Mochigome	54.0	66	62.0	7.0	5.6

[a]Thirty percent slurry concentration, flours stored at −10°C until tested.
[b]Ninety-five percent loss of birefringence.

TABLE V
Hydration Characteristics of Three U.S. Commercial Waxy Rices: Water Uptake During Soaking[a]

Soaking Time	Ampec	Calmochi-202	Mochigome
15 min	27.50	27.64	28.48
30 min	37.87	40.26	36.58
1 hr	41.03	42.34	42.63
2 hr	42.76	44.42	45.56
3 hr	44.94	46.20	46.23
16 hr	44.99	44.57	44.33

[a]Percent absorbed by 20-g sample.

TABLE VI
Moisture Content at Stages of Mochi Making[a]

	Ampec	Calmochi-202	Mochigome
Kernel	13.86	14.02	14.67
Soaked 17 hr	41.04	41.26	40.84
Steamed	45.04	43.89	45.63
Kneaded (*mochi*)	43.68	45.00	44.48

[a]Percent of total weight.

Hydration Characteristics

In Asian cultures in which rice is a dietary staple, rice is commonly soaked in water several hours or overnight before cooking. The water uptake during this hydration period has served as a useful criterion for quality evaluation of rice varieties (Yanase et al 1982a, 1982b; Indudhara Swamy et al 1971). Table V shows the water uptake of the three waxy rices measured on 20-g samples by the method of Yanase et al (1982a). Table VI shows moisture content of aliquots from 1 kg samples taken during *mochi* preparation.

In the 20-g test (Table V), most of the water is taken up in 1 hr. The remaining time equilibrates the moisture throughout the kernels. The differences among the three varieties are minor and variable in rate of water uptake and in the final percentage absorbed. Our values do not appear to account for the differences in *mochi* cake quality ascribed to these varieties. Japanese workers (Yanase et al 1982b) have found greater differences in water uptake when studying rices from worldwide selections. Bhattacharya et al (1972) found that the waxy types and low-amylose nonwaxy types gave higher water uptake than high-amylose rices and attributed this difference to their higher amylopectin content.

When moisture uptake is followed during soaking, steaming, and kneading in the preparation of *mochi*, most of the water in the final product is already present in the hydration (soaking) stage (Table VI). Some additional water is absorbed and retained during steaming and kneading. Again, no trend is apparent to suggest that the preferred Mochigome is different.

Table VI reports moisture as a percentage of total weight of rice and water so should not be compared directly with the water-uptake data of Table V. Both procedures are used in the literature to follow water hydration/absorption. If one were converted into the other for direct comparison, the larger kilogram samples would have higher water uptake, whether measured by weight of sample

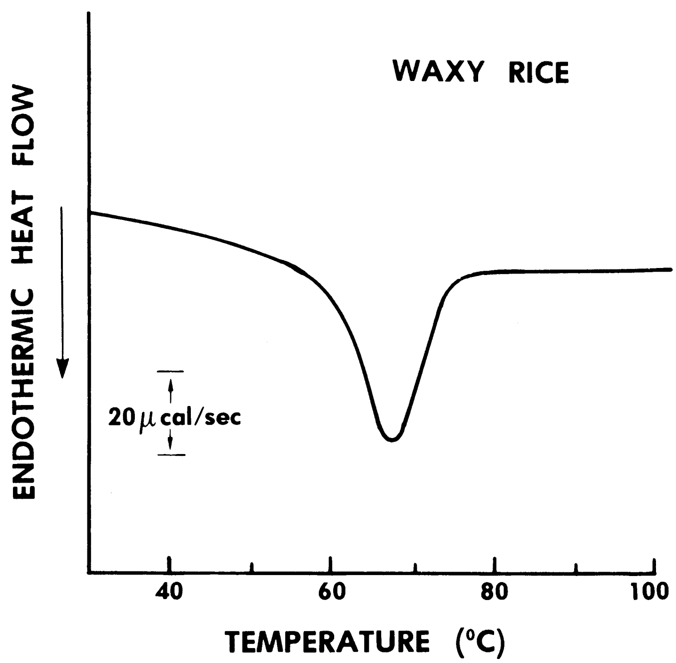

Fig. 2. Differential scanning calorimeter curve for waxy rice flour, Mochigome variety. Sample weight 1.93 mg (db) with 15.14 mg of water. Enthalpy of gelatinization, 2.58 cal/g; T_{max} = 67.1°C.

or by drying-oven techniques. Caution is suggested in using 20-g samples to predict *mochi* moisture contents.

In the United States, most cooking procedures for nonwaxy rices normally have dry rice added to boiling water; thus the more important rice-water relationship is the amount of water to use initially, allowing for absorption by the rice and evaporation during cooking. Such experiments have not been reported for waxy rices and are outside the scope of this article. However, approximately one and one-half parts of water to one part of rice (by volume) would be sufficient to cook the rice by this method.

Limited tests with the waxy rices in American food products suggested potential applications. Freeze-thaw stability observations on flour-water pastes showed that flours from all three waxy varieties yielded smooth pastes that showed no syneresis or retrogradation, whereas flours from medium-grain rice gave curdled pastes, and flours from long-grain rice gave rigid sponges. Early work by Hanson et al (1951, 1953) lead one to expect these results. Some waxy rices from other countries have higher gelatinization temperatures and poorer freeze-thaw stabilities than these California varieties (IRRI 1979).

The soft, sticky nature of cooked, waxy rice flour imparted a desirable soft texture to waffles made with 10–15% rice flour blended with wheat flour. They also imparted the typical crispness afforded by rice flour. The soft and crisp qualities were retained after freezing, thawing, and reheating in a toaster.

CONCLUSIONS

Several physicochemical tests applied to the three waxy rices grown in the United States indicate all the rices have characteristics typical of short, bold, japonica grain type. The minor differences among them were slight, even though traditional users found one variety, Mochigome, preferable for *mochi* rice cakes. In this study, Mochigome variety exhibited slightly lower amylograph viscosity throughout pasting, slightly higher BEPT, and slightly lower alkali spreading value (indicative of higher gelatinization temperature). Although these differences were not marked, they were consistent and all related to starch properties. Independently, Juliano found a higher Wells-Brookfield viscosity value for the Mochigome gel-consistency sample. Further studies using other crop years would confirm or deny the existence of real differences. A study of the basic components, especially the starch, appears necessary to define such differences. This set of three waxy varieties all grown in the same environment appears to offer a suitable set for studying the fine structure of the amylopectin starch component or other components identifiable with varietal differences.

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Note: The spelling of Mochigome in this paper is correct and confirmed by Koda Brothers, owners of the variety. It differs from the spelling of a similar variety in the USDA World Collection of Rice Varieties.

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