Starch Damage and Pasting Properties of Rice Flours Produced by Dry Jet Grinding

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ABSTRACT

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Milling method and particle size affect some properties of rice flour. To prepare ultra-fine rice flour of <30 µm, hammer and dry jet grinding methods were examined and the effect of particle size on starch damage and pasting properties of the flour were elucidated. A jet mill could make finer flour (<10 µm mean size) with a narrower particle size distribution than a hammer mill could. Starch damage increased dramatically at a mean size of <10 µm. Particles of a similar size (<60 µm) had different levels of starch damage between mills. Not only the particle size, but also the milling method affected the level of damaged starch. Flour samples of ≥45 µm mean size had similar viscosity curves, but samples of <20 µm had different curves. Peak viscosity and final viscosity decreased sharply at <10 µm. Setback viscosity for particles of 3 µm from both brown rice and white rice were higher than the peak viscosity. Stability to heat and shearing stress were decreased for <20 µm flours as the breakdown viscosities decreased. Starch damage and pasting properties of flour ground from the nonwaxy japonica cultivar Koshihikari changed dramatically at a mean size of <10 µm.

Rice is a staple food in Asia and it is usually consumed as whole grain. Consequently, most research concerns grain qualities like cooked rice texture (Okabe 1979; Chikubu et al 1985; Ohtsubo et al 1988; Okadome et al 2005). Additionally, use of rice flour in Japanese confectionery and bread has been reported (Takano et al 1980; Arisaka et al 1992).

The quality of flour is affected by the particle size distribution and the proportion of damaged starch (Morrison et al 1994). Starch damage is an important and well-recognized criterion of flour quality (Farrand 1964; Tipples 1969); the particle size distribution is used to evaluate its influence on processing and the characteristics of the final product. The degree of damaged starch signifies the quality of the flour and influences the absorption of water (Nishita and Bean 1982), the rheological properties, and the fermentation of the leavened products, which in turn determine the crumb firmness and the crust color of bread. The absorption of water permitted by the damaged starch brings advantages during the breadmaking process, mainly because it supports sugar fermentation, although the dough volume rise depends merely on the presence of high-quality gluten. Pasting properties depend on the rigidity of starch granules, which in turn affects granule swelling potential (Sandhya Rani and Bhattacharya 1989) and the amount of amylose leaching out (Morris 1990). Increase in viscosity with temperature may be attributed to the removal of water from the exuded amylose by the granules as they swell (Ghiasi et al 1982; Miles et al 1985), and the increase in final viscosity might be due to aggregation of the amylose molecules. Milling methods affect the functional properties of rice flour and hence their use in novel foods (Kadan et al 2008).

Recently, several fine grinding methods have been developed to expand the use of rice flour (Yoza et al 2008). The flour prepared by these methods, now used in bread and confectionary, is >30 µm in mean size. However, few studies have examined rice flour of <30 µm and the physicochemical properties of such finer rice flours are virtually unknown.

The objectives of this study were to develop methods that can grind rice into ultra-fine particles of <30 µm and to elucidate the effects of the particle size on the physicochemical properties of the flour.

MATERIALS AND METHODS

Materials

Nonwaxy japonica cultivar Koshihikari brown rice, grown in 2007 in Ibaraki prefecture Japan, was collected from the local market and used as the main material. It was stored at 5°C. White rice grain was prepared by polishing brown rice in a rice polisher (CBS300AS, Satake, Hiroshima, Japan). Based on brown rice milling yield (MY) from a standard of 100% MY, the brown rice was milled to 91% MY.

Pulverization and Size Measurement

Both brown and white rice flours of different mean sizes were prepared in two different kinds of mills. A water-cooled hammer mill (1018-S-3; Yoshida Seisakusho, Tokyo, Japan) was used to prepare particles with a mean size range of 100–50 µm, sorted by screens of the hammer mill (2, 1, and 0.7 mm screens to obtain ≥100, ≥70, and ≥45 µm, respectively, with a constant feed rate). The yields of the flour were 92–95%. A jet mill (IDS-2, Nippon Pneumatic, Osaka, Japan) was used to pulverize rice by releasing compressed air from a nozzle (Fig. 1), slamming the rice into a ceramic board at faster velocity. The flour is slammed repeatedly, and the fine flour is collected from a cyclone classifier (Fig. 1B) of the jet mill. The cyclone classifier separates the larger and the smaller size particles during grinding. The larger particles go to the grinding chamber repeatedly and the smaller particles go to the sample collector. Particles with a mean size of 50–3 µm were obtained using the jet mill. Different size particles were obtained by changing the distance between the nozzle and the ceramic board impact plate with different pressures and feed rates. To obtain the targeted 3, 15, and 35 µm particles, the nozzle stagnation pressures were 0.65, 0.42, and 0.30 MPa and distances between the nozzle and the impact plate were 62, 92, and 149 mm respectively. The feed rates were 6, 12, and 12 kg/hr to get particles ≥3, ≥15, and ≥30 µm, respectively. The yields of the flours were 89–94% by weight.

Mean particle size of the flour samples were measured using a laser diffraction particle size analyzer (SALD-2100, Shimadzu, Kyoto, Japan).

Hammer 1, Hammer 2, and Hammer 3 represent mean sizes of rice flour of 117 and 113 µm, 91 and 73 µm, and 53 and 48 µm, respectively, for white and brown rice ground by hammer mill. Jet

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1, Jet 2, and Jet 3 represent the mean sizes of 45 and 35 μm, 14 and 16 μm, and 3.2 and 3.8 μm, respectively, for white and brown rice flour ground by jet mill.

Pasting Properties

The moisture content of rice powder was determined by drying 2 g of sample in an oven at 135°C for 1 hr and was expressed as the average value of triplicate determinations on a percent wet basis (%wb). The pasting properties of the samples were measured with a Rapid ViscoAnalyser (RVA-4; Newport Scientific, Warriewood, NSW, Australia) (Toyoshima et al 1997). Either 4.0 g of brown rice flour or 3.5 g of white rice flour (14% moisture basis) was transferred into a canister and 25 ± 0.1 mL of deionized water was added (corrected to compensate for 14% moisture). The slurry was stirred at 160 rpm for 10 sec for thorough dispersion. The slurry was held at 50°C for 1 min, heated to 93°C over 4 min, and held there for 7 min, and then cooled to 50°C over 4 min and held there for 3 min. The pasting temperature (at which viscosity first increases by at least 25 cP), peak viscosity (the maximum viscosity), peak time (when peak viscosity occurred), trough viscosity (the minimum viscosity), final viscosity (at the end of the test after cooling), breakdown viscosity (peak viscosity – trough viscosity), and setback viscosity (final viscosity – peak viscosity) were calculated from the pasting curve with Thermocline v. 2.2 software (Newport Scientific).

Starch Damage

Starch damage was determined according to Approved Method 76-31.01 (AACC International 2010) (Gibson et al 1993) with a starch damage assay kit (Megazyme International Ireland, Bray, Ireland). Damaged starch granules were hydrated and hydrolyzed to maltosaccharides plus α-limit dextrins by carefully controlled treatment with purified fungal α-amylase. Fungal α-amylase treatment was designed to give near complete solubilization of damaged granules with minimum breakdown of undamaged granules. This reaction was terminated on addition of dilute sulfuric acid and aliquots were treated with excess levels of purified amyloglucosidase to give complete degradation of starch-derived dextrins to glucose. Glucose was measured with a high purity glucose oxidase peroxidase (GODPOD) reagent mixture. Determined values were presented as starch (damaged) as a percentage of flour weight on an as-is basis. Rice flour (100 mg) and starch control (supplied with the assay kit) were put into two thick-walled glass centrifuge tubes and incubated with 1 mL of fungal α-amylase at 40°C for exactly 10 min. Diluted sulfuric acid solution (8.0 mL) was added (0.2% v/v) to each tube after exactly 10 min from the time of addition of fungal α-amylase. The tubes were centrifuged at 1,000 × *g* for 5 min. Aliquots (0.1 mL) of the supernatant solution were transferred to the bottom of two test tubes. Amyloglucosidase (0.1 mL) solution (2 U) was added to each tube and incubated at 40°C for 10 min. GOPOD reagent solution (4.0 mL) was added to each tube (including glucose standards and reagent blank tubes) and the tubes were incubated at 40°C for 20 min. The absorbance of all solutions was measured at 510 nm against a reagent blank by UV-VIS spectrophotometer.

Statistical Analyses

All experimental data were expressed as the average value of triplicate determinations. Mean values and the standard deviations were reported. Hierarchical cluster analysis was used with peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, and starch damage as variables. Hierarchical cluster analysis, ANOVA, and mean separations used Duncan's test ($P \leq 0.05$) (v.17.0, SPSS, Chicago, IL).

RESULTS AND DISCUSSION

Pulverization and Particle Size Distribution

The hammer mill produced rice flours with mean sizes of 117–53 μm from white rice and 113–48 μm from brown rice. The temperatures of different flours obtained from the hammer mill were increased up to 50°C. The jet mill produced rice flours with mean sizes of 45–3.2 μm from white rice and 35–3.8 μm from brown rice. The jet mill could produce flour finer than 10 μm, with a narrower particle size distribution than from the hammer mill without changing the temperature.

In size distribution, standard deviations between volume fractions of 10, 50, and 90% decreased for jet mill flours more than those of the hammer mill (Table I). For white (53 μm) and brown rice (48 μm), Hammer 1 (Fig. 2) shows three peaks including one at <1 μm. For Jet 2, both white (14 μm) and brown (16 μm) rice show two peaks, each sample had one peak at <1 μm. Jet 1 brown (3 μm) had two peaks, one at 6.7–12 μm. Hammer 2, Hammer 3, and Jet 3 have one peak each. Hammer 3 produced flour with

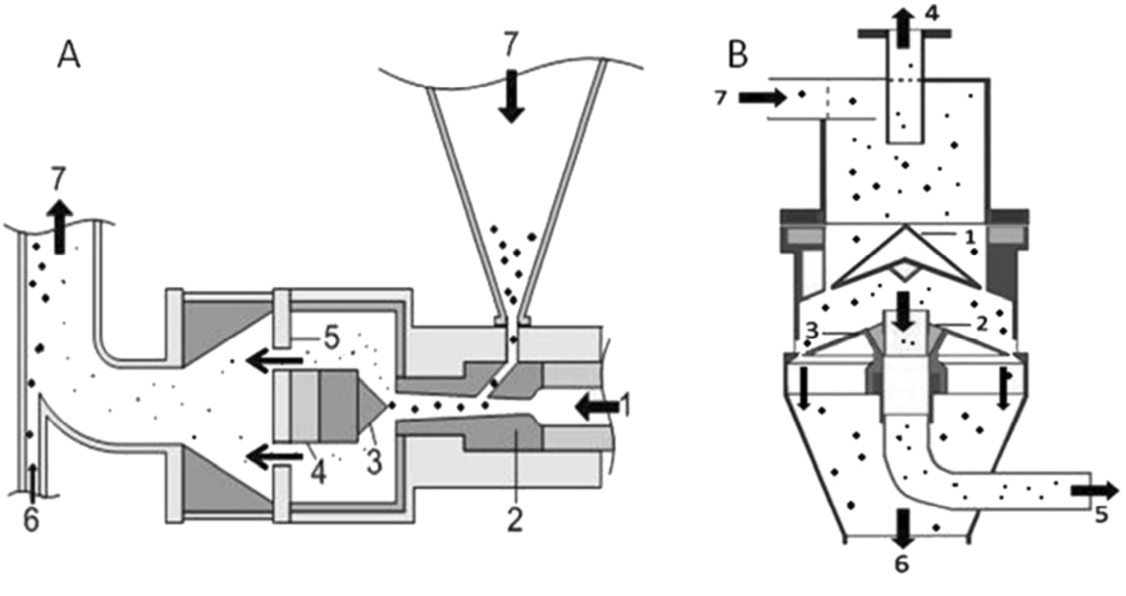

Fig. 1. Schematic of the operating principle of IDS2 jet mill. **A,** Grinding chamber: 1, compressor; 2, nozzle; 3, impact plate; 4, adjust ring for the impact plate; 5, impact plate upholder; 6, feeder; 7, cyclone classifier. **B,** Cyclone classifier: 1, center core; 2, center navel; 3, separate core; 4, exhauster; 5, sample collector; 6, grinding chamber; 7, feeder.

multimodal distribution. However, Jet 1 and Jet 2 produced flours with a bimodal distribution. The average particle size significantly differs for multimodal distribution flour compared with single peak distribution (Di Stasio et al 2007).

TABLE I
Volume Distribution (%µm) with Standard Deviation (SD) of Rice Flours Evaluated

	10.0%	50.0%	90.0%	SD
White rice flour				
Hammer 1	35.2	141.2	292.1	129.1
Hammer2	24.1	113.3	222.7	99.5
Hammer 3	11.7	72.3	190.2	90.7
Jet 1	18.9	51.2	88	34.6
Jet 2	4	18.6	33.6	14.8
Jet 3	1.6	3.28	6	2.2
Brown rice flour				
Hammer 1	23.8	148.1	336.3	157.4
Hammer 2	17	96.6	204.3	94
Hammer 3	10.1	63.5	182.5	88.3
Jet 1	10.6	47.6	90.9	40.2
Jet 2	3.7	22.1	45.3	20.8
Jet 3	1.5	3.7	8.9	3.8

Effects of Mean Particle Size on Starch Damage

Starch damage of rice flour tended to increase with smaller mean size of flours from both mills (Fig. 3). But jet milled white rice flour at 45 µm had less starch damage than flour at 53 µm from the hammer mill, in spite of similar mean size. This result shows that the degree of starch damage depends to some extent on grinding method, even at a similar mean particle size. For samples prepared using a hammer mill, the starch damage changed gradually from 40 to 120 µm. On the other hand, the starch damage for rice flour samples prepared by jet milling increased sharply for <10 µm. Rice starch granules are the smallest of the starch grains produced by plants (3–8 µm), and compound granules with diameters of ≤150 µm form clusters of 20–60 individual granules (Zhongkai et al 2002). Both compound granules and starch granules broke down to 3–5 µm, which explains the sharp increase in damage. Thus, starch damage changed dramatically at <10 µm mean size.

Effects of Mean Particle Size on Pasting Properties

White flour samples of ≥45 µm had comparable viscosity curves (Fig. 4). But samples of <20 µm had different lower viscosity curves, especially at 3.2 µm. Brown rice flour samples showed similar results for ≥48 µm and had comparable viscosity

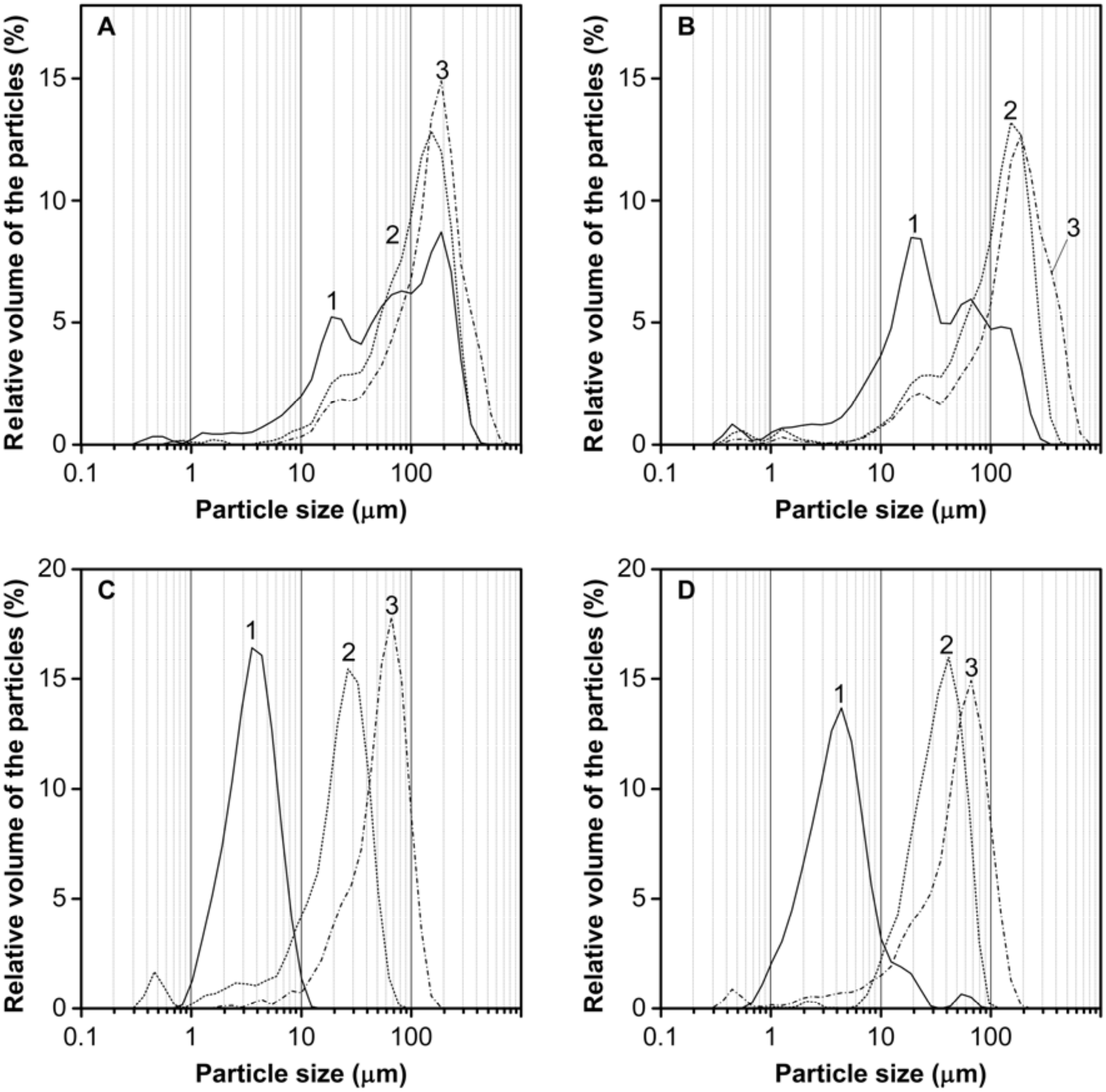

Fig. 2. Particle size distributions of rice flour. **A,** White rice flour: 1, Hammer 3; 2, Hammer 2; 3, Hammer 1. **B,** Brown rice flour: 1, Hammer 3; 2, Hammer 2; 3, Hammer 1. **C,** White rice flour: 1, Jet 3; 2, Jet 2; 3, Jet 1. **D,** Brown rice flour: 1, Jet 3; 2, Jet 2; 3, Jet 1.

curves, but samples <16 µm had lower viscosity curves. The pasting test is often used for evaluating the eating quality of rice because the peak viscosity or breakdown value is highly correlated with eating quality for nonwaxy japonica cultivars (Chikubu et al 1985). In RVA pasting tests of rice flour (Toyoshima et al 1997), japonica cultivars with excellent eating quality such as Koshihikari generally have very high peak viscosity or breakdown values, and the peak viscosity is higher than the final viscosity (Uyen et al 2001). The mean particle size was >45 µm and the flour had a higher peak viscosity than final viscosity using a standard laboratory cyclone mill, as did the RVA measurement (the pasting properties were the same). Unlike Koshihikari, the finest flours (3.2 µm) had a peak viscosity lower than the final viscosity. For particles <10 µm, the characteristics of Koshihikari were lost and the viscosity curve was dramatically changed.

Peak viscosity was almost constant at >50 µm but decreased gradually with the decrease of mean size to <50 µm (Fig. 5), and dramatically at <10 µm. A decrease of peak viscosity shows that the starch granules of smaller rice particles are more resistant to swelling than those of larger particles (Noomhorn et al 1997) and particle size affects the RVA measurement (Bryant et al 2001). Therefore, decrease of peak viscosity was due to reduction of mean size. As RVA breakdown is the difference between the peak viscosity and the trough viscosity, breakdown viscosity showed results similar to peak viscosity (Tables II and III).

The final viscosity decreased gradually with the decrease of mean size but decreased sharply at <10 µm. Rice cultivars with low amylose contents show lower final viscosities (Toyoshima et al 1997). This indicates that decreasing the particle size decreases the ability of the flour to form a gel after cooking and cooling (Bergman et al 2004). In addition, rice flour with low amylose content retrogrades much less than that with high amylose content and the degree of retrogradation is determined by the availability of long chains of amylose (Kim et al 2006). The retrogradation changed with the reduction, not only of the final viscosity but also of the mean size at <10 µm, even in the same cultivar.

Setback (final viscosity – peak viscosity) increased with the decrease in mean size at <50 µm (Fig. 6). The changing of pasting characteristics with grinding method and particle size to some extent support the idea that the pasting properties were greatly influenced by particle size of flour (Halick and Kellly 1959). On the other hand, similar particle size obtained from two grinding

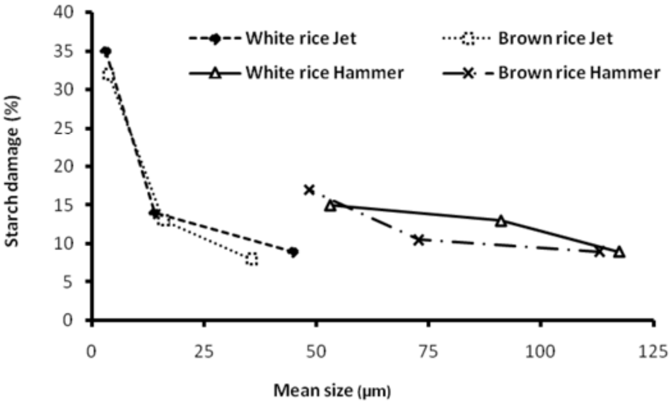

Fig. 3. Effect of particle size and grinding method on starch damage.

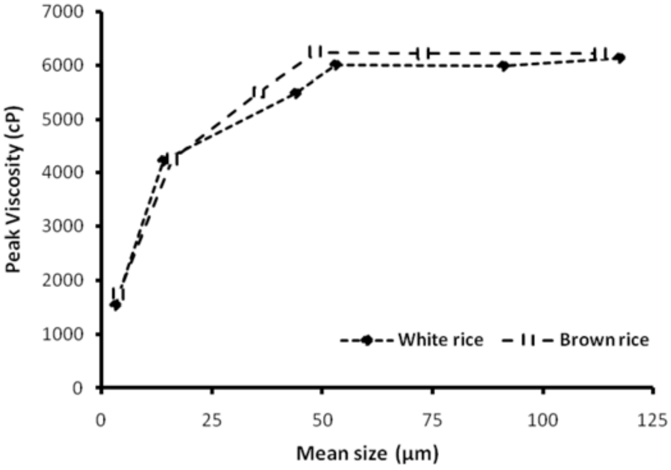

Fig. 5. Effect of particle size on peak viscosity.

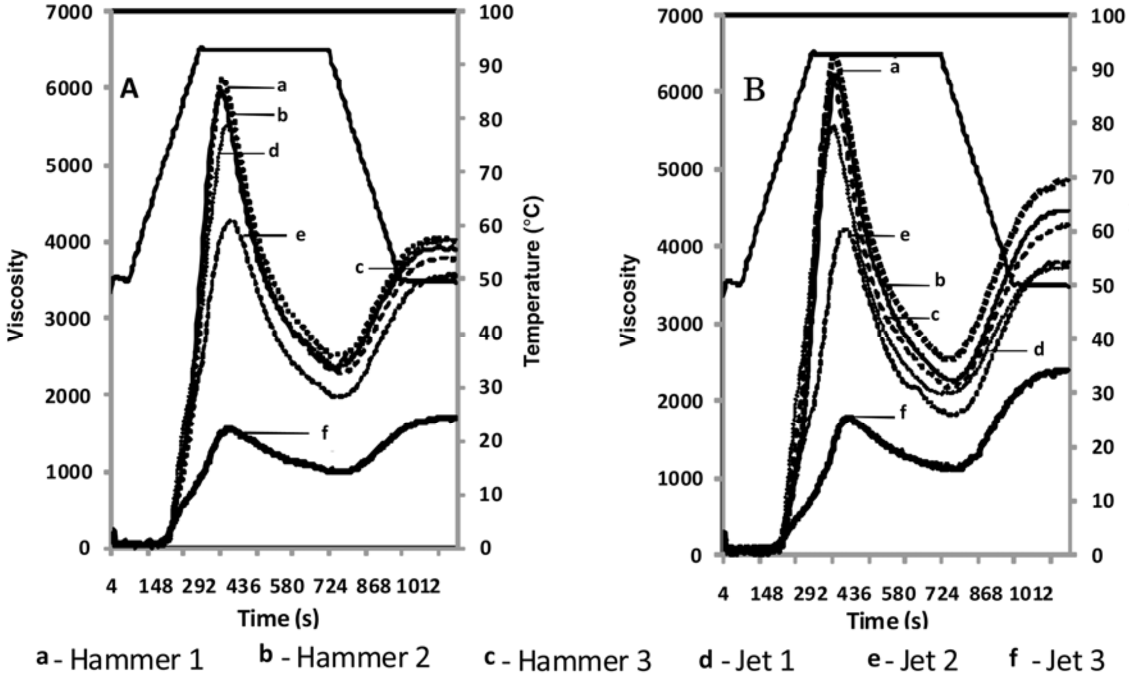

Fig. 4. Effect of particle size and grinding method on pasting characteristics of white rice (**A**) and brown rice flour (**B**).

TABLE II
Pasting Properties and Starch Damage in White Rice Flour by Particle Size and Mill[a]

Sample	Mean Size (μm)	Viscosity (cP) Peak	Trough	Breakdown	Final	Setback	Starch Damage %
Hammer 1	117	6,136 ± 11a	2,528 ± 21a	3,608 ± 32a	4,014 ± 16a	–2,122 ± 5a	9 ± 0.3e
Hammer 2	91	5,986 ± 51b	2,376 ± 28b	3,610 ± 23a	3,899 ± 32a	–2,087 ± 19a	12 ± 0.3d
Hammer 3	53	6,009 ± 52b	2,366 ± 29c	3,643 ± 23a	3,829 ± 91b	–2,165 ± 38a	15 ± 0.4b
Jet 1	45	5,488 ± 32c	2,463 ± 4c	3,025 ± 73b	4,063 ± 56b	–1,425 ± 88c	9 ± 0.2e
Jet 2	14	4,228 ± 61d	2,051 ± 34d	2,177 ± 95c	3,603 ± 68c	–625 ± 128b	14 ± 0.1c
Jet 3	3.2	1,537 ± 42e	1,007 ± 13e	530 ± 55d	1,705 ± 3d	168 ± 45a	35 ± 0.2a

[a] Values followed by the same letter in the same column are not significantly different ($P \leq 0.05$); significant values based on Duncan's test.

TABLE III
Pasting Properties and Starch Damage in Brown Rice Flour by Particle Size and Mill[a]

Sample	Mean Size (μm)	Viscosity (cP) Peak	Trough	Breakdown	Final	Setback	Starch Damage (%)
Hammer 1	113	6,493 ± 12a	2,639 ± 62a	3,858 ± 74b	4,916 ± 63a	–1,577 ± 75d	9.2 ± 0.0e
Hammer 2	73	6,213 ± 40b	2,353 ± 13b	3,860 ± 53ab	4,509 ± 39b	–1,703 ± 79e	10.5 ± 0.1d
Hammer 3	48	6,245 ± 4b	2,226 ± 9b	4,019 ± 13a	4,310 ± 29b	–1,935 ± 25be	17.3 ± 0.3b
Jet 1	35	5,505 ± 19c	2,222 ± 27b	3,283 ± 45c	4,340 ± 76b	–1,166 ± 94c	8.1 ± 0.8f
Jet 2	16	4,256 ± 23d	1,952 ± 89c	2,304 ± 66d	4,037 ± 99c	–368 ± 79b	12.5 ± 0.1c
Jet 3	3.8	1,746 ± 40e	1,118 ± 15d	628 ± 18e	2,374 ± 27d	629 ± 12a	32 ± 0.6a

[a] Values followed by the same letter in the same column are not significantly different ($P \leq 0.05$); significant values based on Duncan's test.

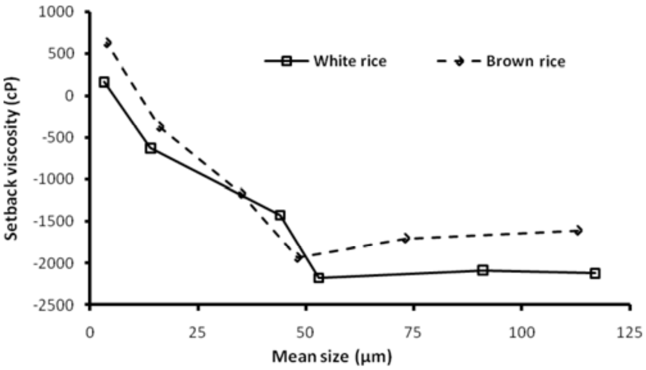

Fig. 6. Effect of particle size on setback viscosity.

methods gave different pasting properties. The use of different mills to prepare rice flour can result different sizes and damaged starch content and both factors affect pasting properties (Nishita and Ben 1982). Hierarchical cluster analysis shows that the flours with mean sizes of 120–50 μm had almost the same physicochemical properties (Fig. 7).

CONCLUSIONS

Hammer mill and jet mill were used to prepare fine rice flour. The jet mill could make much finer rice flour with a narrower particle size distribution. Starch damage increased dramatically at a mean size of <10 μm. Flour samples of ≥45 μm had similar viscosity curves, but samples of <20 μm had different curves, indicating lower viscosity. Peak viscosity and final viscosity decreased sharply at <10 μm. Flours of 120–50 μm had almost the same physicochemical properties. Properties changed gradually at <50 μm mean size and dramatically at <10 μm. Rice flour <10 μm are less stable to heat and shearing stress as the breakdown viscosities were lower for particles <20 μm.

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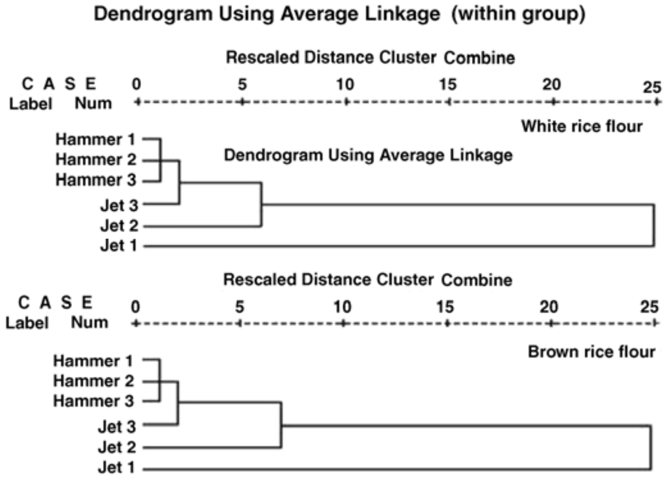

Fig. 7. Classification of starch damage and pasting properties by hierarchical cluster analysis.

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