異なる作物デンプンの微粉砕が糊化特性に与える影響

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著者	Hossen, Md. S. 五月女, 格 竹中, 真紀子 中嶋, 光敏 五十部, 誠一郎 岡留, 博司
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◇◇◇ Technical Paper ◇◇◇

Effect of Particle Size of Different Crop Starches and Their Flours on Pasting Properties

Md. Sharif HOSSEN[1,2], Itaru SOTOME[1], Makiko TAKENAKA[1], Seiichiro ISOBE[1,2], Mitsutoshi NAKAJIMA[1,2], and Hiroshi OKADOME[1,†]

[1]*National Food Research Institute, National Agriculture and Food Research Organization, Tsukuba, Ibaraki 305-8642, Japan*
[2]*Graduate school of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8572, Japan*

The effect of particle size reduction on the pasting properties of rice, wheat, corn (maize), potato, sweet potato, and cassava starches was elucidated. Before pulverizing, the mean particle size and the pasting properties of the starches differed by crop. With increased pulverizing, the mean particle size decreased in all flours (to<10 μm) and the pasting properties converged. Commercial flours containing the larger starch granules have the higher starch damage after pulverization.
Key words: Starch, Pulverization, Particle size, Pasting property, Starch damage

1. Introduction

Rice, wheat, and corn (maize) are the three major sources of starch around the world, and their flours are extensively used for making bread, crackers, flakes and other foods. Potato, sweet potato, and cassava are also made into flours for food manufacture. Root and tuber starches such as these exhibit high viscosity [1]. Potato starch has the highest swelling power and the highest viscosity among all commercial starches [2]. Cassava starch reportedly has a unique, very high single-stage swelling property and peak viscosity [3]. Starches obtained from such crops have different particle sizes, and mixing one starch with another changes the pasting properties [4,5]. The particle size of rice flour affects the pasting properties, starch damage [6], and flowability [7]. Mechanically damaged starch during milling [8] is of considerable importance to the baking industry since damaged starch both absorbs more water and is more susceptible to enzyme degradation than intact starch at dough-forming temperatures [9]. However, no study has reported the effects of pulverization of different starches on their physiochemical properties. A better understanding would extend the use of various flours.

The main objective of this study was to find out the effects of particle size reduction and starch damage by pulverization among different flours on pasting properties.

(Received 3 Nov. 2010: accepted 18 Jan. 2011)
† Fax: +81-29-838-8122, E-mail: okadome@affrc.go.jp

2. Materials and Methods

2.1 Materials

Commercial starches were purchased: rice starch (Sigma: S7260), potato starch (Sigma: S4251); wheat starch, sweet potato starch, cassava starch (Cuoca Planning Co., Ltd., Tokushima Japan); and corn starch (Noguti Food Industry, Japan).

2.2 Experimental and analytical methods

2.2.1 Pulverization of samples

All flours were pulverized three times in a Co-Jet mill (Co-jet system-α MK III, Seishin Enterprise Co. Ltd., Japan). The nozzle pressure was 0.6 to 0.7 MPa. Samples were slammed against the impact plate of the mill with high velocity air and were pulverized. Figure 1 shows the schematic diagram of the Co-jet mill. A cone shaped ceramic impact plate was used with the diameter of 51 mm and pinnacle of 14 mm.

2.2.2 Particle size distribution

The mean size distribution of the flour samples was analyzed by laser diffraction particle size analyzer (SALD-2100; Shimadzu Co., Kyoto, Japan). Deionized water was used as the medium for wet size measurement of flours. Sonic measurements were performed to avoid the aggregation of flours.

2.2.3 Moisture content of starches

The moisture contents of different samples were measured by oven dry method [10]. Samples (2-3 g) were placed in a pre-weighed aluminum container and

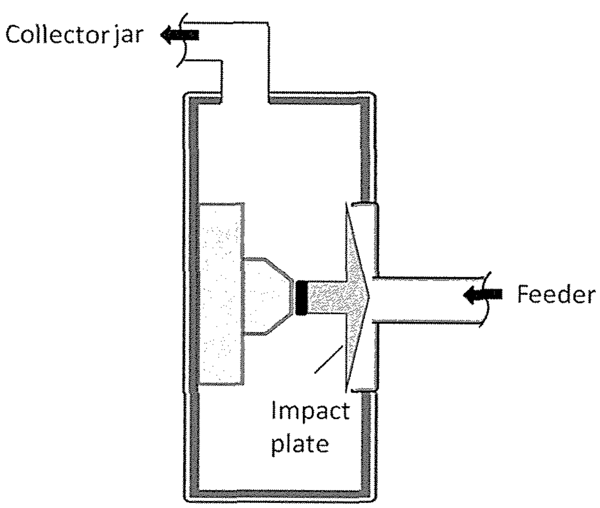

Fig. 1 Schematic diagram of Co-Jet mill grinding chamber.

weighed. The samples were then dried in an oven at 135℃ for 1 h, cooled in airtight desiccators containing silica gel, and reweighed.

2.2.4 Starch damage

Starch damage was determined according to AACC method 76-31 [11] with a starch damage assay kit (Megazyme International Ireland, Ltd., Bray, Ireland). Damaged starch granules were hydrated and hydrolyzed to maltosaccharides plus α-limit dextrins by careful treatment with purified fungal α-amylase, which gives near-complete solubilization of damaged granules with minimum breakdown of undamaged granules. The reaction was terminated by the addition of dilute sulfuric acid. Aliquots were treated with excess purified amyloglucosidase to completely degrade starch-derived dextrins to glucose. The glucose was measured with a high-purity glucose oxidase peroxidase (GOPOD) reagent mixture. Values are presented as damaged starch as a percentage of flour weight on an as-is basis.

Starch flour and starch control (supplied with the assay kit), 100 mg each, were placed in two thick-walled glass centrifuge tubes and incubated with 1 mL fungal α amylase at 40℃ for 10.0 min. Then 8.0 mL of diluted sulfuric acid solution was added (0.2% v/v). The tubes were centrifuged at 3000 rpm for 5 min. Supernatant (0.1 mL) was transferred to the bottom of two test tubes, 0.1 mL amyloglucosidase solution (2 U) was added to each tube, and the tubes were incubated at 40℃ for 10 min. GOPOD (4.0 mL, supplied with the assay kit) reagent solution was added to each tube (including glucose standards and reagent blank tubes), and the tubes were incubated at 40℃ for 20 min. The absorbance of all solutions was measured at 510 nm against a reagent blank in duplicate.

2.2.5 Pasting properties

The pasting properties of the samples were measured with a Rapid Visco Analyser (RVA-4; Newport Scientific, Warriewood, NSW, Australia) [12]. Flour (3.5 g, 14% moisture basis) was transferred into a canister and 25 ± 0.1 mL of deionized water was added (with correction for moisture content). Figure 2 describes measurement procedure and definition of RVA parameters. The slurry was stirred at 960 rpm for 10 s for thorough dispersion and

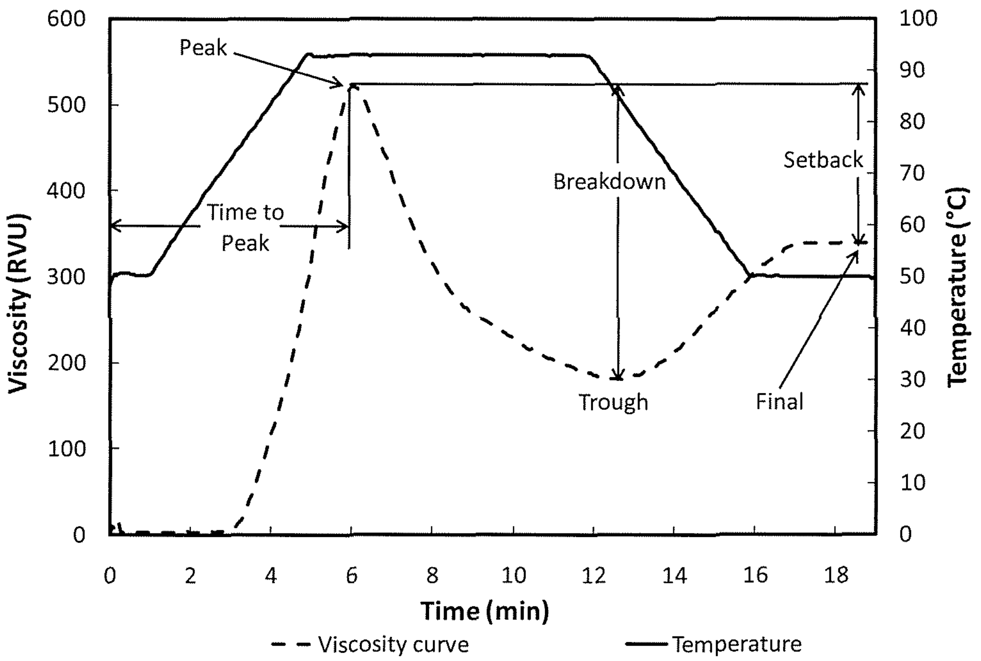

Fig. 2 Measurement procedure and definition of RVA parameters.

then stirred at 160 rpm. The slurry was held at 50℃ for 1 min, heated to 93℃ over 4 min and held there for 7 min, and then cooled to 50℃ over 4 min and held there for 3 min. The pasting temperature (at which viscosity first increases by at least 25 cP), peak viscosity, peak time (when peak viscosity occurs), trough viscosity (minimum viscosity), final viscosity (viscosity after cooling), breakdown (peak viscosity-trough viscosity), and setback (final viscosity-peak viscosity) were calculated from the pasting curve with Thermocline v. 2.2 software (Newport Scientific). Analyses were performed on duplicate samples.

3. Results and Discussion

3.1 Pulverization and moisture content of flours

Table 1 shows particle sizes and moisture contents of different flours with pulverization. The mean size of the commercial flours ranged from approximately 5 to 50 μm before pulverization, and was reduced to <10 μm in all samples after three pulverizations. The mean size reduced gradually with pulverization, and the moisture content reduced. Particles with smaller size had greater surface area exposed to the environment and removal of moisture occurred. Besides high velocity of air inside of the co-jet mill takes away moisture from flours and reduces their moisture contents.

3.2 Particle size distributions of commercial and pulverized samples

Figure 3 describes the particle size of commercial and pulverized starches. Among the commercial samples, the particle size of rice starch was relatively small; those of corn, cassava (both narrow distributions), sweet potato, and wheat starches were medium; and that of potato was large and wide distribution.

After three times pulverizations, the mean size of rice

Table 1 Particle sizes and moisture contents of different flours with pulverization.

Flour	Commercial		1st pulverization		2nd pulverization		3rd pulverization	
	Size (μm)	MC (%)	Size (μm)	MC (%)	Size (μm)	MC (%)	Size (μm)	MC (%)
Rice	4.4	11.7	4.4	5.3	4.3	5.3	3.9	5.0
Wheat	19.4	12.6	11.9	5.9	8.5	5.1	7.1	5.1
Corn	16.9	12.1	12.5	6.3	7.9	4.9	7.9	4.7
Potato	50.4	12.5	30.9	8.0	12.9	6.0	8.1	4.8
Sweet potato	15.5	16.1	11.2	7.2	7.6	6.6	6.6	5.2
Cassava	16.3	12.3	9.7	6.2	7.1	5.6	5.6	5.3

MC=moisture content.

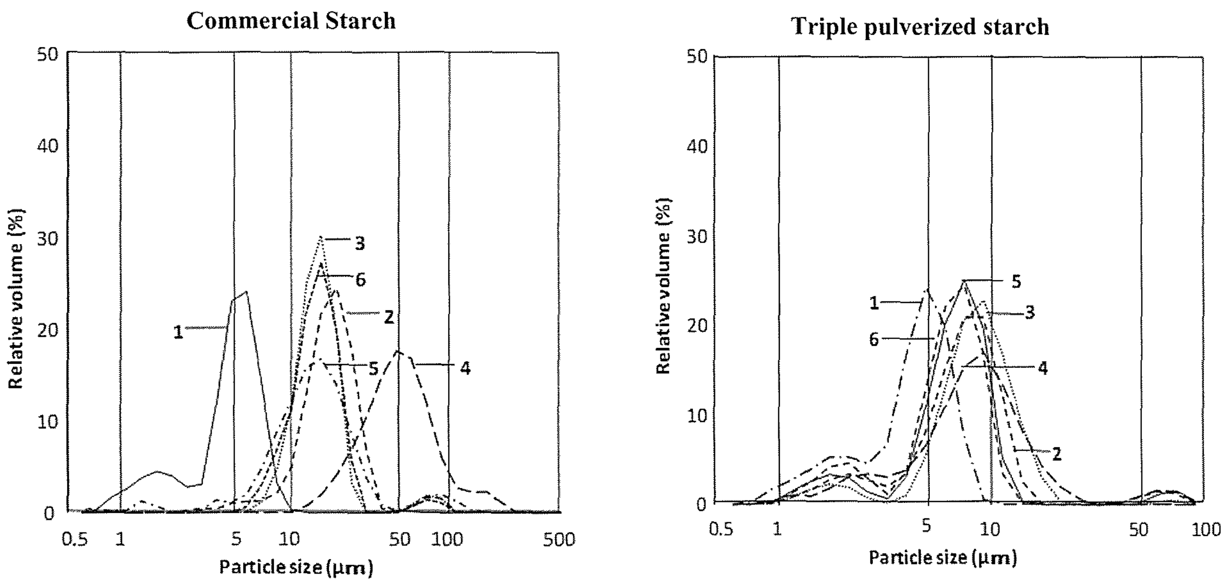

Fig. 3 Particle size distribution of commercial and triple-pulverized starches (1, rice; 2, wheat; 3, corn; 4, potato; 5, sweet potato; 6, cassava).

starch was slightly reduced and the relative volume of the shoulder near 2 μm increased slightly. All other flours developed a similar shoulder near 2 μm, and wheat, potato, sweet potato, and cassava developed another tiny shoulder near 70 μm. The dissimilar size distribution curves before pulverization became similar after pulverization.

3.3 Pasting properties of flours

Figure 4 illustrated RVA pasting curves for commercial and triple-pulverized starches. Among commercial samples, potato showed the highest peak viscosity, followed by cassava, rice and corn showed the lowest values. Cassava and wheat showed the highest final viscosities, and thus had the highest ability to form a gel after cooking and cooling [13].

On the other hand, after pulverization, the peak, trough, and final viscosities of all flours were decreased. The decreased peak viscosity shows that smaller particles are more resistant to swelling [14], and that particle size affects the RVA measurement [15]. Table 2 shows RVA pasting properties of starches with different pulverization. After pulverization, the peak viscosity was highest for rice starch, followed by cassava.

These results show that the potato, cassava, and sweet potato starches became more resistant to swelling or lost their swelling competence after pulverization. Pulverization to tiny particle decreased the ability of all samples to form a gel after heating and cooling. The ability of wheat, corn, potato, and sweet potato starches to form a gel became similar after pulverization, as shown by their almost identical final viscosities. Rice and cassava starches had a slightly higher ability to form a gel. The commercial potato starch showed a very high peak of around 1000 RVU, but after pulverization the peak and curve dropped drastically. Commercial potato, sweet potato, and cassava starches had higher peak viscosities than final viscosities, but pulverization reversed this order.

Figure 5 shows the effect of particle size on peak and final viscosities. Peak and final viscosities decreased with particle size in all flours. Thus, particle size profoundly affects both. After pulverization, the pasting properties became more similar among different flours.

Figure 6(A) shows the effect of particle size on starch damage. Starch damage was minimal in all commercial flours (0.3%–6%) but increased after pulverization, as indicated by the smaller mean particle size (15%–40%). The potato starch showed the highest damage at 8 μm mean size. Cassava, corn, wheat, and sweet potato starches showed a similar trend of increased damage with mean size reduction. The results indicate that in these starches, particles of the similar size have similar level of damaged starch. Commercial rice flour had higher starch damage than the other flours before pulverization and a smaller mean size reduction but a lofty increase of starch damage after pulverization.

Figure 6(B) shows the effect of starch damage on peak viscosity. The correlations between starch damage and peak viscosity were similar among wheat, corn, sweet

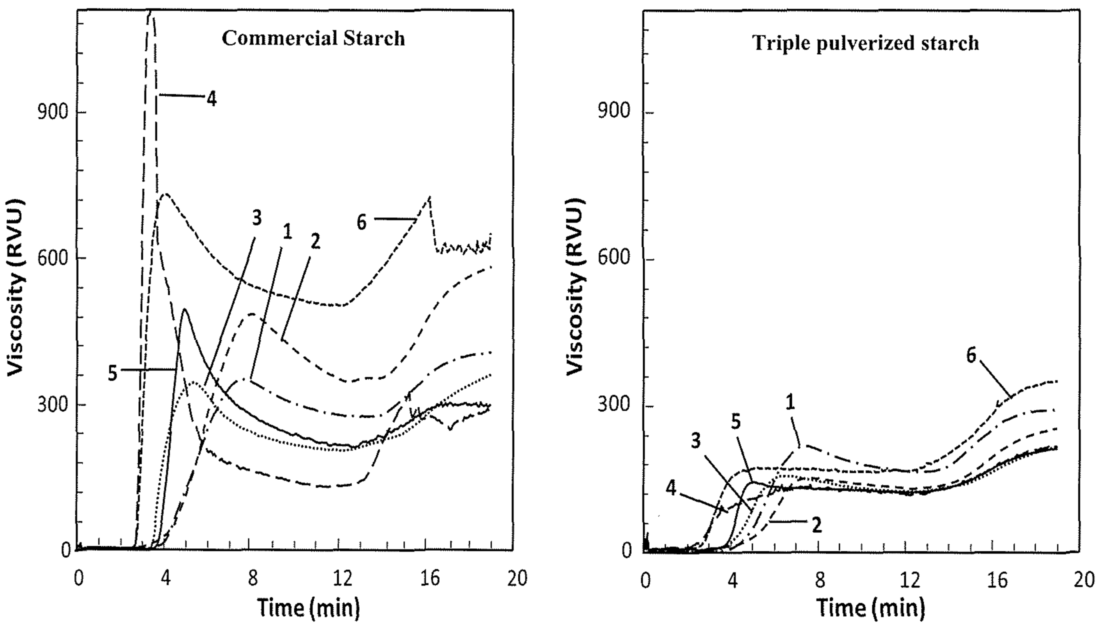

Fig. 4 RVA pasting curves for commercial and triple-pulverized starches (1, rice; 2, wheat; 3, corn; 4, potato; 5, sweet potato; 6, cassava).

Table 2 RVA pasting properties of starches with different pulverization.

Sample name	Starch state	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)
Rice	Commercial	330	274	56	402	72
	1st pulverization	260	211	49	337	77
	2nd pulverization	226	182	45	306	80
	3rd pulverization	209	165	45	290	81
Wheat	Commercial	424	348	76	579	155
	1st pulverization	210	215	5	388	178
	2nd pulverization	157	155	2	300	143
	3rd pulverization	136	131	5	253	117
Corn	Commercial	345	209	136	362	17
	1st pulverization	242	172	70	298	56
	2nd pulverization	172	136	36	231	59
	3rd pulverization	157	125	32	215	58
Potato	Commercial	1087	131	956	345	−742
	1st pulverization	572	216	356	323	−249
	2nd pulverization	328	205	123	311	−17
	3rd pulverization	139	126	13	220	81
Sweet potato	Commercial	496	215	281	302	−194
	1st pulverization	318	186	132	307	−11
	2nd pulverization	192	145	47	256	64
	3rd pulverization	149	124	25	217	68
Cassava	Commercial	727	500	227	636	−32
	1st pulverization	438	331	107	590	152
	2nd pulverization	236	205	31	425	189
	3rd pulverization	182	171	11	363	181

RVU=Rapid visco units. 1RVU≒12 Centipoise

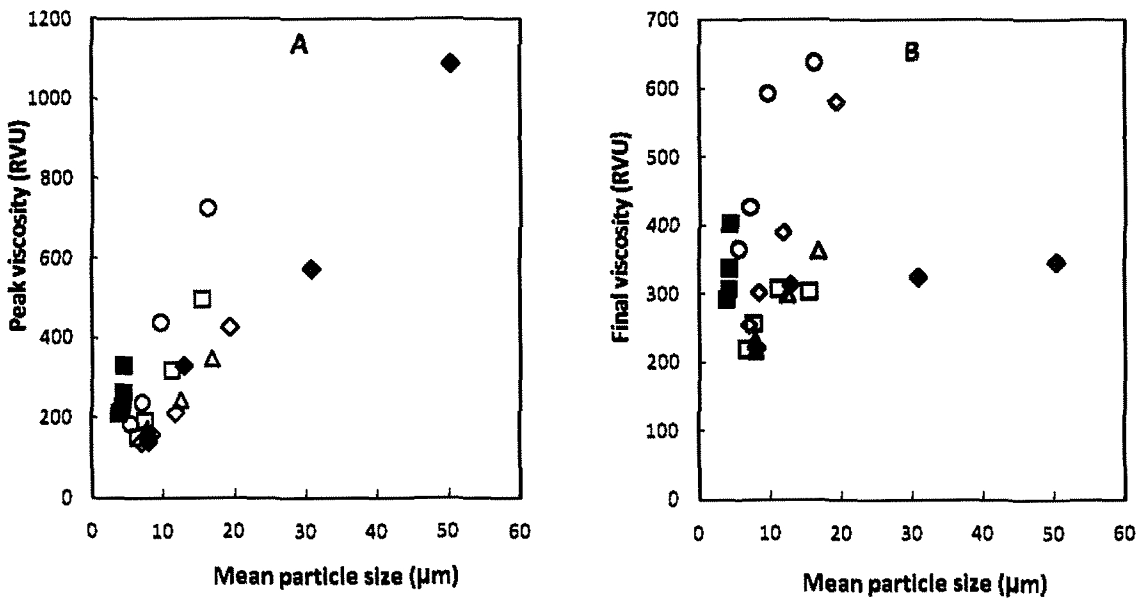

Fig. 5 Effect of particle size on (A) peak and (B) final viscosities (■ rice, ◇ wheat, △ corn, ◆ potato, □ sweet potato, ○ cassava).

potato, and cassava starches. Rice and potato starches showed different trends. The peak viscosity of each sample decreased linearly with increasing starch damage. The characteristics of individual starch granules might be altered by the damage. As damaged starch has less ability to swell, the more-damaged starches showed lower peak viscosity. Pores or cracks in damaged granules may act as sites for amylolytic action and water

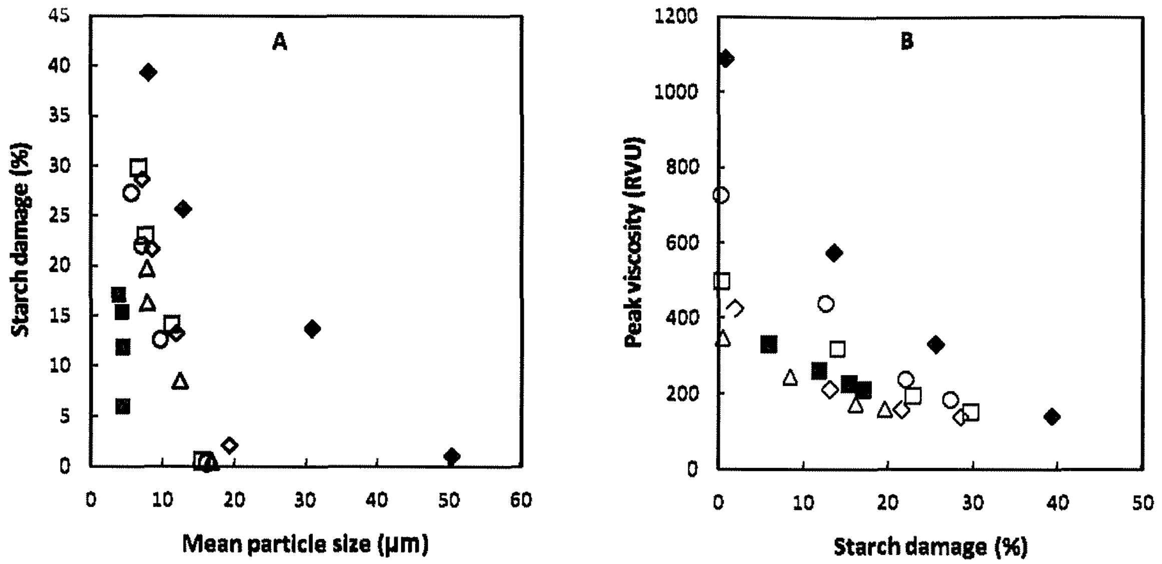

Fig. 6 (A) Effect of particle size on starch damage. (B) Effect of starch damage on peak viscosities (■ rice, ◇ wheat, △ corn, ◆ potato, □ sweet potato, ○ cassava).

absorption [16].

4. Conclusions

In the commercial flours, the mean particle size and pasting properties varied with the crop. As pulverization increased, the mean particle size decreased in all flours (to<10 μm) and the pasting properties converged. Thus, particle size reduction made the pasting properties similar. Pulverization also increased starch damage, which affects the pasting properties. Level of starch damage by pulverization may affect the dough mixing. Commercial starches have lower level of damaged starch and thus have less ability to absorb water for forming dough. Altering the level of starch damage by pulverization may alter the dough mixing ability of different starches. Results of this research may become useful as basic data in controlling water absorption and rheological property of pulverized starch flours during processing.

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◇◇◇ **和文要約** ◇◇◇

異なる作物デンプンの微粉砕が糊化特性に与える影響

Md. シェリフ ホッセン[1,2], 五月女格[1], 竹中真紀子[1], 中嶋光敏[1,2], 五十部誠一郎[1,2], 岡留博司[1,†]

[1]筑波大学大学院生命環境科学研究科
[2]独立行政法人 農業・食品産業技術総合研究機構 食品総合研究所

本研究では微粉砕が米，小麦，トウモロコシ，甘藷およびキャッサバなどデンプンの糊化特性に与える影響を明らかにした．微粉砕前では粒子の平均粒径やデンプンの糊化特性は作物によって異なった．しかし，微粉砕回数の増加とともに粉末の平均粒径は全ての作物で減少し (10 μm未満), それらの粉末は類似の糊化特性を示した．また大きいデンプン粒を含む市販の粉末ほど微粉砕後では損傷デンプンの割合が高かった．

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1 〒305-8642　茨城県つくば市観音台2-1-12
2 〒305-8572　茨城県つくば市天王台1-1-1
† Fax: +81-29-838-8122, E-mail: okadome@affrc.go.jp