Physicochemical Properties of Sonicated Mung Bean, Potato, and Rice Starches

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ABSTRACT

Mung bean, potato, and rice starch solutions (5%, w/w) were sonicated for up to 5 min after heating, and their physicochemical properties were investigated. Alkaline viscosities, including the apparent and inherent viscosities of starches, decreased. The residues of the swollen starch granules after pasting and centrifugation were also reduced prominently by sonication. Average degree of polymerization did not change with sonication. The starch paste became more transparent, and the hot paste viscosity measured at 70°C decreased remarkably. Results indicate that changes in the physicochemical properties of starch were induced by the disruption of swollen granules rather than the breakage of glucosidic linkages with sonication.

Ultrasonic waves generated by converting electrical energy into mechanical vibration result in the intense agitation of the molecules in the medium. High-amplitude waves (10 kHz – 1 MHz) generally are best suited for applications such as cleaning, drilling, emulsification, soldering, medical therapy, welding, and chemical and biological applications, as well as sonar. On the other hand, low-amplitude waves are most effective for applications such as security systems, medical instrumentation, and material testing (Anonymous 1976). In food processing, ultrasonication can be applied to cleaning, emulsifying, mixing, alcohol fermenting, extracting, cutting, drying, spraying, degassing, and cell disruption (Sato 1993).

Jackson et al (1988, 1989) used sonication to dissolve corn and sorghum starch granules (at <1% solids) after heating instead of solubilization in alkali or dimethyl sulfoxide (DMSO) for the analysis of molecular structure through high-performance size-exclusion chromatography. They reported that ultrasonic vibrations disrupt swollen granules, thereby releasing amylose and amylopectin from the granules, resulting in an increase in water solubility of starch.

Increase in solubility implies that sonication may change other physicochemical properties of starch and, consequently, could be used a method for starch treatment. The objective of this work was to investigate the effect of ultrasonic on the physicochemical properties of three types of starches (rice cereal starch, potato tuber starch, and mung bean legume starch) at high concentration.

MATERIALS AND METHODS

Starch

Mung bean starch was isolated from commercial mung beans purchased at a local market using an alkaline steeping method (Chung et al 2000). Potato and rice starches were purchased from Sigma (St. Louis, MO)

Physicochemical Measurements

Starch samples were prepared as follows. Twenty-eight grams of starch slurry (5% solids) were heated at 95°C for 5 min in a Rapid Visco Analyser (RVA model 3D, Newport Scientific, Sydney, Australia) for uniform heating. Starch pastes were then immediately sonicated for 1, 3, and 5 min at the output control of 5 (max. output control 10; manufacturer recommended setting below 7 when using micro tips) using a sonifier (model 450, Branson Ultrasonics Corp., Danbury, CT) equipped with a tapered micro tip (end diameter of 3.2 mm). The end of micro tip was placed at the depth of 1 cm from the surface of pastes. At the condition used for sonication, the meter reading of output was ≈15 (max. 100) and corresponded to the output energy of 30W according to the output chart in the instruction manual. After sonication, samples were lyophilized.

Apparent viscosity was measured using a viscometer (LVDV-II+, Brookfield Engineering Laboratories, Stoughton, MA) equipped with a small sample adapter (SSA 31/13R). Starch (0.5 g, db) was dispersed in 3 mL of water and completely dissolved by adding 27 mL of 1% NaOH solution. Viscosity was measured at 25°C and 100 rpm (Chung and Seib 1991).

Determination of inherent viscosity was made with a No. 75 Cannon-Fenske capillary viscometer. Starch (1 g, db) was dispersed in 100 mL of water and completely dissolved by slowly adding 100 mL of 2*M* NaOH solution with continuous stirring. Starch solution was then gravity-filtered through a G-1 glass funnel, and the viscosity was measured at 25°C (Myers 1964).

Paste clarity was measured as % transmittance at 650 nm with a spectrophotometer (model UV-1601PC, Shimadzu Corp., Kyoto, Japan) (Craig et al 1989). Starch (100 mg, db) was suspended in 10 mL of water in screw-cap tubes, heated in a boiling water bath for 30 min, then cooled to room temperature.

Average degree of polymerization (DP_n) was determined by measuring both the total carbohydrate content using phenol-sulfuric acid method and the reducing power through the modified Park-Johnson method (Hizukuri et al 1981; Chung and Seib 1991). Dry starch (50 mg) with 1 mL of 1*M* NaOH added was stirred with a glass rod until no clots were found. Starch was dissolved completely through gradual dilution using ≈0.5–1 mL of water. The solution was neutralized with 1*M* HCl and diluted to a total volume of 10 mL with water. The neutralized solution was kept in a 50°C water bath to avoid retrogradation until measurement.

Hot Paste Viscosity and Granule Disintegration

For hot paste viscosity, 28 g of starch slurry (3%, w/w) was heated at 95°C for 5 min in an RVA and sonicated for 0.25, 0.5, 1, 3, and 5 min as described previously. Starch paste was then transferred into a screw-cap tube and kept in a 70°C water bath for 30 min. Viscosity was measured at the same temperature using a viscometer (Brookfield) equipped with a small sample adapter (SSA 18/13R).

Granule disintegration was determined using a method to measure the swelling power of starch (Schoch 1964). Starch (2 g for mung bean and rice starches and 0.5 g for potato starch) was mixed with 200 mL of water in a preweighed 250-mL centrifuge tube. The slurries were heated at 65–95°C for 30 min while stirring at 200 rpm with a rectangular paddle. The pastes were then sonicated for 0.25, 0.5, 1, 3, and 5 min as described previously. The sonicated

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pastes were immediately cooled to room temperature in a water and ice bath and centrifuged at 7,000 rpm for 15 min. The precipitated portion was weighed and expressed as the degree of granule disintegration.

Statistical Analysis

All measurements were done at least in duplicate and the Statistical Analysis System (SAS Institute, Cary, NC) was used to analyze data and to calculate Fisher's least significance differences (α = 0.05).

RESULTS AND DISCUSSION

Alkaline Viscosities and DP_n of Sonicated Starches

Sonication reduced both the apparent and the inherent viscosities of starches (Table I). Apparent and inherent viscosities of native mung bean starch were 81.6 cP and 2.92 dL/g, and decreased to 13.3 cP and 1.35 dL/g, respectively, after 5 min of sonication. The decreases in alkaline viscosities were also observed with potato and rice starches. Apparent and inherent viscosities diminished from 59.6 cP and 2.74 dL/g to 10.1 cP and 1.30 dL/g, respectively, for potato starch and from 42.2 cP and 1.85 dL/g to 6.9 cP and 0.88 dL/g, respectively, for rice starch after 5 min of sonication. Reduction in alkaline viscosity was also reported for acid-thinned starch (Rohwer and Klem 1984; Chung and Seib 1991). As the acid concentration or treatment time increased, the viscosity decreased. In addition, reduced alkaline viscosity was observed in oxidized starches (Chung and Seib 1991) and extruded starches (Colonna et al 1984, 1989; McPherson and Jane 2000). In all cases, molecular degradation by the cleavage of glucosidic linkages results in low alkaline viscosity.

However, in the present study ultrasonic did not degrade the glucosidic linkages. All treatments showed no statistically significant changes ($P < 0.05$) in the average DP_n (Table I). On the contrary, Jackson et al (1988) reported that extensive sonication appeared to depolymerize amylopectin. You and Lim (2000) also showed alkaline-dissolved starch was degraded by sonication. The starch concentration they used for experiments appears to have caused different results. They treated starches at relatively low concentration (≈1%) for measuring molecular characteristics through high-performance size-exclusion chromatography. In our experiment, the starch concentration was somewhat higher (5%, w/w), while the energy applied to the starch was lower.

TABLE I
Apparent and Inherent Viscosities and Average Degree of Polymerization (DP_n) of Sonicated Starches[a]

Starch	Sonication Time (min)	Apparent Viscosity[b] (cP)	Inherent Viscosity[b] (dL/g)	Average DP_n[c]
Mung bean	0	81.6 ± 1.3a	2.92 ± 0.00a	3,160 ± 220a
	1	46.7 ± 0.2b	2.14 ± 0.01b	3,380 ± 520a
	3	19.7 ± 0.2c	1.59 ± 0.00c	3,280 ± 650a
	5	13.3 ± 0.1d	1.35 ± 0.00d	2,920 ± 410a
Potato	0	59.6 ± 0.6a	2.74 ± 0.01a	3,930 ± 450a
	1	36.9 ± 0.0b	2.28 ± 0.00b	4,340 ± 1390a
	3	14.3 ± 0.2c	1.60 ± 0.00c	4,220 ± 910a
	5	10.1 ± 0.2d	1.30 ± 0.00d	3,490 ± 470a
Rice	0	42.2 ± 0.6a	1.85 ± 0.01a	1,710 ± 190a
	1	12.3 ± 0.8b	1.24 ± 0.00b	1,790 ± 180a
	3	8.4 ± 0.0c	1.03 ± 0.01c	1,560 ± 210a
	5	6.9 ± 0.0d	0.88 ± 0.01d	1,600 ± 150a

[a] Means in the same column not followed by the same letter for each starch are significantly different at $P < 0.05$.
[b] Mean value of duplicate measurements ± standard deviation.
[c] Mean value of four measurements ± standard deviation.

TABLE II
Disintegration of Starch Granules by Sonication[a–c]

Starch	Sonication Time	Precipitate Weight (g/g dry starch)			
		65°C	75°C	85°C	95°C
Mung bean	Control	3.69b	6.21a	11.34a	14.91a
	15 sec	3.69b	5.65b	11.29a	15.10a
	30 sec	3.61b	5.41b	10.38b	9.37b
	1 min	3.89a	4.94c	6.74c	4.51c
	3 min	3.68b	3.19d	1.23d	1.13d
	5 min	3.03c	2.33e	1.01d	0.57d
Potato	Control	20.26a	35.78a	49.29a	71.04a
	15 sec	9.38b	16.28b	10.33b	8.34b
	30 sec	7.49c	6.35c	4.48c	4.36bc
	1 min	4.45d	3.32d	2.68c	3.06c
	3 min	2.51e	2.20d	1.75c	1.87c
	5 min	2.23e	2.35d	1.68c	2.37c
Rice	Control	3.53a	5.00a	8.61a	9.57a
	15 sec	3.49a	4.93a	8.03b	9.77a
	30 sec	3.42a	4.79a	8.11b	8.90b
	1 min	3.13b	4.57ab	7.89b	8.10c
	3 min	3.02b	4.18bc	5.87c	3.80d
	5 min	2.48c	3.77c	4.24d	1.97e

[a] Heated at 65–95°C for 30 min, sonicated, cooled, and centrifuged.
[b] Mean of duplicates.
[c] Means in the same column not followed by the same letter for each starch are significantly different at $P < 0.05$.

Degree of Disintegration of Starch Granules by Sonication

Instead of breakage of glucosidic linkages, sonication appeared to disrupt the swollen starch granules (Table II). When mung bean starch was sonicated for 5 min after cooking at 95°C, the weight of precipitated swollen granules after centrifugation decreased from 14.91 to 0.57 g/g of dry starch. Starch subjected to sonication

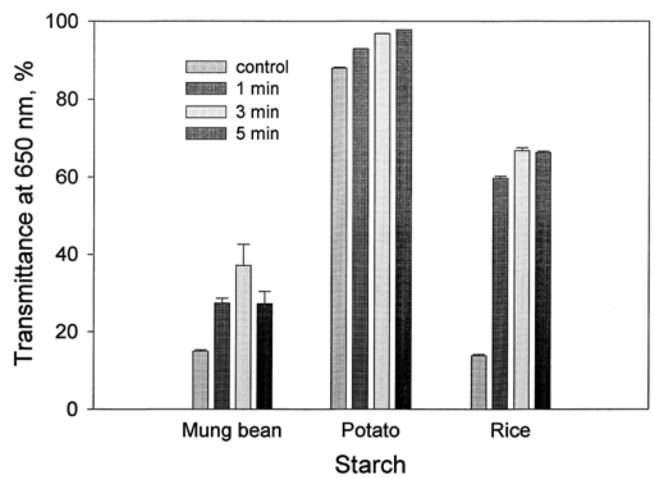

Fig. 1. Clarity of sonicated starches.

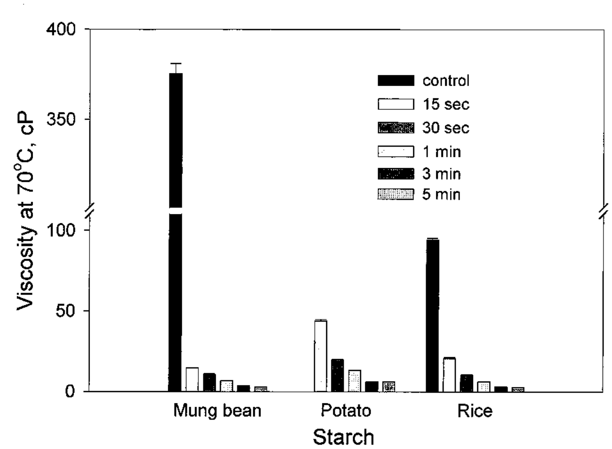

Fig. 2. Hot paste viscosity of sonicated starches.

treatment for 15 sec showed almost no difference from the control starch. With sonication for 30 sec, the weight decreased to 9.37 g. When the cooking temperature was lowered, the disruption in starch granules decreased due to the low swelling degree. At 65°C, the precipitate weighed 3.03 g for the starch sonicated for 5 min, while the control weighed 3.69 g. Rice starch showed a trend very similar to that of the mung bean starch. Potato starch also showed less disintegration with the decrease in heating temperature. But, unlike other starches, potato starch granules were disrupted considerably by sonication even after heating at 65°C due to the relatively high swelling ability at this temperature. Potato starch sonicated for 5 min had 2.23 g of precipitated swollen granules while the control had 20.26 g. Overall, the granular disruption was the most remarkable in potato starch.

Clarity

With sonication, clarity of the starch paste increased (Fig. 1). The increase was most evident in rice starch. Transmittance of control starch was 13.8%, whereas those of starches sonicated for 1, 3, and 5 min were 59.7, 66.8, and 66.0%, respectively. The clarity of potato starch paste was hardly affected because potato starch itself has a high clarity. Transmittance of potato starch increased only from 88.0 to 97.8% during 5 min of sonication. Craig et al (1989) reported potato starch paste is more transparent than other starches because remnants of potato starch granules are largely absent in the paste due to their fragility during cooking. And, the repulsion between the phosphate groups on potato starch keeps the molecules fully hydrated, promoting light transmittance. Increase in transmittance of mung bean starch was between those of rice and potato starches. Increase in clarity appears to have been caused by the disruption of the swollen granules through sonication. Craig et al (1989) also reported that when little or no granular structure and no association of chains after pasting exist, the starch paste becomes highly transparent.

Hot Paste Viscosity

Changes in hot paste viscosity were prominent in all starches. With increasing sonication time, the viscosity decreased remarkably (Fig. 2). Native mung bean starch showed a viscosity of 376 cP at 70°C and decreased to 14.6 cP after 15 sec of sonication, after which the decrease was slight. Hot paste viscosity of native potato starch could not be measured due to the gelation, but after 15 sec of sonication, it was 43.9 cP and further decreased to 6.1 cP after 5 min of treatment. Rice starch showed the least decrease, from 94.3 cP for native starch to 2.8 cP for the starch sonicated for 5 min. These results indicate disruption of starch granules may cause lower hot paste viscosity.

CONCLUSIONS

Alkaline viscosity of starch decreased by sonication after heating, probably due to the disruption of the swollen granules rather than the breakage of glucosidic linkages that can be found in acid-thinned, oxidized, and extruded starches. The disruption was the most remarkable in potato starch which had the highest swelling ability among starches tested. Granular disruption by sonication also induced the starch paste to become more transparent and less viscous. Thus, sonication may be applied for the preparation of a physically modified starch that has good clarity and low viscosity without decrease in chain length.

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