

Application of High-Intensity Ultrasound and Surfactants in Rice Starch Isolation

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ABSTRACT

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High-intensity ultrasound was evaluated as an alternative method to isolate rice starch without the use of chemicals as in the traditional alkaline steeping method. Surfactants, including sodium dodecyl sulfate (SDS), sodium stearyl lactylate (SSL), and Tween 80, at 0.1, 0.3, or 0.5% combined with high-intensity ultrasound were also investigated for rice starch isolation. A rice flour slurry (33%) was subjected to sonication for 15, 30, or 60 min at an amplitude of 25, 50, or 75% and at 40 or 50°C. The starch yield was not significantly affected by the treatment temperature and ranged from 46.7 to 76.2% (starch dry basis) after the sonication treatment; the protein and damaged starch contents of the isolated starches were 0.9–1.7% and 3.1–3.5% (dry basis), respectively. The combi-

nation of 0.5% SDS and high-intensity ultrasound improved the starch yield to 84.9% with low residual protein, however, little improvement was observed with SSL or Tween 80. The pasting properties of isolated starch as measured by a Rapid Visco-Analyser were affected by the treatment temperature and by the amount of residual protein and damaged starch. The thermal properties of the isolated starch were not changed by sonication and the amylose content remained unchanged. The surface of the isolated starch was not damaged by sonication as shown by scanning electron microscopy. High-intensity ultrasound, alone or combined with SDS, showed a great potential for rice starch isolation in a short period of time without generating alkaline effluent.

Rice starch isolation is different from other starches because of the unique rice protein composition. Rice protein consists of albumin (5%), globulin (12%), prolamin (3%), and glutelin (80%) that dissolves in water, salt, ethanol, and alkali, respectively (Juliano 1985). Therefore, rice starch is conventionally isolated by an alkaline steeping method (Domah and Mohamed 1974). However, this method generates large amounts of alkaline waste; thus, it is not a preferable process in the United States. Recently, Lumdubwong and Seib (2000) applied an alkaline protease to isolate rice starch; nevertheless, alkaline and salt waste were still generated in this process because it was conducted at alkaline conditions. Neutral protease was effective in assisting in rice starch isolation at neutral conditions (Wang and Wang 2001), but the reaction time was long (18 hr in that study) to achieve a high starch yield and a low residual protein content.

High-intensity ultrasound has been used in many food applications such as enhancing oxidation, emulsifying, sterilizing, extracting, degassing, filtrating, and drying (Mason 1998; Leadley and Williams 2002). High-intensity ultrasound is believed to cause acoustic cavitation, which relates to bubble activity. The microbubbles will oscillate and grow to many times their original size, and then subsequently rapidly collapse when ultrasound is applied to a liquid system. Such events concentrate the acoustic energy, thus generating high temperatures and pressure in the surrounding area (El'Piner 1964; Suslick 1988). Microjets of liquid are generated, which impinge on a surface when a bubble collapses.

Ultrasound has been used in starch for solubilization, modification, and purification. Cooked corn and sorghum starches were solubilized with ultrasound (Jackson et al 1988, 1989). The ultrasonic treatment could disrupt the swollen starch granules and help release starch molecules from the granules. Chung et al (2002) studied the ultrasonic effect on physicochemical properties of starch by sonicating mung bean, potato, and rice starches, which were previously heated at 95°C for 5 min. The alkaline viscosity of the treated starches decreased; potato starch decreased the most. It was explained that the ultrasound only damaged the swollen granules but not the native granules of starch. However, no data comparing the starch structure before and after the ultrasonic treatment were provided to support that conclusion.

Surfactants have been used in starch purification. Fujii (1973) reported that dodecyl benzene sulfonate (DBS) greatly decreased the residual protein in starch due to the formation of protein-DBS complex. Fujii and Tomiyama (1973) studied the effect of sodium α -olefin sulfonates (0.1–0.5%) on sweet potato protein removal. After 1 hr of stirring, the residual protein content of the starch decreased to 0.08%, a reduction of \approx 50% in residual protein content compared with a 29% reduction when only water was used. Kung et al (1987) employed 0.3–0.5% sodium stearyl lactylate (SSL) in rice starch isolation, and the residual protein content of the resultant starch was 1.6% (db). It was reported that a combination of sonication and Tween 60 improved the color of sago starch and also lowered the ash content (Komoto et al 1982).

The objective of this study was to seek alternative means to isolate rice starch. High-intensity ultrasound alone and combined with surfactants were evaluated as potential alternative methods for rice starch isolation. The properties of the isolated starch were characterized to determine the effectiveness of the treatments.

MATERIALS AND METHODS

Materials

Long-grain rice flour (RL-100) was purchased from Rivland Partnership, Houston, TX. Sodium dodecyl sulfate (SDS), sodium stearyl lactylate (Emplex, SSL), and Tween 80 (EM Science) were obtained from IBI Shelton Scientific (Shelton, CT), American Ingredients Company (Grandview, MO), and VWR Scientific Products (S. Plainfield, NJ), respectively. A high-intensity ultrasonic processor (750W model, 20 kHz) with a 0.75 in. high gain probe was purchased from Sonics & Materials (Newtown, CT).

Rice Starch Isolation

The alkaline steeping procedure to isolate rice starch followed the method of Wang and Wang (2001). Rice flour (100 g) was soaked in 200 mL of 0.1% sodium hydroxide (NaOH) for 18 hr. The slurry was blended with a Waring blender at a high speed for 2 min, passed through a 63- μ m screen, and centrifuged at 1,400 \times g for 10 min. The soft top layer was carefully removed and the bottom starch layer was reslurried and washed with threefold of 0.1% NaOH and centrifuged. The soft top layer was again carefully removed and then the starch layer was washed with deionized water and centrifuged. The starch was then reslurried and neutralized with 1.0N hydrochloric acid (HCl) to pH 6.5, washed with deionized water three more times, centrifuged, dried in an oven at 45°C for 48 hr, passed through a 150- μ m sieve and stored

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in a plastic jar at room temperature until analyses. Starch yield was the recovered starch weight divided by the starch content of the rice flour.

Three factors were studied for starch isolation by high-intensity ultrasound: temperature, sonication duration, and sonication amplitude. Deionized water (200 mL) was warmed up to 30 or 42°C in a 500-mL reaction beaker by a circulator before the addition of the rice flour (100 g, as is). The amplitude is related to the energy content; the greater the amplitude, the greater the distance the probe tip travels. The 100% amplitude setting for the 0.75 in. high gain probe used in this study was 61 µm. The sonication amplitude was set at 25, 50, or 75% with 5 sec on and 5 sec off; the maximum sample temperature was controlled at 40 or 50°C by the temperature probe. The sonication duration was 15, 30, or 60 min, which did not include the off-time. After the treatment, the flour slurry was blended with a Waring blender at a high speed for 2 min, passed through a 63-µm screen, and centrifuged 10 min at 1,400 × g. The soft top layer was carefully removed, and the bottom starch layer was reslurried and washed with deionized water three times. The purified starch was dried at 45°C for 48 hr, passed through a 150-µm sieve and stored in a plastic jar at room temperature until analyses.

Three factors were studied for rice starch isolation by combining surfactant and high-intensity ultrasound: type of surfactant, surfactant level, and sonication duration. The surfactant, including SDS, SSL, and Tween 80, was applied at 0.1, 0.3 or 0.5% level in combination with high-intensity ultrasound at an amplitude of 75% for 0 (stirring at room temperature for 1 hr), 10, or 20 min, and the temperature was maintained at 40°C. Treatments without the addition of surfactant were used as controls, and the starch isolation followed the procedure previously described.

Characterization of Starch Physicochemical Properties

The moisture, protein, total starch, and damaged starch content of the rice flour and the isolated starches were determined by following Approved Methods 44-15A, 46-13, 76-13, and 76-31, respectively (AACC 2000). The pasting properties of rice starches were measured according to Approved Method 61-02 with a Rapid Visco-Analyser (RVA-4 Series, Newport Scientific Pty, Ltd, Warriewood, NSW, Australia). The breakdown viscosity is the peak minus trough viscosity, and the total setback is the final minus trough viscosity. The amylose content of the starch was determined using high-performance size-exclusion chromatography (HPSEC) according to Wang and Wang (2000). Starch was

TABLE I
Starch Yield, Protein Content, and Damaged Starch Contents of Rice Starch Isolated by High-Intensity Ultrasound at Different Temperatures, Durations, and Amplitudes^a

Treatment	Starch Yield (% starch db)	Protein (% db)	Damaged Starch (% db)
Alkaline steeping ^b 40°C	71.6b	0.1e	1.6c
U30min25%amp	47.0f	1.5ab	3.3ab
U60min25%amp	46.7f	1.5ab	3.1b
U15min50%amp	51.6e	1.7a	3.2b
U30min50%amp	62.8c	1.4b	3.2b
U15min75%amp	62.3c	1.5ab	3.4a
U30min75%amp	76.2a	1.2c	3.4a
50°C			
U30min25%amp	46.8f	1.6a	3.4a
U60min25%amp	47.0f	1.6a	3.4a
U15min50%amp	58.0d	1.7a	3.3ab
U30min50%amp	62.8c	1.4b	3.3ab
U15min75%amp	61.5c	1.4b	3.5a
U30min75%amp	74.1a	0.9d	3.3ab

^a U, ultrasound; min, minute; amp, amplitude. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Alkaline steeping at room temperature for 18 hr.

dissolved in 90% dimethylsulfoxide and boiled for 1 hr, stirred overnight, and filtered through a 5-µm filter. The amylose content was calculated as the relative percentage of the amylose peak area over the total peak area.

The thermal properties of the isolated starches were measured by using a Perkin-Elmer Pyris-1 differential scanning calorimeter (DSC, Perkin-Elmer Co., Norwalk, CT) equipped with a cooling system according to the method of Wang et al (1992).

The scanning electron micrographs of isolated starches were taken with a Hitachi S-2300 scanning electron microscope (Tokyo, Japan) at an accelerating voltage of 25 kV. Starch granules were sprinkled onto double-backed cellophane tape attached to a stub before coating with gold-palladium.

Data Analysis

Experimental data were analyzed by using the general linear models procedure (SAS Institute, Cary, NC) and Duncan's multiple range was used to compute the least significance differences at $P < 0.05$.

RESULTS AND DISCUSSION

The rice flour used in this study had 87.6% total starch, 7.7% protein, and 5.4% damaged starch (db). The starch yield, protein, and damaged starch contents of the rice starches isolated by the alkaline steeping and by different high-intensity ultrasound treatments are listed in Table I. The starch yield, protein and damaged starch contents were 46.7–76.2%, 0.1–1.7% and 1.6–3.5% (db), respectively. When the sonication amplitude and duration increased, the starch yield was significantly improved and the residual protein content was slightly decreased, while the damaged starch content of the isolated starch remained unchanged. The sonication temperature, however, had little effect on the starch yield. At the high sonication amplitude (75% for 30 min), the starch yield was

TABLE II
Starch Yield, Protein Content, and Damaged Starch Content of Rice Starches Isolated by Combinations of Surfactant and High-Intensity Ultrasound at 75% Amplitude^a

Treatment	Starch Yield (% starch db)	Protein (% db)	Damaged Starch (% db)
Alkaline Steeping ^b	71.6cd	0.1g	1.6d
Stir 1 hr in H ₂ O ^c	42.5g	2.1b	2.2c
U10minH ₂ O	58.1e	1.6c	2.3c
U20minH ₂ O	76.4c	1.6c	2.5bc
Stir 1 hr in 0.1% SDS	50.8f	2.0b	2.5bc
U10min0.1% SDS	67.0d	1.9b	2.6b
U20min0.1% SDS	78.7bc	1.5c	2.4bc
U10min0.3% SDS	66.0d	0.8e	2.7b
U20min0.3% SDS	80.7b	0.8e	2.9ab
U10min0.5% SDS	74.1c	0.3f	2.8ab
U20min0.5% SDS	84.9a	0.2fg	3.1a
Stir 1 hr in 0.1% SSL5	50.3f	2.0b	2.7b
U10min0.1% SSL	62.8e	1.7c	3.0ab
U20min0.1% SSL	78.3bc	1.6c	2.8b
U10min0.3% SSL	61.6e	1.0d	3.2a
U20min0.3% SSL	77.8bc	1.2d	3.1a
U10min0.5% SSL	62.5e	1.1d	3.1a
U20min0.5% SSL	80.3b	1.1d	3.2a
Stir 1 hr in 0.1% Tween 80	49.0g	2.3a	2.6bc
U10min0.1% Tween80	60.4e	1.6c	3.3a
U20min0.1% Tween80	76.5c	1.4c	2.7b
U10min0.3% Tween80	59.2e	1.2d	3.3a
U20min0.3% Tween80	76.2c	1.3d	3.1a
U10min0.5% Tween80	59.4e	1.2d	3.3a
U20min0.5% Tween80	76.4c	1.2d	3.2a

^a U, ultrasound; min, minute; SDS, sodium dodecyl sulfate; SSL, sodium stearyl lactylate. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Alkaline steeping at room temperature for 18 hr.

^c Stir at room temperature for 1 hr.

higher than that by the alkaline steeping method (74.1–76.2% vs. 71.6%). Nevertheless, the residual protein content of the isolated starch was relatively high (0.9–1.7%) compared with one commercial rice starch sample (Remyline, A&B Ingredients, Fairfield, NJ) of 0.6% (db) and the rice starch isolated by the alkaline steeping method of 0.1% (db). The relatively high damaged starch content might be related to the high residual protein content in the ultrasound-treated starches, although this correlation was not evident for all samples.

The application of high-intensity ultrasound in the rice flour slurry was assumed to cause disruption of the flour particles and breakdown of the noncovalent bonds between protein and starch as a result of the collapsing cavitation bubbles. At higher sonication amplitudes, 50 or 75%, the treated flour slurry was much easier to filter through the 63- μ m screen with a small amount of residue left on the sieve. When sonication amplitude was applied at 25%, the low energy might exert limited impact on rice flour particles, thus starch might still be tightly associated with protein bodies and not recovered after the ultrasound treatment.

The starch yield, protein content, and damaged starch content of rice starch isolated by combining surfactant and high-intensity ultrasound are listed in Table II. Surfactants alone at 0.1% level significantly improved the starch yield from the control of 42.5% to 49.0% and above, and sonication further increased the starch yield up to 78.7% (db). When rice flour treated with 0.3% and 0.5% SDS, the starch yields were 80.7 and 84.9% for 20 min sonication, respectively, which were significantly higher than that by the alkaline steeping method. The rice flours treated with SSL showed an improved yield (80.3%) only at the 0.5% level with 20 min of sonication. Increasing Tween 80 concentration from 0.1 to 0.5% did not improve the starch yield, which was similar to that by the alkaline steeping method. Although the addition of surfactants to the sonication treatment improved the starch yield, the results suggested that the efficacy of starch recovery was still controlled by the sonication treatment.

The residual protein contents of starches isolated with 0.1% surfactants were similar to the control without the addition of surfactant. However, when sonication was applied, the residual protein of starch treated with 0.1% surfactants decreased and a longer sonication time resulted in a lower residual protein content. When the surfactant was increased to 0.3 or 0.5%, the residual protein content decreased more significantly, particularly for those treated with SDS. The starch treated with SDS at 0.3 and 0.5% levels and with sonication had a residual protein content 0.8% and 0.2–0.3%,

respectively. The residual protein contents of the starches treated with SSL and Tween 80 at the 0.3 and 0.5% level were 1.0–1.2% and 1.2–1.3%, respectively. The damaged starch content was slightly higher as the sonication time increased, ranging from 2.3 to 3.3%, which was higher than that by the alkaline steeping method (1.6%). Although the starches treated with 0.5% SDS and sonication had a residual protein similar to that of the alkali-treated control starch, their high damaged starch contents implied that sonication caused damage to starch.

The properties of rice protein and surfactants might also explain the observed differences in residual protein contents. Glutelin, the major component of rice protein, is not soluble in neutral pH due to its hydrophobic bonding, disulfide linkages, high molecular weight, and heterogeneity (Juliano 1985). Ultrasound might disrupt its hydrophobic bonding and expose the hydrophilic sites, thus improving starch isolation. On the other hand, anionic surfactants such as SDS and SSL were effective in separating protein from starch in the present study. It was reported that surfactants could form complex with protein to promote protein extraction (Kinugasa et al 2001). The saturated protein-SDS complex was described by the necklace model where the unfolded protein wrapped around micelle-like clusters (Shirahama et al 1974). The ionic groups in anionic surfactants might contribute more electrostatic binding to extract more protein out of rice flour than nonionic surfactants such as Tween 80. Sonication might assist the separation by creating more interactions between protein and surfactant through cavitation effect.

The pasting properties of isolated rice starches by sonication and the combination of surfactant and sonication are summarized in Tables III and IV, respectively. The rice flours sonicated at 50°C had slightly higher peak but significantly higher final and total setback viscosities than those sonicated at 40°C, and the control treated with alkali had a similar peak but a lower final and total setback viscosities (Table III). The pasting properties of

TABLE III
Pasting Properties of Rice Starches Isolated by High-Intensity Ultrasound^a

Treatment	Viscosity (RVA units)			
	Peak	Breakdown	Final	Total Setback
Alkaline steeping ^b 40°C	369ab	145b	304e	80g
U30min25%amp	352c	152a	299e	99df
U60min25%amp	361b	156a	311d	106d
U15min50%amp	362b	152a	317cd	107d
U30min50%amp	363b	148ab	311d	96f
U15min75%amp	366b	150ab	317cd	101df
U30min75%amp	354c	131c	305e	82g
50°C				
U30min25%amp	365b	138bc	344b	117c
U60min25%amp	379a	134c	347b	102df
U15min50%amp	372ab	143b	370a	141a
U30min50%amp	378a	144b	365a	130b
U15min75%amp	376a	133c	369a	126b
U30min75%amp	364b	134c	324c	94f

^a U, ultrasound; min, minute; amp, amplitude. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Alkaline steeping 18 hr at room temperature.

TABLE IV
Pasting Properties of Rice Starches Isolated by Combinations of Surfactant and High-Intensity Ultrasound^a

Treatment	Pasting Properties (RVA units)			
	Peak	Breakdown	Final	Total Setback
Alkaline steeping ^b	369a	145f	304b	80c
Stir 1 hr in H ₂ O ^c	317de	163d	248e	94bc
U10minH ₂ O	321de	166d	247e	92bc
U20minH ₂ O	326d	176c	245e	95bc
Stir 1 hr in 0.1% SDS	295f	142f	238f	85c
U10min0.1%SDS	312e	144f	271cd	103a
U20min0.1%SDS	329d	147ef	277cd	95b
U10min0.3%SDS	328d	166d	260d	98b
U20min0.3%SDS	330d	175c	248e	93bc
U10min0.5%SDS	340c	207b	230g	97b
U20min0.5%SDS	363a	221a	238f	96b
Stir 1 hr in 0.1% SSL	325d	139f	283c	97b
U10min0.1%SSL	321de	137f	289c	105ab
U20min0.1%SSL	337c	132g	297b	92bc
U10min0.3%SSL	338c	155e	293b	110a
U20min0.3%SSL	342bc	154e	291bc	103ab
U10min0.5%SSL	340c	150e	299b	109a
U20min0.5%SSL	342bc	152e	290bc	100ab
Stir 1 hr in 0.1% Tween80	306e	119h	281c	94bc
U10min0.1% Tween80	347b	129g	310ab	92bc
U20min0.1% Tween80	345bc	132g	311ab	98b
U10min0.3% Tween80	342bc	120h	313ab	91bc
U20min0.3% Tween80	349b	121h	320a	92bc
U10min0.5% Tween80	344bc	124gh	319a	99b
U20min0.5% Tween80	347b	128g	315a	96b

^a U, ultrasound; min, minute; SDS, sodium dodecyl sulfate; SSL, sodium stearyl lactylate. Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

^b Alkaline steeping 18 hr at room temperature.

^c Stir at room temperature for 1 hr.

isolated starches by combining surfactant and sonication were different from those by sonication alone. In general, they showed higher peak, final, and total setback viscosities compared with those treated with sonication only. For SDS treatments, the peak and breakdown viscosity gradually increased as the sonication time and the SDS level increased. Nevertheless, the same trend was not observed for treatments with SSL and Tween 80. It has been reported that the difference in pasting viscosity may be strongly influenced by the residual protein and damaged starch (Lim et al 1999; Wang and Wang 2001). However, the present results did not show clear trend with regard to residual protein and damage starch on peak viscosity. The impact of sonication on starch, although not elucidated, may add additional complexity to the pasting properties besides the contribution from the residual protein and damaged starch.

The amylose content of the isolated rice starches as measured by HPSEC was similar and no difference was observed among different treatments, suggesting that the sonication treatment did not significantly degrade the amylose component in rice starch. The thermal properties of the isolated rice starches as measured by DSC had an average onset temperature of 66.6°C and a peak temperature of 73.1°C and an enthalpy of 12.4 J/g. There were no significant differences among the treatments, indicating that the sonication treatment at given conditions did not alter the starch

crystalline structure. The SEM results did not show any damage on the surface of rice starch granules (Fig. 1). Nevertheless, sonication might affect starch in some fashion that only the pasting properties but not the thermal or morphological properties were affected.

CONCLUSIONS

High-intensity ultrasound had the capability of effectively isolating rice starch without causing undue starch damage. By combining surfactant, particularly SDS, with high-intensity ultrasound, the starch yield was further increased, and the residual protein was drastically decreased.

This method eliminated the steeping step and would not involve any chemicals, therefore the cleaning steps were simplified and the wastewater was drastically reduced. The protein layer removed during starch isolation could be easily recovered as value-added products such as rice protein concentrates because no chemicals were used. For future study, ultrasound will be applied with other techniques to achieve a high starch yield with a low residual protein and damaged starch.

ACKNOWLEDGMENTS

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LITERATURE CITED

- American Association of Cereal Chemists. 2000. Approved Methods of the AACC, 10th ed. The Association: St. Paul, MN.
- Chung, K. M., Moon, T. W., Kim, H., and Chun, J. K. 2002. Physico-chemical properties of sonicated mung bean, potato, and rice starches. *Cereal Chem.* 79:631-633.
- Domah, M. B. A., and Mohamed, M. S. 1974. Studies on rice starch industry in Egypt. I. Composition of polished whole and broken rice, gluten meal and the fluid wastes of rice starch manufacture. *Alexandria J. Agr. Res.* 22:37-44.
- El'Piner, E. A. 1964. *Ultrasounds: Physical, Chemical and Biological Effects.* Consultant Bureau: New York.
- Fujii, T. 1973. Purification and processing of starch: Purification of starch by surface active agents, and fatty substances in starch and its effects on physical properties of starch. *Denpun Kagaku* 19:159-168.
- Fujii, T., and Tomiyama, S. 1973. Purification of starch by surface active agents. XVII. Removal of crude protein in sweet potato starch by sodium α -olefin sulfonates (AOS). *Eiyo To Shokuryo (Japanese)* 26:503-504.
- Jackson, D. S., Choto-Owen, C., Waniska, R. D., and Rooney, L. W. 1988. Characterization of starch cooked in alkali by aqueous high-performance size-exclusion chromatography. *Cereal Chem.* 65:493-496.
- Jackson, D. S., Waniska, R. D., and Rooney, L. W. 1989. Differential water solubility of corn and sorghum starches as characterized by aqueous high-performance size-exclusion chromatography. *Cereal Chem.* 66:228-232.
- Juliano, B. O. 1985. Polysaccharides, proteins, and lipids of rice. Pages 59-174 in: *Rice: Chemistry and Technology*, 2nd Ed. B. O. Juliano, ed. Am. Assoc. Cereal Chem.: St. Paul, MN.
- Kinugasa, T., Sanagi, K., Watanabe, K., and Takeuchi, H. 2001. Effect of interaction between protein and surfactant in aqueous phase on extraction rate of protein into reverse micellar solution. In: *Solvent Extraction for the 21st Century.* Proc. ISEC 99. Soc. Chem. Ind.: London.
- Komoto, M., Fujii, S., Kishihara, S., and Yoshinaga, K. 1982. Improvement of quality of sago starch. I. Effect on the quality of some chemical and/or ultrasonic treatments. *Kobe University Agric. Res. Bull.* 15:141-148.
- Kung, L. L., Chen, H. J., and Sung, H. Y. 1987. A new method for separation of rice protein and starch. *J. Chinese Agric. Chem. Soc.* 25:299-307.
- Leadley, C., and Williams, A. 2002. Power ultrasound—Current and potential applications for food processing. *Review No 32, Campden & Chorleywood Food Research Association.*
- Lim, S. T., Lee, J. H., Shin, D. H., and Lim, H. S. 1999. Comparison of protein extraction solutions for rice starch isolation and effects of residual protein content on starch pasting properties. *Starch* 51:120-125.

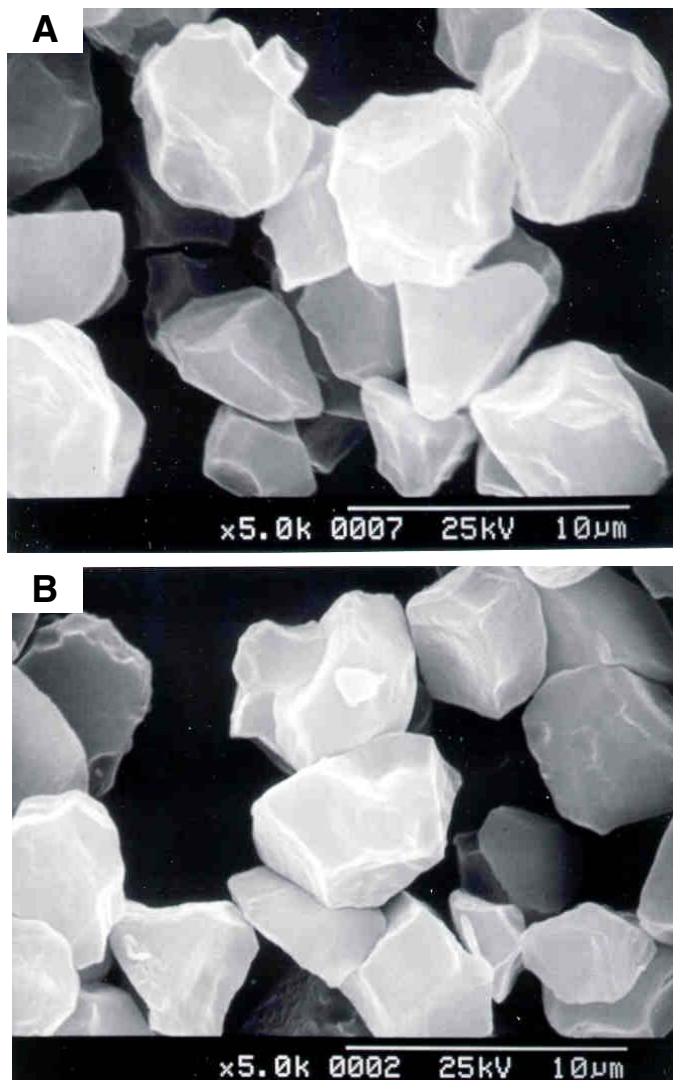


Fig. 1. Scanning electron micrograph of rice starches isolated by (A) room stirring without sonication, and (B) high-intensity ultrasound at 75% amplitude and 50°C for 30 min.

- Lumdubwong, N., and Seib, P. A. 2000. Rice starch isolation by alkaline protease digestion of wet-milled rice flour. *J. Cereal Sci.* 31:63-74.
- Mason, T. J. 1998. Power ultrasound in food processing—The way forward. Pages 105-126 in: *Ultrasound in Food Processing*. M. J. W. Povey and T. J. Mason, eds. Thomson Science: London.
- Shirahama, K., Tsujii, K., and Takagi, T. 1974. Free-boundary electrophoresis of sodium dodecyl sulfate-protein polypeptide complexes with special reference to SDS-polyacrylamide gel electrophoresis. *J. Biochem.* 75:309-319.
- Suslick, K. S. 1988. Its chemical, physical, and biological effects, In: *Ultrasound*. K. S. Suslick, ed. VCH Press: New York.
- Wang, Y.-J., and Wang, L. 2000. Effects of modification sequence on structures and properties of hydroxypropylated and crosslinked waxy maize starch. *Starch* 52:406-412.
- Wang, L., and Wang, Y.-J. 2001. Comparison of protease digestion at neutral pH with alkaline steeping method for rice starch isolation. *Cereal Chem.* 78:690-692.
- Wang, Y.-J., White, P. J., and Pollak, L. 1992. Thermal and gelling properties of maize mutants from the Oh43 inbred line. *Cereal Chem.* 69:328-334.

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