Effects of sodium dodecyl sulphate and sonication treatment on physicochemical properties of starch

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Abstract
Effects of sodium dodecyl sulphate (SDS) and sonication treatment on physicochemical properties of starch were studied on four types of starch, namely, corn, potato, mung bean, and sago. The SDS and sonication treatments caused a significant reduction of protein content for all the starches. The SDS treatment did not cause apparent damage on granular structure but sonication appeared to induce changes such as rough surface and fine fissures on starch granules. The combination of SDS and sonication increased amylose content for all starches. This could be attributed to the removal of surface protein by SDS and structural weakening by sonication which facilitated amylose leaching from swollen starch granule. The X-ray pattern for all starches remained unchanged after SDS treatment, suggesting no complexation of amylose–SDS had occurred. Combined SDS-sonication treatment increased swelling and solubility of corn, mung bean, and potato starch. The treated starches showed significant increase in peak viscosity with reduction in pasting temperature, except for potato starch. Results of the present study indicate the possibilities of exploring SDS and sonication treatments for starch modifications.

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1. Introduction
Starch is an important food ingredient and forms a major constituent of the human diet. Native starch exists as a granular structure and is composed of amylose and amylopectin arranged in amorphous and crystalline regions. Starch granules also contain minimal quantities of minor components like proteins, lipids, pentosans, and minerals (Morrison, 1995). The interactions of these minor components with amylose and amylopectin can influence the properties and functional behaviour of the starch.

Starch granule-associated proteins (SGAPs) are defined as the proteins biologically distinct from plant storage proteins and are tightly bound in and on starch granules (Baldwin, 2001). These protein are mainly starch biosynthetic enzymes and have a molecular weight around 5000–149,000, and possess different polypeptide species such as prolamin, 2S albumin and globulin. The presence of starch granule surface-proteins has been reported in maize starch (Imam, 1989), barley starch (Prentice & Stark, 1992), and in mung bean starch (Oates, 1990). Among the main commercial starches, cereal starches (wheat, maize, barley, and rice) contain more protein (0.25–0.6%, w/w) than tuber (potato, 0.06%), and root (tapioca, 0.1%) starches (Debet & Gidley, 2006). The nature of protein/starch granule interactions is not well characterised but most of the surface-proteins are believed to be adsorbed onto the surface of the starch granule (Baldwin, 2001).

In the enzymatic hydrolysis of starch to produce glucose syrup, the presence of protein layer on the surface would presumably restrict the access of the enzyme, thus reducing the degree of hydrolysis. The removal of the surface protein can enhance the accessibility of enzyme to the granule surface and interior of the granule. For this reason, a number of methods (e.g., salt treatment, rigorous extraction, use of ethanol) have been investigated to improve the hydrolysis of poorly hydrolysable starch granules (Debet & Gidley, 2006). The sodium dodecyl sulphate (SDS) treatment is one of the methods, which can efficiently remove the surface protein of starch granules (Eerlingen, Cillen, & Delcour, 1994).

When a liquid is subjected to the action of ultrasound, rapidly collapsing cavitation bubbles induce high pressure gradients and high local velocities of liquid layers in their vicinity. This in turn may cause shear forces that have no significant influence on small molecules, but are capable of breaking the chains of polymers, provided the chains are longer than a certain limiting value. This is the mechanochemical action of ultrasound on polymers (Czechowska-Biskup, Rokita, Lofy, Ulanski, & Rosiak, 2005). Wang and Wang (2004) reported that the combination of protease with high-intensity ultrasound greatly improved starch yield to 79.8–86.7%, compared to 62.5–71.8% with protease alone. Even more effective was a combination of high-intensity ultrasound with 0.5% SDS which increased starch yield to 85% with 0.2% residual protein.
Several studies have reported the effect of sonication (Iida, Tuziuti, Yasui, Towata, & Kozuka, 2008), SDS (Debet & Gidley, 2006; Radhika & Moorthy, 2008) or combination of SDS and protease (Wang & Wang, 2004) on the physicochemical properties of starch. However, very little data are available on the combined effect of SDS and sonication on the physicochemical properties of starch. Therefore, the main objective of this study was to evaluate the effects of sodium dodecyl sulphate (SDS), sonication and combination of both treatments on the removal of starch granule-associated proteins of corn and mung bean starch because it contained relatively high protein content. Potato and sago starch were used as comparison because these starches contained very little amounts of protein content. The effect of these treatments on the physicochemical and functional properties of the starches would provide more insight into the possibilities of exploiting these treatments for starch modifications.

2. Materials and methods

2.1. Material

Corn, potato and sago starch were procured from the Sims Company Sdn. Bhd, Penang, whereas mung bean flour was from the Pearl Island Packaging Sdn. Bhd, Penang.

2.2. Sodium dodecyl sulphate and sonication treatment

Starch (250 g, 40% w/v) was suspended in 625 ml SDS solvent (2% w/v) at room temperature. The starch suspension was stirred for 30 min using a magnetic stirrer and centrifuged (Kubota 5100, Kubota Corp., Tokyo, Japan) at 2328 g for 15 min. The supernatant was carefully removed. The pellet was washed three times, re-suspended with distilled water, centrifuged and dried in the oven at 40 °C for 12 h. For treatment involving sonication, the sample was subjected to sonication in the Ultrasonic Bath (Transsonic D7700, Elma, Germany) for 10 min and then washed and centrifuged as described previously. Combination of SDS and sonication treatment was done by first treating the starch sample with SDS solvent as previously described. After the pellet was washed three times and, re-suspended with distilled water, it was subsequently subjected to sonication treatment for 10 min and then washed and centrifuged as described previously. One sample from each treatment for each type of starch was prepared and kept until further analysis.

2.3. Moisture and amylose contents of starch samples

Moisture was determined by drying triplicate 5-g samples to constant weight in an air oven at 105 °C (AOAC, 1990). Amylose content was determined using the spectrophotometric method described by McGrance, Cornell, and Rix (1998). Pure potato amylose and amylopectin (Sigma Chemical Company, Steinheim) were used as the standards. The results were expressed on a dry basis. Starch (0.1 g, dry basis) was accurately weighed and dissolved by heating in dimethyl sulfoxide for 15 min on a hot plate at 85 °C while stirring continuously with a magnetic stirrer bar. After the solution had dissolved, it was diluted to 25 ml in a volumetric flask with deionised water. An aliquot (1 ml) of this solution was diluted with 50 ml of deionised water. Five millilitres iodine (0.0025 mol/l) in potassium iodide (0.0065 mol/l) was added with mixing and the absorbance of this solution in a 1 cm path length glass cell read at 600 nm using a UV/visible spectrophotometer (UV-160A, SHIMADZU, Kyoto, Japan). Samples were left for 15 min after the addition of iodine before taking the readings on the spectrophotometer. The reported values are the means of triplicate measurements.

2.4. X-ray diffraction

Prior to analysis, about 0.5 g of native and SDS-treated samples were conditioned at 100% relative humidity at room temperature overnight. X-ray diffraction patterns were determined using a diffractometer (Diffractometer D5000, SIEMENS, Karlsruhe, Germany) operating a 40 kV, 30 mA with Cu Kα radiation (λ = 1.5406 Å) by using 15 μm of Ni-foil. Diffractograms were obtained from 0° to 60°. Scattered radiation was detected using a proportional detector.

2.5. Scanning electron microscopy (SEM)

Four types of starch samples (native starch, SDS-treated starch, SDS + sonication-treated starch and sonicated starch) were photographed using scanning electron microscope (FESEM Leo Supra 50 VP, Carl-Ziess SMT, Oberkochen, Germany). The samples were sprinkled onto double-side adhesive carbon tape attached to a circular aluminium specimen stub and coated with 30 nm layer gold using a sputter coater (Polaron (Fisons) SCS15, VG Microtech, Sussex, UK) under vacuum condition.

2.6. Protein content analysis

Protein content of native starch, SDS-treated starch, SDS + sonication-treated starch and sonicated starch was determined by using macro-Kjeldahl method (AOAC, 1990). The crude protein content in wet basis was calculated by multiplying nitrogen content by a factor of 6.25. Each starch was analysed in triplicate and reported as percent of protein.

2.7. Swelling power and solubility analysis

Swelling power and solubility of starch samples were determined in triplicate as described by Schoch (1964) with minor modifications. Each sample (100 mg in dry basis) were accurately weighed and transferred to 50 ml centrifuge tubes. Distilled water (10 ml) was added and the centrifuge tube was placed in the water bath at peak temperatures (corn = 90 °C, mung bean = 80 °C, potato = 75 °C, sago = 80 °C) of the respective starch samples for 30 min until it become translucent. The peak temperature was previously determined by using RVA.

The solution was centrifuged at 3500 rpm for 15 min and the supernatant was carefully removed. An aliquot (5.0 ml) of the supernatant was pipetted and transferred to a pre-weighed Petri dish and dried at 110 °C in an oven overnight. The swollen starch sediment was weighed. The dish was cooled in a desiccator and weighed to calculate the percentage of solubility. Swelling power was the ratio in weight of the wet sediment to the initial weight of the dry starch. The solubility was the ratio of the dry supernatant to the initial weight of dry starch.

2.8. Pasting property analysis

The pasting property of starch (8% w/w, except potato with 4% w/w, dry starch basis) was analysed in triplicate by using a Rapid Visco™ Analyzer (RVA 4, Newport Scientific, Warriewood, Australia). The starch suspension was heated at a rate of 12 °C/min from 50 °C to 95 °C, then kept at 95 °C for 2.5 min, followed by cooling to 50 °C at the same rate. The paddle rotated at 960 rpm for the first 10 s after which it was kept at 160 rpm. Pasting characteristics such as pasting temperature (temperature where viscosity first increase), peak time (the time at which peak viscosity occurred), peak viscosity (the maximum viscosity after heating cycle ended), trough viscosity (the trough at the minimum hot paste viscosity), final viscosity (the viscosity after cooling to 50 °C for 2 min),
breakdown (difference between peak viscosity and holding strength) and setback (difference between final viscosity and peak viscosity) were calculated. The viscosity was measured in Rapid Visco Unit (RVU), which is equivalent to about 12 cP.

2.9. Statistical analysis

Statistical evaluation of the data was carried out using SPSS, version 11.5 (SPSS Inc., Chicago, USA). The data for all the analysis are averages of triplicate observations. The starch type and type of treatments were two factors that were analysed by analysis of variance (ANOVA). Duncan's multiple range method was used to compare any significant difference between the samples from different type treatments. Type of starch was the independent variable, whereas type of treatments was the dependent variable in this study. Differences were considered significant at $p \leq 0.05$.

3. Results and discussion

In the following discussion, the term “native starch” refers to the starch that has not undergone any form of chemical treatment. “SDS-treated starch” refers to starch that has undergone 30 min treatment with SDS. “SDS + sonication starch” refers to starch that has undergone 30 min treatment with SDS and subsequently subjected to 10 min sonication. “Sonicated starch” or “sonication starch” refer to starch that was stirred with distilled water for 30 min at room temperature and subsequently subjected to 10 min sonication.

3.1. Scanning electron microscopy (SEM)

Fig. 1A–D shows SEM micrographs of (a) native starch, (b) SDS-treated starch, (c) SDS + sonication starch, and (d) sonicated starch samples (shown here for corn starch only because no obvious changes were observed for other starches). Except for corn starch, it appears that the shape and surface of starch granules were not affected by SDS and sonication treatment – no obvious changes between native and treated (SDS and SDS + sonication) starch could be observed. However, the granule surface of sonicated corn starch exhibited fine fissures (Fig. 1D). Prolonged sonication treatment is expected to cause physical damage on starch granular structure as reported by Gallant, Degrois, Sterling, and Guilbot (2006). Gallant et al. (2006) observed deep pitting and damages on some parts of the granule surface when the suspension was subjected to ultrasound (280 kHz, 15 W/cm$^2$) in an atmosphere of air or oxygen. The extent of damage increases with time of radiation and decreases with increasing concentration of starch in the suspension. They suggested that damage produced by ultrasound indicates a primarily radial structure of submicroscopic units in the starch grain. The fact that in our experiment only corn starch granules showed fissures suggests that corn starch has a relatively weaker granular structural integrity compared to sago, potato, and mung bean starch. The presence of natural pores and cavities in corn starch granules (Fannon, Shull, & BeMiller, 1993) probably made the granule more prone to be disrupted by cavitation effect during sonication. The SDS probably affected only the non-covalent bonding between starch and protein without damaging the starch molecular or granular structures. With regard to mung bean, potato and...
sago starches, no prominent fissures or pores could be observed under SEM after being subjected to various treatments.

3.2. X-ray diffraction

Amylose has been reported to form inclusion complexes with SDS as the hydrophilic head of SDS are entrapped in the granules and is kept inside by physical adsorption and hydrophobic interactions (Debet & Gidley, 2006). This type of complex can result in the formation of V-type X-ray pattern. Hence, to look for the possible induction of such changes, X-ray diffraction studies were undertaken to investigate whether the starch has the ability to form complexes with SDS or not.

Both native and SDS-treated corn starch yield a pattern that corresponds to the A-type crystalline structure, while the native and SDS-treated mung bean and sago starch show the diffraction patterns which are typical of C-type (results not shown). Diffraction patterns of native potato starch and SDS- treated starch present a small peak at Bragg angle 5.5° and a single diffraction peak at around 17° 2θ, which are typical B-type. The SDS-treated starch samples revealed an identical X-ray diffraction pattern to that of native starch and did not show the small reflection at about 13° and a larger reflection at 2θ°, which corresponds to the V-polymorph. The results indicate a very minimal effect of SDS on the polymorphic crystalline structures, i.e., no SDS–amylose complex formation have occurred during the treatment. Eerlingen et al. (1994) demonstrated that the SDS–amylose complex could only be formed during heating. Ghiasi, Varriano-Marston, and Hoseney (1982) have reported that the release of surfactant–amylose complexes into the aqueous phase happened at temperatures higher than 85 °C. Hence, considering that our samples were air-dried at 40 °C for 24 h and have no further heating treatment, it may be assumed that no amylose complexes could be formed.

3.3. Protein content analysis

Fig. 2 shows the results for the protein content of corn, potato, mung bean and sago starch. Protein content of corn, potato, mung bean, and sago starch are 0.24%, 0.075%, 0.24% and 0.078%, respectively. This is consistent with values reported by Debet and Gidley (2006) for corn starch (0.25–0.6%) and potato starch (0.06%). Compared to potato and sago starch, protein content for corn starch and mung bean starch decreased significantly (approximately by 20% and 36%, respectively) after SDS, SDS + sonication and sonication treatment. Protein content of potato and sago starches was affected only slightly by these treatments. The results suggest that SDS was able to partially remove the protein of corn. However, no significant differences between the protein content of SDS treated and SDS + sonication-treated corn starch could be recorded. Corn starch granules, which contained more pores and channels, could be more susceptible to SDS, thus facilitating the SDS entry into the granule interior through these pores and channels. Fannon et al. (1993) have proposed that the presence of pores as an anatomical feature of some starches, and the absence of these in other starches affected the pattern of attack by amylases and by at least some chemical reagents. With regard to potato, a significant reduction in protein content was observed for SDS and SDS + sonication treatments but not for sonication alone. SDS-treatments showed reduction in the protein content. However, there was no reduction in protein content of sonicated starch. This suggests that SDS could be used to remove the protein of potato starch but the effect was not as significant as corn starch, which might be due to the absence of pores and channels.

Results on the protein content of SDS-treated sago were significantly different from SDS + sonication-treated sago. Both the protein content of starches was significantly reduced compared to native sago. We postulate that the starches could be separated more easily from protein after sonication was applied after SDS treatment, suggesting that this combination treatment was more effective in loosening the protein matrix around the sago starch granules. SDS would be able to remove protein from starch more effectively once the protein matrix was loosened.

In mung bean, no significant difference was observed in protein content between SDS-treatment and SDS + sonication treatments. However, compared to native starch a significant reduction was recorded. SEM micrographs showed a few granules in SDS-treated starch and sonicated starch to have fine fissures, similar to sonicated corn starch granules shown in Fig. 1. This is believed to provide a larger area for the reaction of SDS indicating that the removal of protein to be quite effective. In mung bean starch, the higher protein on the surface being removed after SDS treatment could be due to the presence of higher amounts of surface protein on mung bean granules as compared to corn starch.

According to Seguchi (1995), aqueous SDS solutions cause granule destabilisation at both room temperature and 50 °C, and thus allow granule gelatinisation at lower temperatures. Granule swelling is required to remove the internal higher molecular weight proteins (59 × 10^3–149 × 10^3) in 1–2% SDS solution at or above 50 °C (Sikkert, Frend, Robson, & Greenwell, 1990). Temperatures of 50 °C are reported to induce granule swelling without full gelatinisation whereas 90 °C in aqueous solution induces full granule gelatinisation and allowing access of maximum agents to the internal SGAPs (Baldwin, 2001). However, as the present experiment was done at sub-gelatinisation temperature (40 °C) the effect of protein removal was not as significant as expected.

3.4. Amylose content analysis

The amylose content in starch granules affect many of the physical, chemical and functional properties like pasting, gelatinisation and swelling properties of starch (You & Izydorczyk, 2002).

Fig. 3 shows the amylose content of four different starches. Results revealed an increase in the amylose content in corn and potato starches after being subjected to all the treatments. The increase in amylose content was attributed to partial depolymerisation of amylose to some extent. This in turn increased the amount of linear chains, hence increased the apparent amylose content of starch. Therefore, we postulated that corn and potato starch have some
degree of depolymerisation after subjected to all treatments. In sago starch, SDS-treatments showed a significant decrease while sonication increased the amylose content. SDS + sonication did not have any significant effect on amylose content of sago starch. The effect of SDS + sonication treatment on sago starch is quite complicated. This might be due to interactive effect between SDS and sonication. In mung bean starch, no significant effect could be recorded after any of the treatments.

3.5. Swelling power and solubility analysis

The swelling power and solubility provide measures of the magnitude of interaction between starch chains within the amorphous and crystalline domains (Singh & Kaur, 2004). The extent of this interaction is influenced by the amylose to amylopectin ratio and phosphorous content and by the characteristics of the amylose and amylopectin in terms of molecular weight/distribution, degree of branching and branch length, and conformation (Singh & Kaur, 2004). The changes observed in swelling power among different samples analysed in the present study is depicted in Fig. 4.

Potato showed the highest swelling power followed by corn, sago, and mung bean. The high swelling power in potato can be attributed to the longer chains in amylopectin structure as well as due to high phosphorus content (Sasaki & Matsuki, 1998). The low swelling power recorded in mung bean is on a par with our observation relevant to highest amylose content. Tester and Karkalas (1996) indicated that the starch granules with higher amylose content were being better reinforced and thus more rigid and swell less freely whereas the starch granules with low amylose content were less rigid and can swell freely when heated.

In the present study, we found no significant difference in swelling power between the native corn starch, SDS-treated corn starch and SDS + sonication-treated starch. Bowler, Williams, and Angold (1980) have shown that cereal starch granules do not show complete swelling until amylose has been leached from the granule, suggesting that amylose restrains swelling if the optimum condition for swelling does not achieve. The presence of natural pores on corn starch granular structure weakens the integrity of the starch granule. Therefore, the increase in swelling power in corn starch was not significant after removal of protein from corn starch granule. In SDS-treated starches, the amorphous region containing primarily amylose might have been disrupted and consequently weakened the granular structure. As a result, the granules could not attain their maximum swelling capacity. Mung bean followed the same trend as corn and did not show any significant difference in swelling power after treatments. Oates (1990) suggested the possible existence of peptide cross-links within the amylopectin fraction of mung bean starch that could be responsible for maintaining the structure of starch ghosts.

Results on sago starch revealed a significant decrease in the swelling power after SDS and SDS + sonication treatments compared to the native starch. The reduction in the swelling power after treatment might be attributed to structural disintegration within the granules of the starch during the process of modification. The disruption of sago granule may affect the water binding capacity of granules hence decreasing the ability to swell.

In potato, swelling power of SDS and SDS + sonication-treated potato starch increases significantly over native starch. Disruption of the structure of protein by SDS and sonication might have allowed the gelatinised granules to swell to a greater extent than what was possible in its native state. However, the increase in swelling power in potato starch might not due to removal of protein from potato starch granule but it may due to the effect of treatment on the amorphous region of the granule which allows the amorphous region in potato starch to absorb water easily, hence swelling to a greater extent as compared to its native state. Increase in swelling power and solubility of the treated starch could be attributed to the leaching of the amylose chain after the removal of protein envelope layer. According to Tester and Morrison (1990), amylose tends to retard water absorption, swelling, and pasting of starch granules. Therefore, the leaching of amylose chain after the removal of protein envelope layer allows starch granules to absorb more water and swell to maximum extent.

Fig. 5 shows solubility of different kind of starches under different condition. A progressive increase in solubility of all the four starches for SDS- and SDS + sonication-treated starches compared to native starches. Leaching could occur from swollen starch granules when immersed in water at temperatures of 57–100 °C (Young, 1984). Mobile amylose molecules and low molecular weight molecules can diffuse out from swollen granules when leaching occurs. The effective removal of the protein surface, which might have restricted the leaching, could contribute to these observed results. The increase in solubility after sonication might be attributed to depolymerisation and structural weakening of the starch. It is well known that high swelling power will contribute to high solubility (Tester & Morrison, 1990). When the granule swells larger, more amylose can be leached out to the soluble phase. Except for sago starch, this holds true for all the starches in the present study.
starches. It is possible that water washing after the centrifugation observed after SDS treatment. However, this is not true for potato and Gidley (2006), wherein a big increase of peak viscosity was starch because of the higher swelling power exhibited by these corn starch. The peak viscosity of SDS-treated starches was ex-

moval of protein layers that help to increase the swelling power of SDS and sonication treatment. This could be due to the effective re-

ever, the corn starch exhibited the highest peak viscosity after the treatment. This could be attributed to the weakened structure of the gran-

ules during SDS and sonication treatment, thus facilitating disrup-

tion of the granular structure. These results clearly show that the stability of treated starch during thermal processing was substan-
tially reduced. By comparing the breakdown between the native starches, potato had the highest value followed by sago, corn, and mung bean. However, SDS-treated corn starch revealed the highest breakdown when compared with treated starches. The high peak viscosity starch appears to have a greater breakdown and it is reported that a relationship occurs between swelling capacity and rheodestruction, wherein the more swollen the starch granules, the more shear-sensitive the pastes become (Doublier, Llamas, & Le Meur, 1987). The parameters of setback are reported to have significant correlation with the degree of polymerisation (Sandhya Rani & Bhattacharya, 1995). Setback value has been reported to be positively correlated with amylose content in many studies on starch pasting properties (Singh, Kaur, & Ezekiel, 2005). However, this was not consistent with our results. High lev-

eels of breakdown were associated with a high degree of collapse of swollen starch granules corresponding to a greater release of solu-
bilised starch capable of reassociation during the cooling portion of the RVA profile (high total setback). However, this is only true for SDS-treated corn, SDS and sonication-treated corn and SDS and sonication-treated potato since they showed a significant increase in setback after treatment. The treated mung bean and sago starches reduced significantly compared to their native state.

SDS extraction converted slow swelling starches to rapid swell-
ing types except potato. This is because the peak time and pasting temperature of treated starches reduced significantly. Shorter time and lower pasting temperature is required to achieve the peak viscosity. We found that the pasting profiles of SDS-treated starches and SDS and sonication-treated starches have the similar profile.

### 3.6. Pasting properties

Table 1 shows the changes recorded in the pasting properties of starches after subjecting to various treatments. From the pasting profile of native starches, we found that potato starch had the highest peak viscosity followed by corn, sago, and mung bean. This might be due to a higher content of phosphate groups on adjacent chains, which increase hydration by weakening the extent of bonding within the crystalline domain (Galliard & Bowler, 1987). However, the corn starch exhibited the highest peak viscosity after the SDS and sonication treatment. This could be due to the effective removal of protein layers that help to increase the swelling power of corn starch. The peak viscosity of SDS-treated starches was expected to be significantly higher than that of native or control starch because of the higher swelling power exhibited by these starches. These results are consistent with the experiments of Debet and Gidley (2006), wherein a big increase of peak viscosity was observed after SDS treatment. However, this is not true for potato starches. It is possible that water washing after the centrifugation process caused some solubilisation of amylose from potato starch granules, resulting in a lower peak viscosity. For all the other starches, water washing during SDS treatment had no detectable effect on subsequent viscosity profiles. All of the SDS and sonica-
tion-treated starches showed a significant decrease of peak viscosity compared to SDS-treated starch. This indicates that sonication could weaken the granule structure and the rupture will cause the peak viscosity to decrease.

The breakdown viscosity of all the SDS and sonication-treated starches were substantially higher than that of native starch (Table 1). This could be attributed to the weakened structure of the granules during SDS and sonication treatment, thus facilitating disruption of the granular structure. These results clearly show that the stability of treated starch during thermal processing was substantially reduced. By comparing the breakdown between the native starches, potato had the highest value followed by sago, corn, and mung bean. However, SDS-treated corn starch revealed the highest breakdown when compared with treated starches. The high peak viscosity starch appears to have a greater breakdown and it is reported that a relationship occurs between swelling capacity and rheodestruction, wherein the more swollen the starch granules, the more shear-sensitive the pastes become (Doublier, Llamas, & Le Meur, 1987). The parameters of setback are reported to have significant correlation with the degree of polymerisation (Sandhya Rani & Bhattacharya, 1995). Setback value has been reported to be positively correlated with amylose content in many studies on starch pasting properties (Singh, Kaur, & Ezekiel, 2005). However, this was not consistent with our results. High levels of breakdown were associated with a high degree of collapse of swollen starch granules corresponding to a greater release of solubilised starch capable of reassociation during the cooling portion of the RVA profile (high total setback). However, this is only true for SDS-treated corn, SDS and sonication-treated corn and SDS and sonication-treated potato since they showed a significant increase in setback after treatment. The treated mung bean and sago starches reduced significantly compared to their native state.

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<table>
<thead>
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<th>Table 1</th>
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<tr>
<th>Starch sample</th>
<th>Peak viscosity (RVU)</th>
<th>Breakdown (RVU)</th>
<th>Setback (RVU)</th>
<th>Peak time (min)</th>
<th>Pasting temp. (°C)</th>
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</thead>
<tbody>
<tr>
<td>Corn</td>
<td>Native</td>
<td>78.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.8 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.5 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.4 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>SDS treatment</td>
<td>146.7 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>78.4 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>77.3 ± 0.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.7 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>SDS treatment + sonication</td>
<td>136.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>67.4 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>65.9 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.8 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>Sonication</td>
<td>83.8 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>16.6 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.7 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mung bean</td>
<td>Native</td>
<td>69.8 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.5 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.8 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.8 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>SDS treatment</td>
<td>89.9 ± 1.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>32.0 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.0 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.0 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>SDS treatment + sonication</td>
<td>83.6 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>30.8 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.6 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.0 ± 0.1&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Sonication</td>
<td>69.6 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.7 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>23.6 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.0 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Sago</td>
<td>Native</td>
<td>77.4 ± 1.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>48.6 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.8 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>SDS treatment</td>
<td>107.7 ± 1.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>73.1 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.5 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>SDS treatment + sonication</td>
<td>106.3 ± 1.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>72.2 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.6 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.6 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<td></td>
<td>Sonication</td>
<td>81.0 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>52.2 ± 0.7&lt;sup&gt;a&lt;/sup&gt;</td>
<td>14.1 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.7 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>Potato</td>
<td>Native</td>
<td>176.5 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>83.4 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.6 ± 0.6&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.2 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>SDS treatment</td>
<td>97.7 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>27.4 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.1 ± 0.8&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.3 ± 0.0&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>SDS treatment + sonication</td>
<td>93.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.9 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>13.1 ± 0.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.4 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>Sonication</td>
<td>197.3 ± 0.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>100.5 ± 0.3&lt;sup&gt;a&lt;/sup&gt;</td>
<td>11.0 ± 0.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>4.1 ± 0.1&lt;sup&gt;a&lt;/sup&gt;</td>
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Values followed by the same letter in any column are not significantly different (p > 0.05) (n = 3).

Values are means of triplicate determinations ± standard deviation.
4. Conclusion

Four types of selected starches of different botanical origin exhibited different physicochemical properties after SDS and sonication treatment. All starches showed a significant increment in solubility and the overall change in the pasting profile for the treated starches was a reduction in pasting temperature, pasting time accompanied with increase in peak viscosity, except for potato starch. SEM analysis revealed that SDS did not cause major damage to the structure but sonication changed the surface of the starch granules. The protein analysis showed a significant reduction of protein content after SDS and sonication treatment. The differences of physicochemical and functional properties of starches with different kinds of treatment are mainly attributed to their origin.

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References


