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Effect of NaCl and sugar on physicochemical properties of flaxseed polysaccharide-potato starch complexes

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ABSTRACT: To investigate the effect of salt and sugar on the physicochemical properties of flaxseed polysaccharide-potato starch (FG-PS) complexes we measured pasting, gelling, swelling properties, and freeze-thaw stability by methods of rapid viscosity analysis, texture analysis, centrifugation, and freeze-thaw storage, respectively. In the presence of NaCl, the pasting temperature, peak viscosity, final viscosity, breakdown value, and swelling power of FG-PS complexes increased as the NaCl level increased. The hardness of FG-PS complexes gradually reduced with increasing NaCl level. Syneresis of FG-PS complexes was the lowest with addition of high levels of NaCl. These results indicate that both starch-salt and hydrocolloid-salt interactions might govern the physicochemical properties of FG-PS complexes in the presence of NaCl. In the presence of sugar, an increase in pasting temperature, peak viscosity, final viscosity, breakdown value, and gel hardness of FG-PS complexes was observed with increasing added level of sucrose and glucose, while swelling power and syneresis decreased.

KEYWORDS: freeze-thaw stability, gel properties, pasting properties, swelling power

INTRODUCTION

Starch is a biological macromolecule widely used in food industry. The most important physicochemical properties of starch include pasting properties, gel properties, swelling properties, and freeze-thaw stability[1]. As salt and sugar are the most important ingredients usually used in food industry, the physicochemical properties of starch-based food often change by addition of salt and sugar during food processing and storage. Viscosity of corn starch could be increased with salt[2]. Peak viscosity of cassava starch could be promoted with 2.5–5% NaCl[3]. Rice starch with high content of amylopectin exhibits better swelling properties. But the swelling power of rice starch is reduced by adding salt[4]. The influence of sugar on pasting properties of starches have also been studied[5–7].

The properties of native starch could be improved by adding an anionic polysaccharide. The interaction between anionic polysaccharide and starch had been investigated in recent years[8]. Pasting, gelling, and swelling properties of starch could be changed with a small amount of added polysaccharide. The interaction between polysaccharide and starch depends on factors that include negative charge, polymerization degree, and molecular weight[9]. Starch tolerance to salt could also be improved by adding an anionic polysaccharide, but the properties of anionic polysaccharide-starch complexes modified by salt are less known. Peak viscosity of xanthan gum-pea starch could be significantly enhanced with NaCl[10]. Pasting temperature, peak viscosity, and breakdown value of xanthan gum-potato starch mixtures were promoted by NaCl or $CaCl_2$[11]. Sugars added into starch-gum combinations influence the pasting temperature[12].

Flaxseed polysaccharide (FG) is an anionic polysaccharide possessing the thickening, weak-gelling, emulsification properties, and emulsifying stability[13–16]. Flaxseed polysaccharide could form a thermo-reversible gel, the hardness of which could be influenced by monovalent or divalent cations[14]. So far, it is unknown how NaCl affect pasting, gelling, swelling properties, and freeze-thaw stability of flaxseed polysaccharide-potato starch complexes (FG-PS).

The main objective of this study was to determine the pasting, swelling, gelling properties, and freeze-thawing stability of potato starch (PS) alone or FG-PS complexes in the presence and absence of salt, sucrose, or glucose. This design was necessary to determine the effect of NaCl and sugar on the physicochemical properties of FG-PS complexes.

MATERIALS AND METHODS

Materials

Flaxseed polysaccharide (moisture content 10%) was kindly provided by Linseed Biological Technologies Co., Ltd (Sinkiang, China). Potato starch (moisture content 17%) was purchased from Tingfung Starch Development Co., Ltd (Tianjin, China). All other reagents were of analytical grade.

Preparation of the samples

To prepare a PS suspension, accurately weighed PS was dispersed in different level of NaCl, sucrose, or glucose solutions. To prepare FG-PS complexes, FG was first dispersed in distilled water with NaCl, sucrose or glucose under magnetic stirring for 30 min; then heated to 80 °C for 8 min; and cooled to room temperature. PS was then poured into the FG solutions. The complexes were stirred sufficiently to avoid the formation of lumps.

The concentration of FG (0.3%, w/w) selected in the present work was based on our previous study and the levels usually found in food formulations to get practical technological applications.

Determination of pasting properties

A sample of 2.1 g PS (7%, w/w) was dispersed in solutions containing 0–1.8 g of NaCl (0–6%, based on the total dispersion system, w/w), or 0–4.0 g sucrose (0–10% based on the total dispersion system, w/w), and combined with 0 g or 0.12 g FG (0.3% based on the total dispersion system, w/w). The pasting properties of the FG-PS complexes were examined with a Rapid Visco Analyser (RVA Starchmaster, Newport Ltd., Australia) and pasting profiles were recorded. FG-PS complexes of 30 g was used in this measurement. The FG-PS complexes were stirred at 960 r/min for 10 s before the shear input decreased and held constant at 160 r/min during the following heating and cooling cycles. The FG-PS complexes were heated from 50 °C to 95 °C at the rate of 12 °C/min and held at 95 °C for 2.5 min, then cooled to 50 °C at the same rate. Pasting temperature, peak viscosity, final viscosity and breakdown value were recorded. All determinations were done in triplicate.

Gel hardness analysis

A sample of 2.8 g PS (7%, w/w) was dispersed in solutions containing 0–2.4 g (0–6%, based on the total dispersion system, w/w) of NaCl, sucrose, or glucose (0.3% based on the total dispersion system, w/w) combined with 0 g or 0.16 g of FG. FG-PS complexes of 40 g was poured in a cylinder vessel (diameter of 4 cm, height of 6 cm). The complexes were pasted in a boiling water bath for 10 min, then cooled in an ice water bath for 5 min, and stored at 4 °C for 24 h to allow gel forming before analysis. Before measurement, the samples were returned to room temperature. Hardness analysis was performed with a Texture analyser (TA-XT. Plus, Stable Micro Systems Ltd., England) using a P/0.5 probe. Gel was compressed to 90% of original height by the test speed of 0.5 mm/s. The maximum of force that made the gel ruptured was recorded as gel hardness. The result was reported as the average of quintuplicate.

Determination of swelling power for the complexes

The determination of swelling power was performed according to the method of Hyun-Seok et al with slight modifications[10]. PS of 0.4 g (1%, w/w) was dispersed in solutions contained NaCl, sucrose or glucose of 0–0.8 g (0–2%, based on the total dispersion system, w/w) combined with FG of 0 g or 0.4 g (0.1%, based on the total dispersion system, w/w), respectively. FG-PS complexes of 40 g were put into centrifuge tubes (the weight of dried starch in centrifuge tube was recorded as W) with closed screw caps and heated at 95 °C for 30 min. Then, the centrifuge tubes were immersed in an ice bath to be cooled to room temperature immediately. The samples were centrifuged at 1600g for 20 min and then the supernatants were collected and dried to a constant weight at 105 °C. Then, dried supernatant (A) and wet precipitated paste (P) were weighed. All determinations were done in quintuplicate. The swelling power (SP) was calculated as

$$\mathrm{SP} = \frac{P}{W - A}.$$

Determination of freeze-thawing stability

Freeze-thawing stability was determined according to the method of Arunyanart et al[17]. Samples of 0.9 g (3%, w/w) PS were dispersed in solutions containing 0–1.5 g (0–5%, based on the total dispersion system, w/w) NaCl, sucrose, or glucose combined with 0–0.3 g (0.1% w/w, based on the total dispersion system) FG. The complexes of 30 g were pasted in a boiling water bath for 20 min with continuous stirring, and then cooled in an ice water bath for 5 min. A 30 ml sample was poured into centrifuge tubes with closed screw caps (the weight of the centrifuge tube was recorded as M). The samples were frozen at −18 °C for 24 h, and then thawed at 37 °C for 12 h. The above freeze-thaw procedure was repeated for five cycles. After each freeze-thaw cycle, the randomly selected samples were centrifuged at 3600g for 10 min

Table 1 Pasting properties of PS alone dispersed in aqueous solution of NaCl.

NaCl concentration (%)	Pasting temperature (°C)	Peak viscosity (RVU)	Final viscosity (RVU)	Breakdown value (RVU)
0	71.5 ± 0.3^{a}	523 ± 5^{a}	282 ± 5^{c}	293 ± 5^{a}
0.5	72.6 ± 0.0^{b}	317 ± 3^{c}	279 ± 2^{c}	107 ± 7^{b}
2	72.8 ± 0.2^{b}	345 ± 7^{c}	314 ± 1^{b}	106 ± 2^{b}
6	73.1 ± 0.0^{c}	392 ± 12^{b}	377 ± 5^{a}	102 ± 6^{b}

Values are given as means ± SD. In the column, mean values followed by different letters are significantly different ($p < 0.05$).

to remove supernatant. The precipitate weight was recorded as m. All determinations were done in quintuplicate. The syneresis (WS) was calculated as

$$\text{WS} = \left(1 - \frac{m}{M}\right) \times 100\%.$$

Statistical analysis

The statistical analysis of the results was conducted by ANOVA (SPSS 17.0, SPSS Inc., Chicago, IL) and Tukey's test. All significant differences were reported at a significance level of 0.5.

RESULTS AND DISCUSSION

Pasting properties in the presence of NaCl

Pasting parameters of PS the presence or absence of NaCl are presented in Table 1. There was a slight increase in pasting temperature as the NaCl concentration increased. Compared with the PS in the absence of NaCl, pasting temperature of PS with 6% NaCl increased by 1.6 °C. This result could be confirmed by the observation that the swelling power of PS decreased after adding NaCl (Fig. 1a). A plausible explanation may be that anions, chloride in this case, were prevented to penetrate into the PS by an electrical double layer of cations surrounding the PS [12]. Adding NaCl decreased the PS peak viscosity, however it slightly increased it with further NaCl additions (Table 1). Comparable results have been found for rice starch [4], and wheat starch granules [18]. For cassava starch, however, no significant change in peak viscosity was observed when the NaCl level increased from 0.05–2%, while it slightly increased at 2.5 and 5% NaCl [3]. Differing from cassava starch, PS molecule contains phosphate groups which would affect the viscosity by interacting with NaCl [19]. The increase in peak viscosity of PS could be interpreted as the interactions between NaCl and the phosphate group of PS. Final viscosity of PS alone was significantly increased, while breakdown value was decreased obviously by addition of NaCl, which could also be interpreted as the interactions between NaCl and PS.

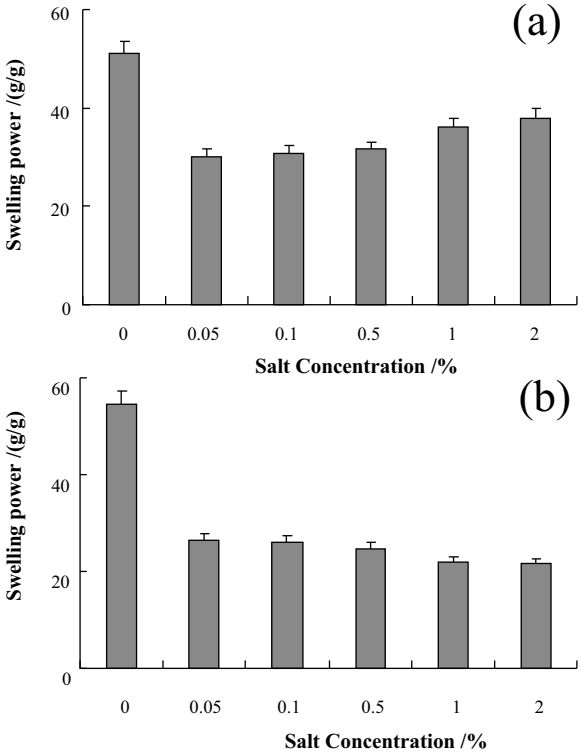

Fig. 1 Swelling power: (a) PS alone; (b) FG-PS complexes. Bars are mean ± SD.

Table 2 Pasting properties of FG-PS complexes dispersed in aqueous solution of NaCl.

NaCl concentration (%)	Pasting temperature (°C)	Peak viscosity (RVU)	Final viscosity (RVU)	Breakdown value (RVU)
0	76.5 ± 0.0^{b}	581 ± 1^{a}	285 ± 4^{e}	336 ± 4^{a}
0.5	77.4 ± 0.2^{a}	467 ± 3^{d}	310 ± 3^{d}	220 ± 2^{c}
1	76.6 ± 0.3^{b}	491 ± 6^{c}	324 ± 1^{c}	246 ± 9^{cd}
2	77.7 ± 0.7^{a}	494 ± 0^{c}	327 ± 10^{b}	255 ± 8^{c}
6	77.6 ± 0.5^{a}	523 ± 6^{b}	388 ± 0^{a}	292 ± 3^{b}

Values are given as means ± SD. In the column, mean values followed by different letters are significantly different ($p < 0.05$).

The pasting characteristics of FG-PS complexes in the presence and absence of NaCl determined by RVA is summarized in Table 2. In the absence of NaCl, pasting temperature, peak viscosity, and breakdown value of PS were significantly increased after addition of FG (Table 1 and Table 2). The result is consistent with that of other researchers [11,20,21]. An increase in the pasting temperature for PS with added FG might be the result of strong hydrophilic properties of FG, which prevented the swelling of PS during

heating[22]. An increase of peak viscosity of FG-PS complexes is attributed to the thickening properties of FG[4].

In the presence of NaCl, pasting temperature, peak viscosity, final viscosity, and breakdown value of FG-PS complexes increased obviously as NaCl level increased. This could be interpreted as the neutralization of negative charged carboxyl group from FG and phosphate group from PS with added cations. This neutralization results in intramolecular electrostatic repulsion promoting a network of FG and PS that inhibits the expansion and swelling of the potato starch granules. These results are in agreement with those reported by Brennan et al[23]. Addition of NaCl, however, did not produce an effect on peak viscosity of xanthan gum-rice starch[20]. Unlike PS, rice starch has no ionic group on its molecular structure. It is also surprising to find that a significantly negative effect on pasting properties was observed with NaCl compared to the control without NaCl. This observation was also reported for rice starch[4]. In general, the effect of NaCl on pasting temperature, peak viscosity, and breakdown value showed similar trends to that of PS alone. The result indicated that the starch-salt interaction might be the predominant effect on the pasting properties of FG-PS complexes. The viscosity properties of FG was affected strongly by addition of NaCl, more than previously reported[13], indicating that hydrocolloid-salt interactions could also govern the pasting properties of FG-PS complexes.

Swelling properties in the presence of NaCl

To investigate the effect of NaCl on the starch granules during heating, swelling power was determined. The results are shown in Fig. 1. For PS alone a slight increase in swelling power was observed with addition of NaCl. This might be explained as that both the electrostatic interaction between starch and ions from NaCl and the competition between the salts and starch for available water molecules[4] limit the swelling of the starch granules. NaCl shows a limited promoting effect on wheat starch at higher temperatures[18], however salt significantly decreases the swelling power of cassava starch or rice starch.

In the absence of NaCl, swelling power of PS was slightly increased with addition of FG. A similar influence of hydrocolloids on promoting the swelling power of starch granules was reported for tapioca starch[24].

For FG-PS complexes, swelling power was decreased slightly with addition of NaCl. Swelling powers was also found to decrease by addition of NaCl to xanthan gum-rice starch complexes and guar gum-rice starch complexes[4]. The result exhibited a similar trend to that of PS alone. This indicates that the swelling of starch granules is predominantly influenced by the added salt. In general, the above results were accordance with the changes in peak viscosity of FG-PS complexes determined by RVA. These results imply that both swelling power and peak viscosity were affected by the interaction between hydrocolloids and cations from added salt.

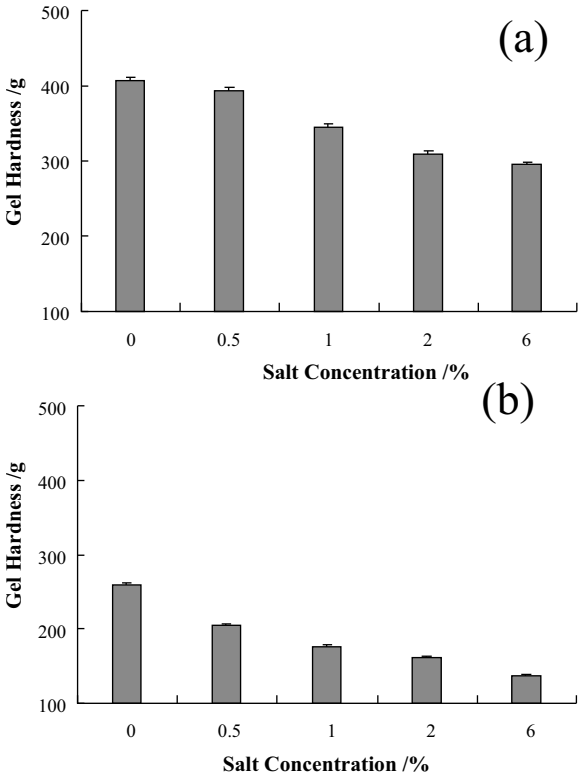

Fig. 2 Gel hardness: (a) PS alone; (b) FG-PS complexes. Bars are mean ± SD.

Gelling properties in the presence of salts

Gel hardness of PS alone and FG-PS complexes with or without NaCl are depicted in Fig. 2. Considering the effect of NaCl on PS alone, gel hardness decreased strongly with NaCl levels more than 0.5%. This might be attributed to the electrostatic repulsion between phosphate group of PS and salt. In the absence of NaCl, gel hardness of PS decreased significantly with addition of FG. This might be explained as that FG could form a weak-gel with low hardness[15], which reduces the hardness of FG-PS complexes. In the presence of NaCl, hardness of FG-PS complexes was reduced gradually with increasing NaCl level. Wang also found a similar trend that more than 0.1 M added

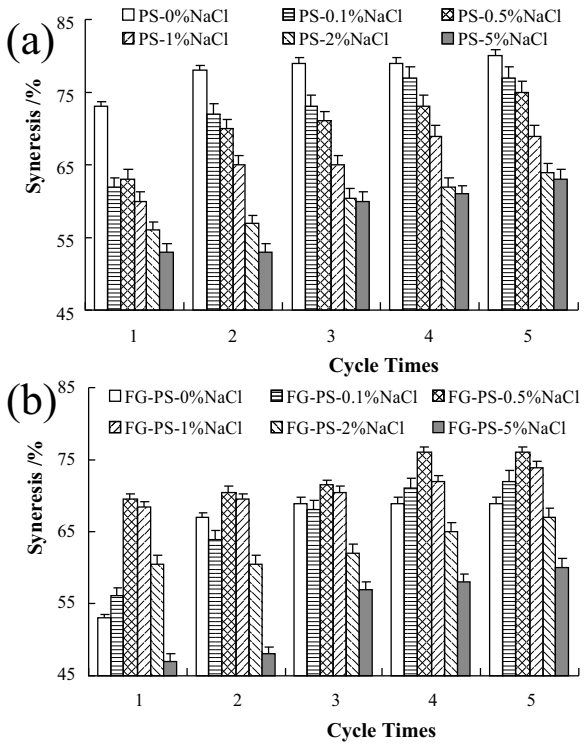

Fig. 3 Freeze-thaw stability: (a) PS alone; (b) FG-PS complexes. Bars are mean ± SD.

NaCl resulted in a decrease of hardness in guar gum-starch-soya bean protein complexes[25]. Intramolecular electrostatic repulsion among FG, PS, and salt could explain the results. In addition, both starch-salt interaction and hydrocolloid-salt interaction might also affect the gelling properties of FG-PS complexes in the presence of NaCl.

Freeze-thaw stability in the presence of NaCl

Freeze-thaw stability is important in food industry. During freeze-thaw treatment, disruption of the gel matrix of starch could occur. The matrix would be more susceptible to the freeze-thaw treatment if there were excess of water[26]. This phenomenon may affect the functional properties, such as viscosity or gelling properties.

Syneresis of PS alone and FG-PS complexes with or without NaCl is shown in Fig. 3. For PS alone and fixed freeze-thaw cycle numbers, syneresis decreased with increased NaCl levels. This could be interpreted as that water activity might be reduced and more bound water might be formed with added NaCl, reducing the available water to form ice crystals on freezing and lowering syneresis on thawing. For fixed NaCl level, syneresis of the gelatinized PS pastes increased with increasing numbers of freeze-thaw cycle. This result is in good agreement with that observed by Pongsawatmanit et al[27]. It implies that the starch gel network is easily disrupted by ice crystal formation and syneresis increases on thawing[28].

In the absence of NaCl, syneresis of PS decreased significantly with added FG. The result is in agreement with that observed by Pongsawatmanit et al[27]. It indicates that FG might reduce the damage to the network and could minimize freeze-thaw damage by reducing the available water to form ice crystals.

For FG-PS complexes and fixed freeze-thaw cycle number, syneresis increased significantly if NaCl levels were less than 0.5%, while decreased if NaCl levels were more than 1%. For all freeze-thaw cycle number, syneresis of complexes with 5% NaCl was the lowest. The results exhibited a similar trend to that of PS alone. This indicated that starch-salt interaction might be the predominant effect on the syneresis of FG-PS complexes.

Table 3 Pasting properties of PS alone dispersed in aqueous solution of sugar with different concentration.

Type of sugar	Addition level (%)	Pasting temperature (°C)	Peak viscosity (RVU)	Final viscosity (RVU)	Breakdown value (RVU)
sucrose	0	71.5 ± 0.3^{b}	523 ± 5^{b}	282 ± 5^{b}	293 ± 5^{c}
	0.5	71.7 ± 0.2^{b}	592 ± 19^{b}	261 ± 15^{b}	358 ± 29^{b}
	6	73.0 ± 0.2^{a}	669 ± 21^{a}	327 ± 15^{a}	390 ± 27^{a}
glucose	0	71.5 ± 0.3^{a}	523 ± 5^{c}	282 ± 5^{b}	293 ± 5^{c}
	0.5	71.4 ± 0.6^{a}	602 ± 7^{b}	290 ± 8^{b}	359 ± 0^{b}
	6	72.5 ± 0.4^{a}	655 ± 2^{a}	313 ± 6^{a}	381 ± 2^{a}

Values are given as means ± SD. In the column, mean values followed by different letters are significantly different ($p < 0.05$).

Pasting properties in the presence of sugar

The effects of sucrose and glucose on the pasting properties of PS alone is summarized in Table 3.

For PS alone, pasting temperature increased gradually with increasing sugar levels (both sucrose and glucose). The observation is in agreement with that reported by Eliasson et al[6]. This might be attributed to the hydration of the sugar, which leads to less free water for the hydration of starch and inhibition of starch swelling.

Addition of sugar enhanced peak viscosity and final viscosity of PS alone. A similar trend in tapioca starch, or corn starch with added sugar has also been found[29–31]. Changes in viscosity might be interpreted as a crosslinking between the sugar molecules and the starch chain[30]. In cassava starch, however, an opposite trend has been found with a decrease in peak viscosity and final viscosity with added sugar[32].

Table 4 Pasting properties of FG-PS complexes dispersed in aqueous solution of sugar with different concentration.

Type of sugar	Addition level (%)	Pasting temperature (°C)	Peak viscosity (RVU)	Final viscosity (RVU)	Breakdown value (RVU)
sucrose	0	76.5 ± 0.0^{c}	581 ± 1^{c}	285 ± 4^{c}	336 ± 4^{b}
	0.5	77.2 ± 0.6^{b}	582 ± 7^{c}	309 ± 1^{b}	321 ± 4^{c}
	2	78.0 ± 0.0^{b}	628 ± 5^{b}	301 ± 3^{b}	344 ± 2^{b}
	6	80.4 ± 0.4^{a}	623 ± 5^{b}	327 ± 6^{a}	341 ± 6^{b}
	10	80.5 ± 0.5^{a}	671 ± 6^{a}	322 ± 7^{a}	496 ± 1^{a}
glucose	0	76.5 ± 0.0^{d}	581 ± 1^{d}	285 ± 4^{e}	336 ± 4^{c}
	0.5	77.6 ± 0.6^{c}	562 ± 7^{e}	292 ± 1^{d}	318 ± 4^{d}
	2	77.9 ± 0.5^{c}	595 ± 6^{c}	304 ± 7^{c}	342 ± 1^{c}
	6	78.6 ± 0.1^{b}	647 ± 2^{b}	323 ± 3^{b}	385 ± 3^{b}
	10	79.6 ± 0.0^{a}	676 ± 2^{a}	346 ± 2^{a}	523 ± 2^{a}

Values are given as means ± SD. In the column, mean values followed by different letters are significantly different ($p < 0.05$).

Breakdown value was increased with increasing added sugar levels, as it has been reported previously[31,33]. This observation implies that starch paste formed through hydrogen bonding would be more sensitive to disruption by isothermal shear with added sugar. A different trend of a decrease breakdown value with added sugar was found in cassava starch[32].

The above results imply that the competition between sucrose and starch for water requires more energy to make the starch gelatinization in the presence of sugar.

The pasting characteristics of FG-PS complexes in the presence and absence of sugar determined by RVA are summarized in Table 4. An increase in pasting temperature, peak viscosity, final viscosity, and breakdown value of FG-PS complexes was observed with increasing added sugar level. The maximum pasting temperature was observed at sucrose levels of 10%, which increased by 4 °C compared with that without sugar. This phenomenon was also observed with tapioca starch and xanthan gum mixtures[31] while for gum-corn starch complexes an inverse trend of a decrease in pasting temperature with added sugar was observed[30]. This might be attributed to a reduction of available water by added sugar, which would cause retardation in FG-PS complexes pasting[34]. Sugars with anti-plasticizing effect might inhibit the hydration of starch granules or hydrocolloids. Thus in the complexes with added sugar, the competition among sucrose/glucose, starch, and FG to be hydrated by water might result in an increase in pasting temperature. The maximum peak viscosity and final viscosity was observed at the glucose level of 10%. A similar trend was also found by Sudhakar et al[30], Chantaro et al[31]. This could be explained as the occurrence of polymer-polymer interactions and polymer-solvent interactions. It suggests that a synergistic effect of sugar and FG-PS complexes might play an important role. The highest breakdown value was observed at glucose levels of 10%, which was increased by 187 RVU compared to that without sugar. Chantaro et al also found a similar trend[31].

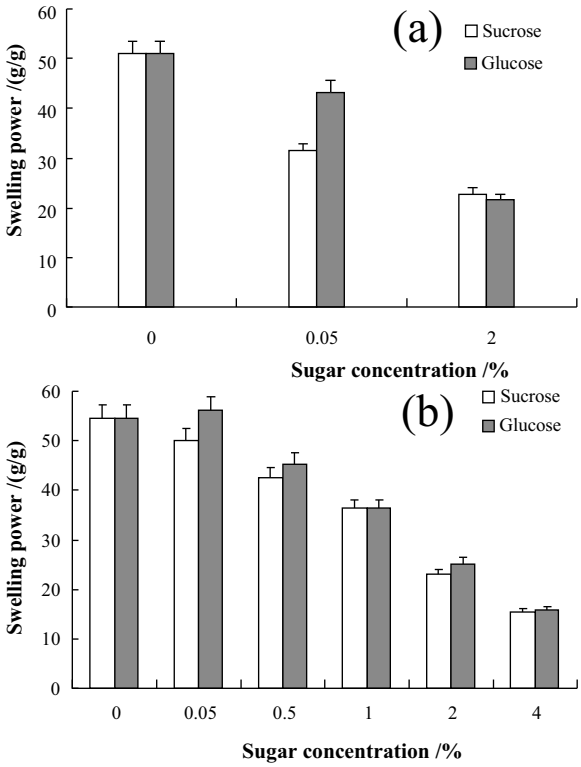

Fig. 4 Swelling power of PS alone (a) and FG-PS complexes (b) in the presence and absence of sugar. Bars are mean ± SD.

The results might be interpreted as that the formed aggregates among polysaccharide and sugar and polymer entanglement were more sensitive to disruption under isothermal shear with added sugar. The above results implied that in the presence of sugar, as the solvent becomes bound to the sugar, polymer-polymer interaction might predominate over polymer-solvent interactions.

Swelling properties in the presence of sugar

To investigate the effect of sugar on the starch granules during heating, swelling power was determined (Fig. 4). For both PS and FG-PS complexes, a significant decrease in swelling power was observed with addition of sucrose or glucose. This might be explained as that water activity was reduced and more bonding water was formed in the presence of sugar. This indicates that the swelling of starch granules

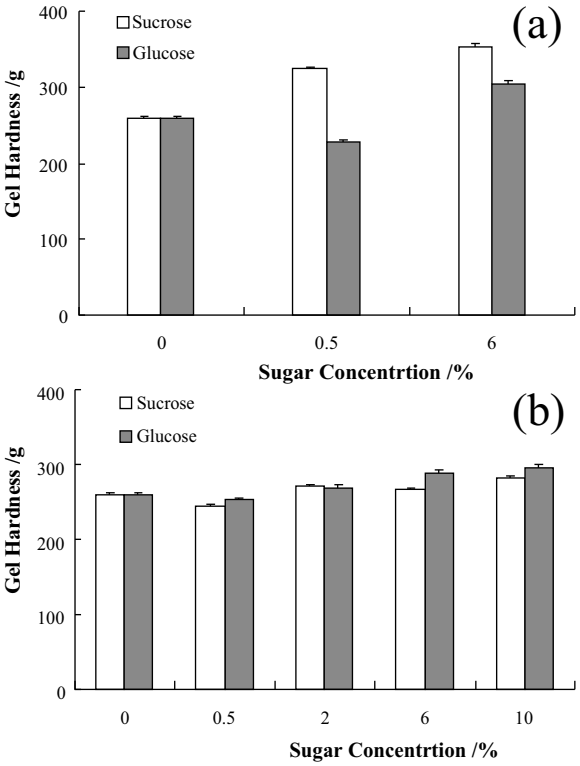

Fig. 5 Gel hardness of PS alone (a) and FG-PS complexes (b) in the presence and absence of sugar. Bars are mean ± SD.

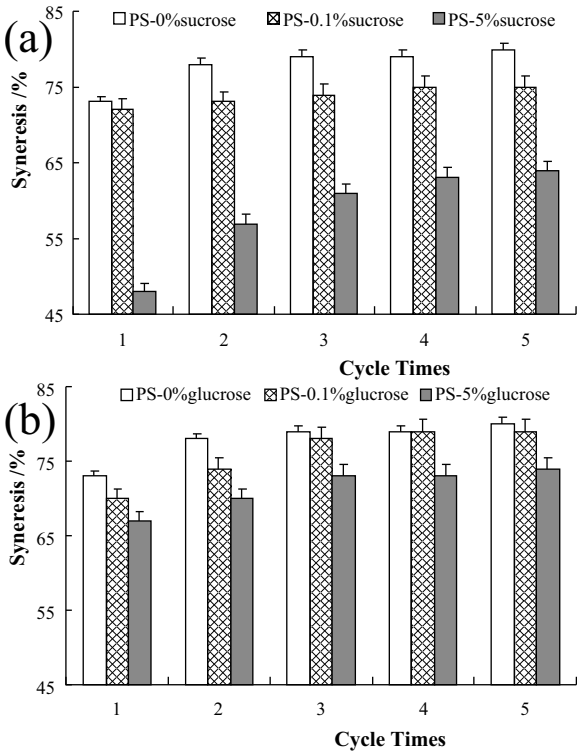

Fig. 6 Syneresis of PS alone in the presence and absence of sugar: (a) sucrose, (b) glucose. Bars are mean ± SD.

was predominantly influenced by the added sugar. In general, the above results were disagreement with the changes in peak viscosity of FG-PS complexes determined by RVA. These results imply that sugar could affect the swelling power value, while peak viscosity of the complexes is greatly affected by polymer-polymer interactions and polymer-solvent interactions as discussed above.

Gel properties in the presence of sugar

Gel hardness of PS alone and FG-PS complexes with or without sugar are shown in Fig. 5. For both PS alone and FG-PS complexes, a slight increase in gel hardness was observed in the presence of sucrose and glucose. Addition of sugar could improve the network or structure of starch gel, which would result in high resistance to the disruption of starch gel by strong press. In sago starch, the presence of sugar improved the gel texture making the gel smoother[34].

Freeze-thaw stability in the presence of sugar

Syneresis of PS alone and FG-PS complexes with or without sugar is shown in Fig. 6 and Fig. 7. For PS alone, there was a significant decrease in syneresis with added sugar was observed, while that of FG-PS complexes occurred at higher sugar levels ($> 0.5\%$) at fixed freeze-thaw cycle number. With lower sugar levels (particularly $> 0.5\%$), slight changes in syneresis of FG-PS complexes were found. In other studies, it was found that sucrose decreases the syneresis of starch, while glucose increases it[17,34]. As discussed before, addition of sugars reduced the swelling power of starch granules during pasting, which resulted in a decrease in aggregation. Thus high level of sugar could promote the freeze-thaw stability of PS and FG-PS complexes, indicating that starch-sugar interaction might be the predominant effect on the syneresis of FG-PS complexes.

CONCLUSIONS

In the presence of NaCl, the physicochemical properties of FG-PS complexes might be governed by both starch-salt interaction and hydrocolloid-salt interaction. In the presence of sugar, the physicochemical properties of FG-PS complexes were mainly affected by polymer-polymer interactions and polymer-solvent interactions.

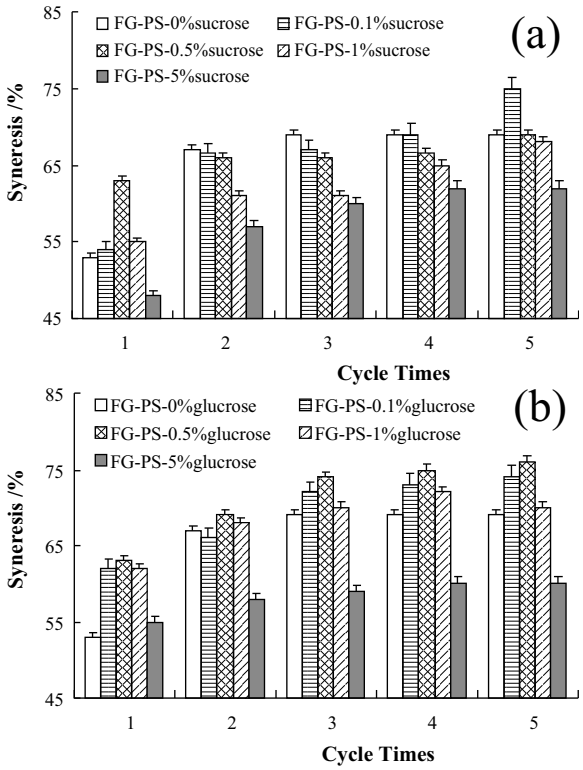

Fig. 7 Syneresis of FG-PS complexes in the presence and absence of sugar: (a) sucrose, (b) glucose. Bars are mean $\pm$ SD.

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