

RESEARCH ARTICLE

Effect of salt addition on gelatinization and rheological properties of sweet potato starch–xanthan gum mixture

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The effect of NaCl at different concentrations (1.0–5.0%) on the gelatinization and rheological properties of sweet potato starch (SPS)–xanthan gum (XG) mixtures was examined. Steady shear rheological properties of SPS–XG–NaCl mixtures were determined from the rheological parameters for the power law and Casson flow models. The consistency index (K), apparent viscosity ($\eta_{a,100}$), and Casson yield stress (σ_{oc}) values of SPS–XG–NaCl mixtures were much lower than those of the control (0% NaCl) and also decreased with an increase in the NaCl concentration. The storage modulus (G') values of SPS–XG–NaCl mixtures were much higher than the loss modulus (G''), indicating that the addition of NaCl influences the synergistic effect in the elastic properties of XG in the SPS–XG–NaCl mixture systems. The addition of NaCl resulted in a significant increase in the peak, breakdown, final, and setback viscosities, and pasting temperature of SPS–XG mixture. In general, differential scanning calorimeter (DSC) studies conveyed that the presence of NaCl resulted in an increase in the gelatinization temperatures (T_o , T_p , and T_c) and a decrease in gelatinization enthalpy (ΔH). In general, these results suggest that the addition of the NaCl to SPS–XG mixtures modified the pasting, rheological, and thermal properties, depending on the NaCl concentration.

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1 Introduction

Sweet potato (*Ipomea batatas* L. Lam) and sweet potato-based materials (e.g., flour and starch) are widely used in Africa and Asia as ingredients to prepare a variety of products. Sweet potato has been grown for domestic consumption and is mainly consumed in a baked, boiled, or steamed form [1], whereas sweet potato starch (SPS) is mainly used as an ingredient in limited sweet potato products such as noodles, snacks, and bread [2]. Therefore, it is necessary to expand the range of applications of native SPS in the food industry by modifying and controlling its physical properties.

Generally, it is known that native starches are limited in their food applications due to their heat, shear, and acid instability associated with the processing conditions, even though they can provide thickening, bulk, and body as well as improve the texture with the advantages of lower cost and easier handling and processing [3]. To improve the properties of starch-based products, starch–gum mixtures have been widely used in the food industry because they can modify and control the physical properties [4, 5]. Because gums affect physical properties of starches, knowledge regarding the gelatinization and rheological properties of starch–gum mixtures is important to understand the molecular interactions that occur between gum and starch [5, 6]. In general, because starch and gum usually co-exist with other ingredients (such as sugars or salts) in many food systems, their interaction in the presence of other ingredients has a strong impact on the physical properties of foods containing them.

Salts have been shown to have a significant effect on the gelatinization and rheological properties of various native starches [3–9]; moreover, it has been found that salts play an

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Abbreviations: DSC, differential scanning calorimeter; RVA, rapid-visco analysis; SPS, sweet potato starch; XG, xanthan gum

important role in gelatinization and retrogradation of starch pastes, depending on the type of salt as well as on the salt concentration. Therefore, understanding the gelatinization and rheological properties of starch–gum mixture systems in the presence of salts is also necessary for process and product development in terms of process design, quality, and extension of shelf life [10]. Several researchers have studied the rheological and/or gelatinization properties of various starch–gum mixtures in the presence of salts, including rice starch–xanthan gum (XG) [10], corn starch–carrageenan gum [11], corn starch–guar gum [12], corn starch–XG mixtures [13], and pea starch–XG [14]. They reported that the rheological and gelatinization behaviors of starch–gum–salt mixtures are influenced by the addition of salts, which also depend on the type and concentration of salt. However, there is little information on the gelatinization and rheological properties of SPS–gum mixture in the presence of NaCl. In the present study, XG was selected among the gums used in the food industry because it has been widely and more extensively used to enhance to the texture in bakery products, sauces, dry mix formulations, confectionary, and dairy products due to its unique and useful properties.

The main objective of this study was to investigate the rheological, pasting, and thermal properties of SPS mixed with XG in the presence of NaCl. Understanding the gelatinization and rheological properties of SPS–XG–NaCl mixtures with different NaCl concentrations will lead to improving the formulations of SPS-based products for further application in product development.

2 Materials and methods

2.1 Materials and preparation of SPS–XG–NaCl mixture dispersions

Commercial SPS (27.5% amylose) was supplied from Yanggu Agriculture and Fishery Co. (Yeoju, Korea). XG and sodium chloride (NaCl) were purchased from Sigma Co. (St. Louis, MO, USA). The SPS contained 17.0% moisture, 0.6% protein, 0.2% fat, 0.2% ash, and 82.0% carbohydrate (by difference), which were determined according to AOAC [15]. SPS–XG mixture dispersions (5% w/w) at a 9:1 mixing ratio (SPS/XG) containing 1.0, 2.5, and 5.0% (weight basis) NaCl levels were prepared by stirring for 30 min at room temperature. A mixture dispersion with no salt (the control) was also prepared.

For the rheological measurements, all SPS–XG–NaCl mixture dispersions were heated at 95°C in a water bath for 30 min with mild agitation in order to avoid entry of air into the mixture. Finally, the hot pastes were immediately transferred to the rheometer plate in order to measure the steady and dynamic shear rheological measurements.

2.2 Swelling power

The swelling power was determined using the SPS–XG mixture dispersion at 0.5% w/w following the modified method by Yoo and Yoo [16] and Chaisawang and Supphantharika [17]. SPS–XG–NaCl mixture dispersions containing 1.0, 2.5, and 5.0% (weight basis) NaCl levels were prepared, as previously described. The SPS–XG–NaCl mixture dispersion was moderately stirred for 1 h at room temperature, and then heated at 95°C in a water bath for 30 min. The hot paste was cooled to room temperature by immersing in an iced water bath for 5 min and centrifuged at 2300g for 30 min. The supernatant was carefully removed and the starch swollen sediment was weighed. The swelling power was calculated based on the assumption that the total amount of gum remained in the supernatant, as noted by Chaisawang and Supphantharika [17]. The swelling power was determined as the ratio of the weight of the sediment to the weight of dry starch. All measurements were performed in triplicate.

2.3 Rheological measurements

The rheological properties of the SPS–XG–NaCl mixtures were determined under steady and dynamic shear, as described in a previous study [2]. The steady and dynamic shear rheological properties were obtained with a rheometer (Carri-med CLS100, TA Instruments, New Castle, DE, USA) using a plate system (4 cm diameter) at a gap of 500 µm. Each sample was transferred to the rheometer plate at 25°C. The sample was sheared continuously from 0.4 to 1000 s^{−1}. The data were fitted to the well-known power law (Eq. 1) and Casson (Eq. 2) models in order to describe the steady shear rheological properties of the samples, which are as follows:

$$\sigma = K\dot{\gamma}^n \quad (1)$$

$$\sigma^{0.5} = K_{oc} + K_c\dot{\gamma}^{0.5} \quad (2)$$

where σ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{−1}), K is the consistency index (Pa s ^{n}), n is the flow behavior index (dimensionless), and $(K_c)^2$ is the Casson plastic viscosity (η_c). Casson yield stress (σ_{oc}) was determined as the square of the intercept (K_{oc}), which was obtained from a linear regression of the square roots of shear rate–shear stress data.

Dynamic shear data were obtained from the frequency sweeps over the range of 0.63–62.8 rad/s at the 2% strain, which was in the linear viscoelastic region. Frequency sweep tests were also conducted at 25°C. The TA rheometer Data Analysis software (ver. VI. 1.76) was used to obtain the experimental data as well as to calculate the storage modulus (G'), loss modulus (G''), and loss tangent ($\tan \delta = G''/G'$). All samples were allowed to rest for 5 min at their initial temperatures prior to the steady and dynamic shear

rheological measurements. Further, all rheological measurements were performed in triplicate.

2.4 Pasting properties

The pasting properties of SPS–XG–NaCl mixtures were determined using a rapid visco-analyzer (Model RVA 4, Newport Scientific Pty. Ltd., Warriewood, Australia). SPS–XG mixture dispersions (5% w/w) containing 1.0, 2.5, and 5.0% (weight basis) salt levels were prepared, as previously described. The dispersions (28 g) were then poured into aluminum canisters and stirred manually using a plastic paddle for 20–30 s prior to insertion into the rapid-visco analysis (RVA) machine. The heating and cooling cycles were programmed in the following manner. The dispersion was held at 50°C for 1 min, heated from 50 to 95°C at a rate of 7.5°C/min, and then held for 5 min at 95°C. It was subsequently cooled back to 50°C at a rate of 7.5°C/min, and then held at 50°C for 5 min, while maintaining a rotation speed of 160 rpm. Then, the peak viscosity (maximum viscosity during pasting), breakdown viscosity (the difference between the peak viscosity and the minimum viscosity during pasting), setback viscosity (the difference between the maximum viscosity during cooling and the minimum viscosity during pasting), final viscosity (the viscosity at the end of the RVA run), and pasting temperature (temperature indicating an initial increase in viscosity) of the SPS–XG–NaCl mixture dispersions were determined.

2.5 Thermal property measurements

Thermal analyses of the SPS–XG–NaCl mixtures were conducted using a differential scanning calorimeter (DSC; Q200, TA Instruments) equipped with a refrigerated cooling system in order to investigate the gelatinization process. The SPS–XG mixture sample was directly weighed onto the aluminum DSC pan and distilled water with NaCl, which was added with a micropipette in order to create suspensions with a 20% SPS–XG mixture concentration. The total content of all SPS–XG mixture samples was selected to be 20% due to the sensitivity of the instrument. The sample pan was hermetically sealed and allowed to stand for 1 h at room temperature prior to heating in the DSC. Then, the samples were heated at 10°C/min from 30 to 130°C. The instrument was calibrated using an indium and an empty pan as reference. From the curve obtained, the onset temperature (T_o), peak temperature (T_p), conclusion temperature (T_c), and enthalpy (ΔH) of the starch gelatinization were calculated using the Universal Analysis software provided by the manufacturer. The results reported were the average of the three measurements.

2.6 Statistical analysis

The results are reported as the mean value with a SD of triplicate analyses for each sample. The analysis of variance

(ANOVA) and Duncan's test were used to establish the significance of differences among the mean values at the 0.05 significance level. Statistical analyses were performed using the Statistical Analysis System program (version 9.2) (SAS Institute, Cary, NC, USA).

3 Results and discussion

3.1 Swelling power

The swelling power values of SPS–XG–NaCl mixtures with different NaCl concentrations (0, 1.0, 2.5, and 5.0%) were in the range of 15.0–38.9 (g/g), as shown in Table 1. The swelling power values (15.0–30.2 g/g) of SPS–XG–NaCl mixtures were significantly lower than that (38.9 g/g) of the control with no added NaCl; further, it decreased with an increase in the NaCl concentration, indicating that the addition of NaCl results in a significant decrease in the swelling power of SPS–XG mixtures. This is in good agreement with the results of Samutsri and Supphantharika [4], who found that the addition of NaCl significantly decreased the swelling power of rice starch–XG mixtures. They also reported that the swelling inhibitory effect of salts on starch pastes could be explained by two mechanisms, the electrostatic interaction between starch and ions from salts [18, 19], and the competition between salts and starch for the available water. Recently, the microscopic observations of starch granules in the rice starch–XG–NaCl mixture systems also clearly revealed that the presence of salts resulted in a smaller granule size, indicating that salts inhibited the swelling of the starch granules [4]. This reduction in the swelling of SPS granules with an NaCl concentration can also be explained by a shift in the DSC gelatinization temperatures to higher temperatures (Table 5). In the present study, the NaCl concentration also indicated significant correlations with the swelling power ($R^2 = 0.96$) in the SPS–XG–NaCl mixtures, indicating that NaCl addition influenced the intensity of change in the swelling power of SPS–XG mixtures.

3.2 Flow behavior

The shear stress (σ) versus shear rate ($\dot{\gamma}$) data for RS–XG–NaCl mixtures of different NaCl concentrations at 25°C are

Table 1. Effect of NaCl concentration on swelling power of SPS–XG mixtures

NaCl (%)	Swelling power (g/g)
0	38.9 ± 0.8 ^a
1.0	30.2 ± 1.4 ^b
2.5	23.2 ± 1.0 ^c
5.0	15.0 ± 0.2 ^d

Mean values in the same column with different superscript letters are significantly different ($p < 0.05$).

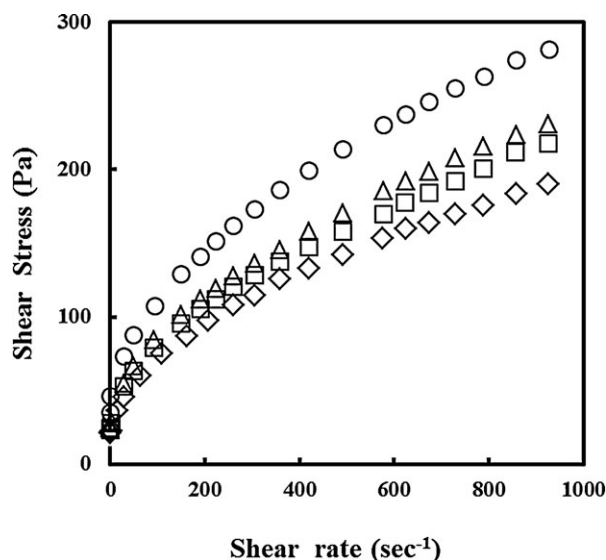


Figure 1. Shear stress–shear rate plots of SPS–XG mixtures in the presence of NaCl with different concentrations: (○) 0%, (□) 1%, (△) 2.5%, and (◇) 5%.

shown in Fig. 1. The experimental results of σ and $\dot{\gamma}$ data were well fitted to the simple power law model (Eq. 1) and Casson model (Eq. 2) with high determination coefficients ($R^2 = 0.98$ – 0.99) (Table 2). The n values (0.33–0.43) of the SPS–XG–NaCl mixtures were slightly higher than those (0.31) of the control (0% NaCl). Furthermore, no significant differences were observed between the n values for the SPS–XG–NaCl mixtures, indicating that the addition of NaCl reduced the shear-thinning of SPS–XG–NaCl mixture samples compared to the control, and that the NaCl concentration in the SPS–XG–NaCl mixture systems had no effect on the n values. Similar results were reported in studies of corn starch–XG–NaCl mixtures [13].

The magnitudes of the consistency index (K), apparent viscosity ($\eta_{a,100}$), and yield stress (σ_{oc}) of the SPS–XG–NaCl mixtures, which were obtained from the power law and Casson models, were much lower than that of the control; moreover, they also decreased with an increase in the NaCl concentration (Table 2 and Fig. 1), suggesting that the addition of NaCl resulted in less resistance to flow. This tendency was in good agreement with that found in

corn starch–XG–NaCl mixtures [13]. However, these rheological parameter data are clearly in contradiction with those previously reported for SPS–XG mixtures in the absence of NaCl [2]. Therefore, adding NaCl to the SPS–XG mixture resulted in a decrease of viscosity, even though the synergistic effect of XG on SPS paste viscosity in the SPS–XG mixture systems has been described by Choi and Yoo [2]. This indicates that the synergistic effect of XG on starch increasing viscosity is less effective, probably due to the conformation change in the XG in the presence of NaCl, as described by Sudhakar et al. [13]. Wyatt and Liberatore [20] also reported that the addition of NaCl screens the electrostatic repulsions between charges along the backbone of the xanthan chain, resulting in a smaller, more compact conformation of xanthan chains, which lead to a reduction in viscosity. From these observations, it can be concluded that SPS pastes mixed with XG in the presence of NaCl could have lower rheological parameter values compared to the SPS–XG mixture (0% NaCl) and moreover, their steady shear properties were apparently influenced by the addition of NaCl as well as NaCl concentration.

3.3 Dynamic shear properties

Plots of frequency (ω) versus storage modulus (G') and loss modulus (G'') for the SPS–XG mixtures with NaCl (0–5.0%) at 25°C (Fig. 2) revealed that the magnitudes of G' and G'' increased with an increase in ω and that G' was much higher than G'' at all values of ω with frequency dependency. Such behavior is in good agreement with that found in rice starch–XG pastes in the presence of NaCl [4, 9]. Table 3 shows G' and G'' at 6.28 rad/s of the SPS–XG–NaCl mixtures at different NaCl concentrations. The SPS–XG–NaCl mixtures showed higher dynamic moduli values than the control, and they increased with an increase in the NaCl concentration. However, the addition of NaCl slightly changed the G'' values when compared to G' . This indicates that NaCl stabilized the SPS–XG mixtures by contributing to more elastic behavior. In general, the dynamic moduli (G' and G'') of XG in the presence of NaCl could increase due to the salt-induced self-aggregation of XG molecules, as noted by Meyer et al. [21]. Wyatt and Liberatore [20] also reported that the addition of salts enhanced the intermolecular interaction of XG molecules due to the charge screening effect, which causes a reduction in the hydrodynamic size of the molecule, thereby promoting a network formation. This network formation can cause an increase in the elastic properties of SPS–XG–NaCl mixtures, evidenced by the higher G' compared to G'' (Table 3). It is also known that the synergistic effect of XG on the dynamic properties of SPS pastes can be explained as an increase in the elastic properties of XG, due to the increase in its local concentration in the continuous phase [2]. Therefore, it is obvious that the addition of NaCl greatly influences the synergistic effect in the elastic

Table 2. Effect of NaCl concentration on steady shear rheological properties of SPS–XG mixtures

NaCl (%)	$\eta_{a,100}$ (Pa s)	K (Pa s ^{<i>n</i>})	n (–)	σ_{oc} (Pa/s)
0	1.99 ± 0.00 ^a	29.1 ± 0.36 ^a	0.31 ± 0.00 ^b	41.2 ± 0.94 ^a
1.0	0.90 ± 0.01 ^b	18.6 ± 0.12 ^b	0.34 ± 0.00 ^a	27.3 ± 0.18 ^b
2.5	0.80 ± 0.01 ^c	17.3 ± 0.09 ^c	0.33 ± 0.01 ^a	24.8 ± 0.04 ^c
5.0	0.74 ± 0.02 ^d	15.1 ± 0.34 ^d	0.34 ± 0.00 ^a	21.2 ± 0.45 ^d

Mean values in the same column with different superscript letters are significantly different ($p < 0.05$).

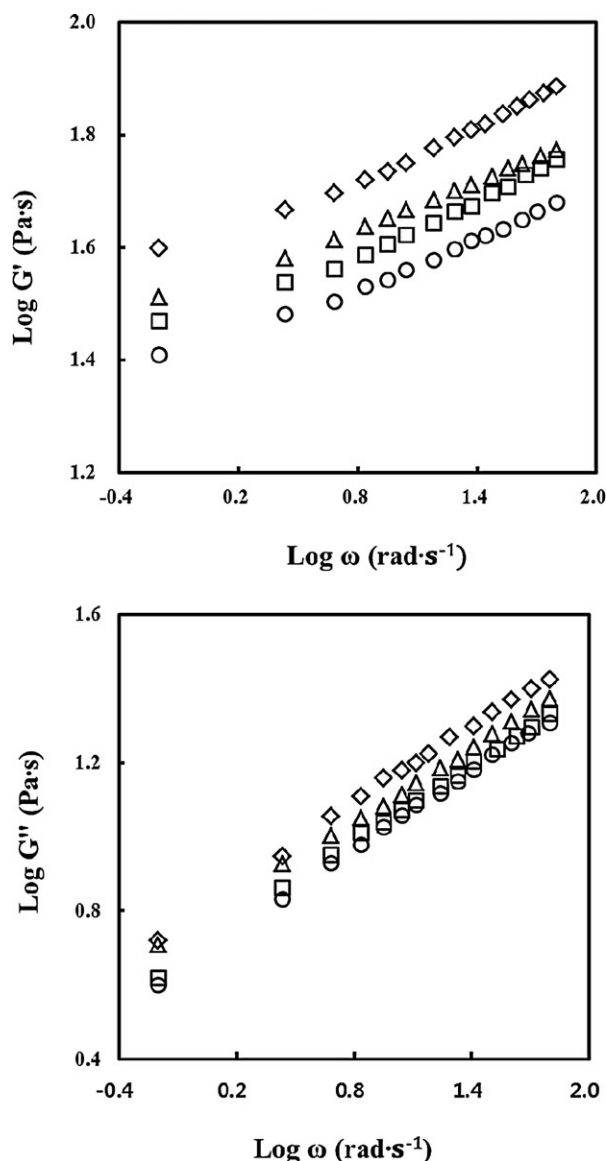


Figure 2. Plots of $\log G'$ and G'' versus ω of SPS-XG-NaCl mixtures with different NaCl concentrations: (○) 0%, (□) 1%, (△) 2.5%, and (◇) 5%.

Table 3. Storage modulus (G') and loss modulus (G''), and $\tan \delta$ at 6.28 rad/s of SPS-XG-NaCl mixtures with different NaCl concentrations

NaCl (%)	G' (Pa)	G'' (Pa)	$\tan \delta$
0	34.4 ± 0.22^d	9.68 ± 0.46^c	0.28 ± 0.01^a
1.0	37.0 ± 0.37^c	10.1 ± 0.28^c	0.27 ± 0.00^a
2.5	43.6 ± 0.32^b	11.0 ± 0.26^b	0.25 ± 0.01^b
5.0	52.9 ± 0.68^a	12.7 ± 0.43^a	0.24 ± 0.01^b

Mean values in the same column with different superscript letters are significantly different ($p < 0.05$).

properties of XG in the SPS-XG mixture systems, resulting in a significant increase in the G' values of the SPS-XG-NaCl mixtures. Based on the above observations, it was found that such higher dynamic moduli of SPS-XG mixtures in the presence of NaCl may be attributed to both the thickening properties of XG and the synergistic effect of the NaCl.

The $\tan \delta$ values of all samples were within the range of 0.24–0.28 (Table 3), which are much smaller than the unity, indicating that all the samples are predominantly elastic. No significant change in $\tan \delta$ was observed when the concentration of NaCl was increased from 0 to 1.0%; however, a slight decrease was noticed at a higher NaCl concentration (2.5 and 5.0%), suggesting that the elastic properties of SPS-XG-NaCl mixtures can be more pronounced at higher NaCl concentrations. From these observations, it could be concluded that a decrease in $\tan \delta$ values of the SPS-XG mixtures in the presence of NaCl appeared to be due to the salt-induced self-aggregation of XG molecules, which had a more pronounced effect on the elastic properties of SPS pastes.

3.4 Pasting properties

All pasting parameters of the SPS-XG-NaCl mixtures with different NaCl concentrations are summarized in Table 4. Considering the effect of the NaCl concentration on SPS-XG mixtures, the addition of NaCl resulted in a significant increase in the peak, breakdown, final, and setback viscosities, and their viscosity values also significantly increased with increasing NaCl concentration ($p < 0.05$). The increased peak and final viscosity values could be due to the interaction between NaCl and starch, resulting in the reduced mobility of starch granules, as described by Bircan and Barringer [22]. Our results are also in good agreement with those reported by Samutsri and Suphantharika [4] and Viturawong et al. [10]. The pasting temperature is increased by the addition of NaCl and increased with increasing NaCl concentration. An increase in the pasting temperature is consistent with the inhibition of the starch granule swelling in the presence of NaCl [14], as previously discussed. Such increase in the pasting temperature with NaCl concentration can also be explained by a shift in the DSC gelatinization temperatures to higher temperatures. Similar observations were reported for the rice starch-XG [4, 10].

3.5 Thermal properties

The onset (T_o), peak (T_p), and conclusion (T_c) gelatinization temperatures along with enthalpy (ΔH) determined by the DSC for PSP-XG-NaCl mixtures at different NaCl concentrations are shown in Table 5. The magnitudes of T_o , T_p , and T_c of PSP-XG-NaCl mixtures were found to be significantly increased by the addition of the NaCl; moreover, they also increased with an increase in NaCl concentration. The ΔH

Table 4. Pasting properties of SPS–XG–NaCl mixtures with different NaCl concentrations

NaCl (%)	Peak viscosity (mPa s)	Breakdown (mPa s)	Final viscosity (mPa s)	Setback (mPa s)	Pasting temperature (°C)
0	967 ± 2.52 ^d	33.7 ± 1.15 ^d	1030 ± 4.51 ^d	96.7 ± 2.31 ^d	76.4 ± 0.11 ^d
1.0	1780 ± 4.62 ^c	821 ± 3.46 ^c	1542 ± 2.31 ^c	584 ± 1.15 ^c	77.9 ± 0.04 ^c
2.5	1830 ± 2.89 ^b	865 ± 4.62 ^b	1562 ± 2.89 ^b	597 ± 4.62 ^b	81.4 ± 0.00 ^b
5.0	2076 ± 9.19 ^a	1009 ± 0.71 ^a	1718 ± 11.3 ^a	651 ± 1.41 ^a	83.3 ± 0.14 ^a

Mean values in the same column with different superscript letters are significantly different ($p < 0.05$).

showed a behavior different to the gelatinization temperatures. The ΔH values (4.31–12.4 J/g) of SPS–XG–NaCl mixtures were significantly lower than those ($\Delta H = 16.5$ J/g) of the control, and decreased with an increase in the NaCl concentration. Similar observations have been reported by Viturawong et al. [10] for the rice starch–XG–NaCl mixtures. In the starch–NaCl mixture systems, the gelatinization temperatures of starch dispersion also shifted to higher temperatures in the presence of NaCl [23, 24]. However, Samutsri and Supphantharika [4] reported that the ΔH values of rice starch–gum mixtures were increased by adding NaCl. Generally, it is known that salts increase or decrease the gelatinization temperatures and ΔH , depending on the type of salt as well as on the salt concentration [25]. Jane [26] proposed that the effect of salts on the gelatinization properties of starch could be explained by two mechanisms: the effects on the water structure and electrostatic interaction between the OH group of starch and the ions. She suggested that anions increase the water structure and tend to repel the OH groups of starch, stabilizing starch granules, whereas cations break the water structure and attract OH groups of starch, thereby destabilizing the starch granules. However, she also found that both effects stabilize starch granules; as the concentration of anions increase, the gelatinization temperature increases. These two mechanisms conflict with one another and result in complex effect patterns, depending on the type and concentration of salts [10].

Many researchers have reported that gelatinization temperatures of starches were significantly increased by the gum addition in the starch–gum mixture systems, whereas their ΔH values decreased [27–30]. They found that an increase in gelatinization temperatures and a decrease in ΔH

can be attributed, at least in part, to a decrease in the water availability, engendering a partial gelatinization of crystalline regions in the starch granules, and the effect of SPS–XG interactions, as described by Viturawong et al. [10]. According to Oosten [19, 31] and Sudhakar et al. [12], in the presence of salts, anions are known to be the actual gelatinizing agents. They also indicated that Cl^- assists gelatinization by breaking the hydrogen bonds between starch chains, as evidenced by the reduction of ΔH values in this study. Based on these observations, these results indicate that the thermal properties of SPS–XG mixtures were affected by adding NaCl, and in particular, their gelatinization temperatures and ΔH were dependent on the NaCl concentration.

4 Conclusions

Rheological parameters for the power law and Casson flow models decreased with an increase in the NaCl concentration, indicating that the synergistic effect of XG on starch increasing viscosity is less effective than the SPS–XG mixtures in the absence of NaCl. An increase in the dynamic moduli of the SPS–XG mixtures in the presence of NaCl appeared to be attributed to the thickening properties of XG and the synergistic effect of the NaCl. RVA demonstrated that the peak, breakdown, final, and setback viscosities as well as the pasting temperature of SPS–XG–NaCl mixtures increased with increasing NaCl concentration. The presence of NaCl apparently influenced the gelatinization characteristics of the SPS–XG mixtures significantly by increasing the gelatinization temperatures (T_o , T_p , and T_c) and decreasing gelatinization enthalpy (ΔH). The results convey that the addition of the NaCl to SPS–XG mixtures modified the gelatinization and rheological properties, depending on the NaCl concentration. The results of this study contribute to our understanding of rheological, pasting, and thermal properties of SPS–XG mixture in the presence of NaCl to improve the formulations of SPS-based food products.

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The authors have declared no conflict of interest.

Table 5. Gelatinization characteristics of SPS–XG–NaCl mixtures by DSC thermograms

NaCl (%)	T_o (°C)	T_p (°C)	T_c (°C)	ΔH (J/g)
0	63.2 ± 0.16 ^c	70.0 ± 0.10 ^c	79.5 ± 0.10 ^d	16.5 ± 0.17 ^a
1.0	65.2 ± 0.33 ^b	71.1 ± 0.21 ^b	80.8 ± 0.30 ^c	12.4 ± 0.37 ^b
2.5	66.2 ± 0.24 ^b	71.7 ± 0.10 ^a	82.5 ± 0.13 ^b	8.51 ± 0.28 ^c
5.0	67.8 ± 0.45 ^a	71.9 ± 0.15 ^a	84.5 ± 0.57 ^a	4.31 ± 0.25 ^d

Mean values in the same column with different superscript letters are significantly different ($p < 0.05$).

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