Effect of inulin on the pasting, textural, and rheological properties of sweet potato starch

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\textbf{ABSTRACT}

The influences of inulin on pasting, textural, and rheological properties of sweet potato starch (SPS) were explored. Subsequently, the interactions between inulin and SPS were analyzed. Results showed that inulin could make the pasting temperature increase and all viscosity parameters of SPS-inulin blends decline. With the increased inulin, SPS gel hardness decreased; while both spriginess and resilience first increased and then decreased, and reached to the maximum at an addition level of 5%. SPS-inulin blends paste displayed a pseudoplastic and shear-thinning property. Results of dynamic viscoelasticity indicated that inulin improved liquid-like characteristics of SPS-inulin blends pastes, and temperature of $G''_{\text{Max}}$, $G'_{\text{Max}}$ increased with the increase in inulin. Additionally, the swelling of SPS granules was obviously inhibited by inulin, and granules were mostly concentrated in the smaller. Inulin also greatly decreased the leached amylose content ($p < 0.05$). The interaction between SPS and inulin was the hydrogen bond.

1. Introduction

Sweet potato (\textit{Ipomoea batatas} Lam), belonging to the family of \textit{Convolvulaceae}, is ample food material cultivated in many countries, and ranks the sixth most-cultivated crops worldwide (Abegunde, Mu, Chen, & Deng, 2013; Lai, Wang, & Gao, 2016). Starch is the main component of sweet potato and takes up 50\% - 80\% proportion of the dry weight (Lai et al., 2016), and is broadly used in noodles, bread, cookies, and so on (Monte et al., 2019; Yadav, Yadav, Kumari, & Khatkar, 2014). However, native sweet potato starch (SPS) exhibits higher peak viscosity, intolerance of shear, poor freeze-thaw stability, and easy retrogradation, which could not meet the requirements of SPS-based food products (Hoover, 2001; Hung & Morita, 2005). Consequently, physical, chemical, and enzymatic methods have been investigated to modify the physical and chemical properties of SPS (Gou et al., 2019; Guo, Tao, Cui, & Janasawamy, 2019; Lee & Yoo, 2011; Zhou, Zhang, Chen, & Chen, 2017). Recently, non-starch hydrocolloids have been used to improve the property of native starch (Charoenrein, Tatirat, Rengsutthi, & Thongngam, 2011; Chen, Tian, Tong, Zhang, & Jin, 2017; Choi & Yoo, 2009).

Being a dietary fiber, inulin, belonging to the fructan family, is a linear polysaccharide and linked with $\beta$ (2→1) fructose (Luo et al., 2017). Its chain lengths vary from 2 to 60 monomers (Mensink, Frijlink, van der Voort, & Hinrichs, 2015). The average polymerization degree and molecular weight of natural inulin is 10–12, about 5 kDa, respectively. Inulin can be used as fat substitute, sugar replacer, and dietary fiber supplement in baked foods, dairy and meat products, due to its higher water holding capacity, good gel texture properties, as well as satisfying taste (Gao, Brennan, Mason, & Brennan, 2016; Karimi, Azizi, Ghasemlou, & Vaziri, 2015; Kuntz, Fiates, & Teixeira, 2013; Meyer, Bayarri, Tárrega, & Costell, 2011; Paola & Sancho, 2018). Additionally, inulin had been reported to have many nutritional properties, e.g. nourishing beneficial intestinal bacteria, promoting the absorption of mineral, regulating
glucose and lipids level of blood, and enhancing immunity (Shoaib et al., 2016).

At present, there is a growing interest in investigating the influence of inulin on the gelatinization, rheology, and retrogradation properties of starch from potato, wheat, rice, and waxy maize (Kou et al., 2018; Krystyjan, Ciesielski, Khachatryan, Sikora, & Tomasik, 2015; Luo et al., 2017; Wang, Wan, Liu, Xia, & Ding, 2019; Witczak, Witczak, & Ziobro, 2014; Ye et al., 2018). Wang et al. found that inulin enhanced the pasting temperature, decreased the viscosity parameters and improved the shear stability of rice starch (Wang et al., 2019). Similar result was found with Witczak et al. (2014), who reported that the partial replacement of potato starch by inulin significantly changed rheological and thermal properties of potato starch. According to Ye et al. (2018), inulin could enhance the water holding capacity, reduce the freezable-water amount of rice starch gel. Additionally, natural inulin had an influence on the texture parameters and significantly enhanced the fluidity of wheat starch gels, which was observed by Kou et al. (2018). However, to the best of our knowledge, little attention has been paid to the interactions between inulin and SPS. Therefore, the aim of this research was to explore the influence of inulin on the pasting, textural, and rheological property of SPS.

2. Materials and methods

2.1. Materials

Inulin was obtained from Baijin Xirui biological engineering Co., LTD. And the inulin content was 92%. SPS was supplied by The Second Economics and Trade Ltd., Beijing, China. It contained 86.49% total starch, 0.28% protein, 1.24% free lipid. Amylose and amylopectin standards from potato were bought from Sigma-Aldrich. All the other chemicals used in this paper were of analytical grade.

2.2. Preparation of SPS-inulin blends

SPS-inulin blends were prepared by mixing SPS with inulin. And inulin addition was shown in Table 1.

2.3. Pasting characteristics of SPS-inulin blends

Pasting characteristics of SPS-inulin blends were measured using RVA 4500 (Perten Instruments, Stockholm, Sweden) according to the published method (Wan et al., 2017). Three grams of SPS-inulin blends and 25 mL of distilled water were mixed with each other. The slurry of all samples was heated from 50°C to 95°C at the rate of 6°C/min, kept at 95°C for 5 min, then cooled to 50°C at the rate of 6°C/min, maintained for 2 min at 50°C. The parameters of pasting were determined.

2.4. Preparation of SPS-inulin blends paste

Six grams of SPS-inulin blends was dissolved in 100 g of distilled water to obtain a suspension. The suspension were agitated for 20 min at 20 °C, and followed by agitation at 95°C for 30 min in a water bath. And the stirring rate was 300 rpm. During heating, the mouth of beaker was covered with plastic wrap (three layers). After that, SPS-inulin blends paste was obtained.

2.5. Texture analysis of SPS-inulin blends gels

The texture of SPS-inulin blends gels was determined by TA-XT2i Texture Analyzer (Stable Micro System, England) according to the reported method (Wang, Yin, Zhang, Xie, & Sun, 2008) with some modifications. The pastes obtained with the method of 2.4 were transferred to the plastic containers and cooled to 25 °C. After storage at 4°C for 24 h, the prepared gels were cut into a cylinder with the diameter 30 mm and thickness 30 mm. The obtained cylindrical gel samples were carefully placed on the platform, and detected under TPA mode. Each cylinder was compressed to 30% height. The speed of pre-test, test, and post-test was 1.0 mm/s, and the force was 0.1 N. A cylinder probe was P50. The hardness (N), springiness, resilience, chewiness (N), gumminess, and chewiness were obtained.

2.6. Rheological analysis

Rheological properties were analyzed using a rheometer Haake Mars 60 (Thermo Fisher Scientific, Germany).

2.6.1. Steady shear analysis of SPS-inulin blends gels

Prior to measurement, the pastes obtained according to the method of 2.4 were slowly cooled to 25 °C. The changes of shear stress (τ) along with shear rate (γ) of SPS-inulin blends samples were measured at 25°C. The shear rate was from 0 to 120 s⁻¹. C3STiL parallel-plate geometry was used and the gap size was 0.06 mm. The power law equation was used to fit the data and the equation was shown as follows:

\[ \tau = K \cdot \gamma^n \]

where, τ was the shear stress (Pa), γ was the shear rate (s⁻¹), K was the consistency coefficient (Pa·sⁿ), n was the flow characteristic index.

2.6.2. Dynamic oscillatory analysis

2.6.2.1. Temperature sweep tests

The slurries of 6% (w/w) SPS-inulin blends were agitated for 15 min at 25°C with a magnetic stirrer, then loaded onto the plate. Before detection, a thin layer of low-density silicone oil was covered on the edge of the sample. Parallel-plate geometry (P60TiI) with 1.00 mm gap was used. The frequency was 1 Hz, and the strain was 0.4%. The samples were heated from 25 to 110 °C, and then cooled to 25°C at a rate of 5 °C/min. Storage modulus (G’), and loss modulus (G’’), were recorded. The maximum values of G’ and G’’ during the heating process were obtained as G’ Max and G’’ Max respectively.
2.6.2.2. Frequency sweep tests. The samples prepared with the method of 2.4 were cooled down to 25°C, and then loaded on the plate. A thin layer of low-density silicone oil was covered on the geometry periphery. During the frequency sweep tests, the strain was set at 1% and the frequency was taken at 0.1–10 Hz. G', G'', and tan δ (G'/G'') of samples were recorded.

2.7. Granule size analysis

The granule size was evaluated using a particle size analyzer BT-9300H (Bettersize, Dandong, China) according to the reported method (Kim & Qin, 2014). The paste prepared with the method of 2.4 was quickly transferred into the sample dispersion cell. The flow velocity of the distilled water was 60%.

2.8. Determination of the leakage amount of amylase

The leakage amylase amount of SPS was determined according to the reported method (Zhu, Zhang, Hong, & Gu, 2011) with minor modifications. Two grams of SPS-inulin blends were mixed with 100 mL of distilled water to prepare the slurry. The slurry was heated at 95°C for 20 min in a water bath. After being cooled to 25°C, the pastes were centrifuged at 12 000 × g for 20 min at 25°C by using freezing centrifuge (Sorvall ST40, Thermo Fisher Scientific, Germany). The supernatant was collected and added with 6 mL of 0.5 mol/L NaOH, and then heated at 95°C for 15 min in a water bath. The solution was transferred to 100 mL volumetric flask and diluted to 100 mL with distilled water after being cooled. Subsequently, 1 mL of the sample solution, 1 mL of 1 mol/L acetic acid, 2 mL of 0.01 mol/L iodine reagent was added to 100 mL volumetric flask in turn. And then, it was diluted to 100 mL with distilled water and stood in the darkroom at 25°C for 20 min. The absorbance was detected at 620 nm, and the standard curve of amylose \( y = 4140.9x \) \( R^2 = 0.9994 \) was obtained according to the method of Chrastil (1987).

2.9. Analysis of the interaction force between SPS and inulin

The interaction force between SPS and inulin was analyzed according to the method of Tang (2013). Briefly, 3g of SPS-inulin blends (prepared by mixing 2.7 g of SPS and 0.3 g inulin) was mixed with 50 mL of 0, 0.2, 0.6, 1.0 mol/L NaCl, or 0.2, 0.6, 1.0 mol/L thiorea, respectively. The slurry was heated at 95°C for 20 min in a water bath. After the hot pastes were cooled to 25°C, G' and G'' of the sample was detected as the method of 2.6.2(2).

2.10. FT-IR spectroscopy analysis

Samples prepared with the method of 2.4 were freeze-dried, and mixed with KBr (the ratio of sample to KBr was 1:100, w/w). Subsequently, it was pressed into filmy pellets and detected by using FT-IR a TENSOR 27 (Bruker Optics, Billerica, MA). The scanning range was between 4000 and 400 cm\(^{-1}\), the resolution was 4 cm\(^{-1}\).

2.11. Statistical analysis

All experiments were conducted in triplicates. The results were expressed as mean ± standard deviation and analyzed using one-way analysis of variance. Significance of differences was analyzed with LSD test at a level of 0.05 by using SPSS 19.0 (SPSS Incorporated, Chicago, USA).

3. Results and discussion

3.1. Effect of inulin on the pasting properties of SPS

The pasting curve and parameters of SPS and SPS-inulin blends were illustrated in Figure 1 and Table 2, respectively. Compared with SPS alone, inulin enhanced the pasting temperature (GT) and decreased all the viscosity parameters such as peak viscosity, breakdown, final viscosity, trough viscosity, and setback (Table 2). When the inulin addition was above 5%, the GT was obviously higher than that of SPS.

Table 2. Pasting characteristics of SPS and SPS-inulin blends.

| Inulin addition (%) | PV (cP)  | TV (cP)  | BD (cP) | FV (cP)  | SB (cP)  | GT (°C) |
|---------------------|----------|----------|---------|----------|----------|---------|
| 0                   | 4285 ± 39a | 3481 ± 47a | 804 ± 37a | 4976 ± 24a | 1494 ± 71a | 81.15 ± 0.95c |
| 2.5                 | 4271 ± 15a | 3478 ± 32a | 793 ± 18a | 4899 ± 35b | 1422 ± 61a | 81.20 ± 0.95c |
| 5                   | 4505 ± 44b | 3322 ± 30b | 737 ± 16b | 4726 ± 28c | 1402 ± 10a | 82.78 ± 0.58b |
| 10                  | 3727 ± 34c | 3012 ± 82c | 714 ± 49b | 4239 ± 74d | 1226 ± 62b | 83.18 ± 0.16b |
| 20                  | 2445 ± 23d | 1888 ± 16d | 557 ± 36c | 2516 ± 11e | 628 ± 13c | 89.95 ± 0.05a |
| 100                 | 177 ± 3e   | 167 ± 3e  | 10 ± 1d  | 168 ± 4f  | 1 ± 1d   | -       |

*PV*-peak viscosity, TV-trough viscosity, BD-breakdown, FV-final viscosity, SB-setback, GT-pasting temperature.

Values are means ± standard deviations (n = 3). Means within columns with different letters are significantly different (p < 0.05).

*PV*-viscosidad máxima, TV-viscosidad mínima, BD-desglote, FV-viscosidad final, SB-retroceso, GT-temperatura de pegado.

Los valores son medias ± desviaciones estándar (n = 3). Las medias dentro de las columnas con letras diferentes son significativamente diferentes (p < 0.05).

Figure 1. Pasting curves of SPS and SPS-inulin blends.

Figure 1. Curvas de amasado de SPS y mezclas de SPS-inulina.
alone (p < 0.05). A similar result was found with Wang et al. (2019), who found that the GT of rice starch increased after being mixed with inulin.

Peak viscosity (PV) represented starch’s maximum swelling value before disintegration. PV of SPS-inulin blends was much lower than that of SPS alone when inulin addition level was above 5% (p < 0.05). The similar trends of rice starch-xanthan mixtures were observed by Viturawong, Achayuthakan, and Suphantharika (2008). The reported factors including the expansion of granules, and the leaching of amylose could affect PV of starch (Zhang et al., 2018). Inulin was highly hygroscopic, and could reduce water availability for starch swelling, then cause the fall in the amount of leached amylose, which resulted in the decrease of PV of SPS-inulin blends. These were in agreement with the results obtained in Table 5 and Figure 6.

Breakdown (BD) value indicated starch granule stability during the heating process of starch, a lower BD value suggested higher integrity of starch granule. Table 2 indicates that inulin addition resulted in a declining in BD value, and the influence was significant when adding a level of inulin was more than 5%. When inulin addition was 20%, the BD value was only 557 cP, which was distinctly lower than that of SPS alone (p < 0.05). The result of BD suggested that inulin could improve the heat resistance of starch (BeMiller, 2011). Similar results had been reported when inulin was added to rice, potato, and wheat starch (Wang et al., 2019; Witczak et al., 2014; Ye et al., 2018).

Setback (SB) value usually reflected the degree of starch recrystallization during the process of cooling, and was more closely associated with amylase (Chen, Ren, Zhang, Tong, & Rashed, 2015; He, Zhang, Hong, & Gu, 2015). SB values decreased with the elevated addition of inulin. When the adding contents of inulin were above 5%, inulin had stronger inhibition on the short-term retrogradation of SPS (p < 0.05) (Table 2). Because of having higher water-holding ability, inulin could bind more water of paste, reduce the chains mobility of starch, so that retard the retrogradation of SPS.

### 3.2. Effect of inulin on the texture characteristics of SPS gel

The hardness of gel mainly depended on the amylose in a short time (BeMiller, 2011). The hardness of SPS gel showed a trend of going down with the increase of inulin addition (Table 3). This result was similar to the previous findings. Diao (2015) reported the texture of rice starch gel became soft when inulin was added, and Charoenrein et al. (2011) found that konjac glucomannan softened the gel of rice starch. The cohesiveness of SPS-inulin blends gel slightly increased first and then significantly decreased with the increase in inulin addition. Chewiness was an important index to evaluate gel. Table 3 indicates that the chewiness of SPS gel decreased with inulin addition. Additionally, with the increase amount of inulin, both springiness and resilience first increased and then decreased. When the addition content of inulin was 5%, both the springiness and resilience of SPS gel reached to the maximum and was slightly larger than that of SPS gel without inulin, while their differences were not significant (p < 0.05). This result suggested that a suitable addition amount of inulin should be carefully taken into consideration so that to effectively modify the textural parameters of SPS gel.

### 3.3. Effect of inulin on rheological characterization of SPS

#### 3.3.1. Steady shear rheological properties

The shear stress of SPS-inulin system increased with the increase of shear rate (Figure 2). At the same shear rate, the shear stress of SPS-inulin blends system was smaller than that of SPS alone. It was interesting that, with the increase of inulin content, the shear stress of SPS-inulin system increased first and then decreased (Figure 2).

The consistency coefficient (K) and the flow characteristic index (n) in Table 4 were empirical constants and were related to the properties of liquid. As reported, the lower K was, the more elastic liquid was. And n deviated from 1 greatly, reflecting the fluid had stronger pseudo-plasticity (Kou et al., 2018). When inulin addition was more than 5%, K of the blended gel decreased significantly and n increased slightly. And n of SPS alone and SPS-inulin blends gel were all less than 1, which indicated that the fluid of SPS-inulin blends system showed shear thinning. The characteristic of shear thinning had important significance in molding during material processing (Kou et al., 2018).

#### 3.3.2. Temperature sweep

As shown in Figure 3, the G' values of all samples were higher than those of G'', which indicated that SPS and SPS-inulin blends exhibited weak gel-like behavior. The trend of structure stability of SPS-inulin blends gel with the change in temperature was similar to the reported results of Torres, Raymundo, and Sousa (2013).

In the early stage of heating, the increases in G' and G'' were relatively small, and the differences of G' and G'' between SPS and SPS-inulin blends gel were not significant. The possible explanation was that, the amylose molecules would have dissolved from the starch granules and the suspension became a sol at the early stage of heating (Singh, McCarthy, Singh, Moughan, & Kaur, 2007). With the

### Table 3. Textural properties of the gel prepared by SPS and SPS-inulin blends.

| Inulin addition (%) | Hardness(N) | Springiness | Cohesiveness | Gumminess(N) | Chewiness | Resilience |
|---------------------|-------------|-------------|--------------|--------------|-----------|------------|
| 0                   | 3.74 ± 0.49a | 0.90 ± 0.02ab | 0.87 ± 0.03a | 3.25 ± 0.42a | 298.12 ± 39.52a | 0.59 ± 0.01a |
| 2.5                 | 3.05 ± 0.24b | 0.84 ± 0.04c | 0.81 ± 0.01b | 2.66 ± 0.38b | 227.00 ± 34.02b | 0.50 ± 0.04b |
| 5                   | 2.11 ± 0.28c | 0.92 ± 0.02a | 0.87 ± 0.03a | 1.84 ± 0.20c | 178.31 ± 22.71b | 0.65 ± 0.04a |
| 10                  | 1.49 ± 0.16d | 0.90 ± 0.04ab | 0.77 ± 0.04b | 1.15 ± 0.18d | 106.57 ± 21.53c | 0.49 ± 0.07b |
| 20                  | 1.20 ± 0.03d | 0.86 ± 0.01bc | 0.62 ± 0.01c | 0.74 ± 0.03d | 64.79 ± 1.76c | 0.43 ± 0.00b |

*Values are means ± standard deviations (n = 3). Means within columns with different letters are significantly different (p < 0.05).
*Los valores son medias ± desviaciones estándar (n = 3). Las medias dentro de las columnas con letras diferentes son significativamente diferentes (p < 0.05).
The change in the storage modulus ($G'_\text{inulin}$) and loss modulus ($G''_\text{inulin}$) of SPS-inulin blends gel was higher than gel of SPS alone, which indicated the viscosity of the blended gel changed faster than elasticity, suggesting that SPS-inulin blends showed a trend of going on rising first and then declining, and both $G'$ and $G''$ reached a maximum at the addition level of 5%. While their values were always lower than those of pure SPS gel. This indicated that inulin molecules could interact with each other to form a weak elastic gel, which was easy to be deformed (Kou et al., 2018). It was also observed by Wang et al. (2019), who found that rice starch blended with inulin displayed weak gel-like behavior.

The tan $\delta$ represented the ratio of $G''$ to $G'$. The larger tan $\delta$ was and the liquid-like behavior was, while the lower was and the stronger solid-like behavior was (Ptaszek & Grzesik, 2007). As illustrated in Figure 5, tan $\delta$ of SPS-inulin blends gel was higher than gel of SPS alone, which indicated the viscosity of the blended gel changed faster than elasticity, suggesting that SPS-inulin blends gel showed stronger liquid-like behavior, which was consistent with the decrease of hardness, cohesiveness, and chewiness of SPS-inulin blends gel obtained Table 3. The similar result was found with Kim and Yoo (2011), who reported the tan $\delta$ of acorn starch gel gradually increased when galactomannan concentration increased.
3.4. Effect of inulin on the leached amylose content of SPS

The pasting process of starch involves the swelling of granule, destruction of crystalline region, and leaching of amylose from starch. During gelatinization of starch, amylose had less space barrier than amylopectin, so that it was easier to leak out from starch. After adding inulin, the leakage of amylose of SPS-Inulin blends was significantly lower than that of SPS alone (p < 0.05) (Figure 6). With the increase of inulin addition, the leached amylose content remarkably decreased. When inulin addition was 20%, the content was only 12.64%, which indicated that the inulin molecules mainly interacted with amylose. This result was in accordance with the previous findings. Li (2017) reported that the leakage of amylose content of wheat starch was reduced after adding the inulin. Zhu et al. (2011) found that the leakage of amylose of tapioca starch declined with the addition of xanthan gum.

3.5. Effect of inulin on the particle size of SPS

The median diameter and volume average diameter size of SPS-inulin blends heated at 95 °C for 20 min were smaller than that of SPS (Table 5). To better analyze the effect of inulin on the granulometric size of SPS, the diameter values were divided into three sections (the small particles-diameter <45 μm, the medium-sized particles-diameter between 45 and 75 μm, large particles-diameter >75 μm). With the increase of inulin addition, the distribution ratio of SPS in the large-sized particle range decreased and was much lower than that of SPS alone. While those of both small and medium-sized particles increased. When inulin addition was 20%, compared to the pure SPS, the volume fraction of the small and medium-sized particle of SPS-inulin blends increased by 6.19% and 11.95%, respectively (Table 5, Figure 7). The results indicated that, the swelling of SPS granules was obviously inhibited by inulin, and starch granules were mostly concentrated in the smaller granules, thereby the gelatinization temperature of sweet potato starch increased.

3.6. Intermolecular interaction between inulin and SPS

The interaction between SPS and inulin could be quite complicated. In general, hydrogen bonding, electrostatic or hydrophobic interactions may exist in the polysaccharide system. Sodium chloride (NaCl) mainly affects the electrostatic action in the system, but has little influence on the hydrogen bond action in the system, while thiourea mainly destroys the hydrogen bond action, and has little effect on the electrostatic action (Li, 2017). So that, the force type of SPS-inulin system was determined by adding sodium chloride and thiourea. Frequency scanning curves of SPS-inulin blends by sodium chloride and thiourea were shown in Figure 8. With the increase of NaCl concentration, the G' of SPS-inulin blends increased slightly. It was inferred that the interaction between SPS and inulin was not electrostatic. While, the G' of SPS-inulin blends gel decreased significantly with the increase of thiourea concentration, which indicated that the addition of thiourea had a strong weakening effect on the force of the system. It was presumed that the interaction between SPS and inulin was mainly due to the hydrogen bond between hydroxyl groups on the molecular chains. In addition, since inulin is a highly hydrophilic polysaccharide, there are no hydrophobic groups in the molecular structure, so there was no strong hydrophobic interaction between SPS and inulin.

Table 5. Effect of inulin on the granular size distribution of SPS.

| Inulin addition (%) | Median diameter (µm) | Volume average diameter (µm) | Volume fraction (%) |
|---------------------|----------------------|-----------------------------|--------------------|
|                     | <45 µm               | 45-75 µm                    | >75 µm             |
| 0                   | 43.04 ± 0.38a        | 46.54 ± 0.08a               | 30.63              |
| 2.5                 | 42.58 ± 0.84ab       | 46.02 ± 0.37a               | 31.07              |
| 5                   | 41.61 ± 0.86bc       | 45.16 ± 0.35b               | 31.72              |
| 10                  | 41.43 ± 0.15cd       | 43.81 ± 0.89c               | 33.53              |
| 20                  | 40.53 ± 0.31d        | 42.42 ± 0.36d               | 34.29              |

* Values are means ± standard deviations (n = 3). Means within columns with different letters are significantly different (p < 0.05).

* Los valores son medias ± desviaciones estándar (n = 3). Las medias dentro de las columnas con letras diferentes son significativamente diferentes (p < 0.05).
3.7. FT-IR spectroscopy analysis

The FT-IR spectra for SPS and SPS-inulin blends were determined at the range from 4000 to 400 cm\(^{-1}\) were shown in Figure 9 and Table 6. The band between 3800 and 3100 cm\(^{-1}\) belonged to the -OH stretching. The band in the region of 3000–2800 cm\(^{-1}\) was related to -CH stretching vibration. And peak bands at wavenumbers 1157, and 1022 cm\(^{-1}\) were attributed to C-O bond stretching vibration. The band at 3700 cm\(^{-1}\) was related to -OH stretching, which indicated that there was free O-H in the system of SPS-inulin blends. With the increase of inulin, the band shifted to low wavenumber (3700 cm\(^{-1}\)) that reflected the number of free O-H increased, corresponding to the stronger hygroscopicity and more hydrogen bonds of inulin (Li, 2017; Pawlak & Mucha, 2003). The band at 3200 cm\(^{-1}\) was also related to the associative -OH stretching. Addition of inulin made the

![Figure 7. Differential distribution of granule size of SPS and SPS-inulin blends heated at 95 °C for 20 min. a, b, c, d, and e are granular size differential distribution for SPS, SPS-2.5% inulin, SPS-5%inulin, SPS-10%inulin, SPS-20%inulin, respectively.](image)

*Figure 7. Difusión diferencial del tamaño de gránulos del SPS y mezclas de SPS e inulina calentadas a 95°C durante 20 min. a, b, c, d y e indican la distribución diferencial del tamaño granular para SPS, SPS-2.5% inulina, SPS-5% inulina, SPS-10% inulina, SPS-20% inulina, respectivamente.*
Figure 7. (Continued.)
Figura 7. (Continuación.)

Figure 8. Effects of the different solutions on the storage modulus ($G'$) and loss modulus ($G''$) of SPS-inulin blends.
Figura 8. Efectos de las diferentes soluciones sobre el módulo de almacenamiento ($G'$) y el módulo de pérdida ($G''$) de las mezclas de inulina y SPS.
band shift to low wave number ($3200 \text{ cm}^{-1}$), which indicated that the hydrogen bond between inulin and starch was enhanced. Additionally, as illustrated in Figure 9, no new absorption peak bands were found for SPS-Inulin blends compared to the pure SPS, indicating that there were no chemical groups were destroyed or produced.

### 4. Conclusions

The addition of inulin enhanced the pasting temperature of SPS and decreased all the parameters of viscosity such as peak viscosity, breakdown, trough viscosity, final viscosity, and setback. The hardness of SPS gel decreased, while both springiness and resilience first increased and then decreased with the increase of inulin addition. Rheological measurements showed that the addition of inulin decreased the yield stress and consistency coefficient, and SPS-inulin blends pastes displayed a pseudoplastic and shear thinning property. The enhancement of tan $\delta$ value revealed that addition of inulin promoted the liquid-like characteristics of SPS-inulin blends pastes. Additionally, inulin obviously inhibited the swelling of SPS granules, and significantly decreased the leached amylose content ($p < 0.05$). FT-IR spectra indicated that there was no new absorption peaks of SPS-Inulin blends compared to the pure SPS, and the hydrogen bond was interaction force between SPS and inulin. In general, inulin had an influence on the pasting, textural parameters, and rheological properties of sweet potato starch.

### Disclosure statement

All authors declare that there are no conflict of interest.

### Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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