Effects of inulin with short and long-chain on pasting, texture and rheological properties of sweet potato starch

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\textbf{ABSTRACT}

Effects of inulin with short and long-chain on pasting, texture and rheological properties of sweet potato starch (SPS) were investigated. Subsequently, the interaction mechanism between inulin and SPS was discussed. Both short and long-chain inulin could decrease all the viscosity parameters and raise the pasting temperature (GT) of SPS-inulin mixes. With the increase of inulin addition, the hardness and gumminess of SPS gel decreased, while tan δ and temperature of \( G'_{\text{Max}} \) rose. Inulin could inhibit SPS granule swelling, and made SPS granules concentrate in the smaller ones. Inulin also remarkably lowered the content of leached amylose (\( p < 0.05 \)). The hydrogen bond was the mainly interacting force between SPS and inulin. Additionally, \( G' \) and \( G'' \) of SPS-SI gel was lower than those of SPS-LI samples at the same addition level. Generally, short-chain inulin could significantly affect GT and paste viscosity of SPS than long-chain inulin at lower addition level.

Efectos de la inulina de cadena corta y larga en el pegado, la textura y las propiedades reológicas del almidón de batata [camote, boniato]

En el presente estudio se investigaron los efectos de la inulina de cadena corta y larga en el pegado, la textura y las propiedades reológicas del almidón de batata (SPS). Posteriormente, se examinó el mecanismo de interacción entre la inulina y el SPS. Tanto la inulina de cadena corta como la de cadena larga pudieron disminuir todos los parámetros de viscosidad y aumentar la temperatura de pegado (GT) de las mezclas de inulina y SPS. Con el aumento de la adición de inulina, la dureza y la gomosidad del gel SPS disminuyó, mientras que el color marrón \( \delta \) y la temperatura de \( G'_{\text{Max}} \) aumentó. La inulina pudo inhibir la hinchazón de los gránulos de SPS, e hizo que estos se concentraran en los más pequeños. La inulina también disminuyó notablemente el contenido de amilosa lixivida (\( p < 0.05 \)). El enlace de hidrógeno fue la fuerza de interacción principal entre el SPS y la inulina. Además, la \( G' \) y la \( G'' \) del gel de SPS-SI era más baja que la de las muestras de SPS-LI al mismo nivel de adición. En general, la inulina de cadena corta puede afectar significativamente la GT y la viscosidad de la pasta de SPS que la inulina de cadena larga a un nivel de adición más bajo.

1. Introduction

Sweet potato (\emph{Ipomoea batatas} L.), as one kind of dicotyledo-

"nous plants, is a nutritious food source for human and ani-
mals, and is the sixth most-planted crops in the world (Abegunde et al., 2013; Lai et al., 2016; H. Wang et al., 2020). The annual yield of sweet potato in China reaches 117 million tons, which accounts for nearly 90% of the world’s total output. Starch, taking up about from 50% to 80% of the dry weight, is the main component of sweet potato tuber (Ji et al., 2019; Lai et al., 2016). Sweet potato starch (SPS) could be widely used in baked food, noodles, candy products and so on (Azeem et al., 2020; Monthe et al., 2019; Yadav et al., 2014). Because of the higher peak viscosity, worse stability of freeze-
thaw and shear, and easier retrogradation of native starch, the utilization of SPS in starch-based foods was limited (Hoover, 2001; Hung & Morita, 2005). In order to meet the raw material demand of SPS-based products, chemical, physical and enz-
matic methods could be employed to improve the physico-
chemical properties of SPS (Gou et al., 2019; Guo et al., 2019; Zhang et al., 2020; Zhou et al., 2017). Green, safe and efficient modification of SPS would be favoured by producers and consumers. Recently, non-starch hydrocolloids had attracted increasing attention due to that they could effectively modify the properties of starch (Charoenrein et al., 2011; Fang et al., 2020).

Inulin, predominately obtained from chicory root, is a linear polysaccharide, which is composed of D-fructose linked by \( \beta \) (2→1) glycosidic bonds (Luo et al., 2017; Mensink et al., 2015). The chain length of inulin varies in the range of 2 to 60 monomers. Depending on the degree of polymerization (DP), inulin could be classified into short-chain inulin (SI, DP value ≤10), long-chain inulin (LI, DP value ≥ 23), and natural inulin (NI, DP value in range of 2 and 60) (Luo et al., 2020). Inulin could be applied in baked foods, meat and dairy products to replace the fat and sugar, to improve the viscosity and texture, and to supplement the dietary fiber (Gao et al., 2016; Paola & Sancho, 2018; Y. Zhang et al., 2020).

Recent reports showed a growing interest in attention to the effects of inulin with different chain-length on physical
and chemical properties of starch (Kou et al., 2018; Krystyjan et al., 2015; Luo et al., 2017; R. Wang et al., 2019; Witzczak et al., 2014; Ye et al., 2018; Zhang et al., 2019). Kou et al. (2018) reported that inulin with different chain-length could affect the texture of wheat starch gel, and natural inulin significantly decreased the stability of the gels, while both short and long-chain inulin maintained the stability of starch gel. R. Wang et al. (2019) found that addition of inulin with different chain-length reduced the viscosity and raised the pasting temperature of rice starch. Additionally, short-chain inulin exerted stronger effect on viscosity parameters than long-chain inulin. According to Luo et al. (2017), inulin with short-chain influenced the retrogradation of wheat starch more effectively than long-chain inulin. However, to the best of our knowledge, such researches remained less in focusing on the effect of inulin with different chain-length on the properties of SPS. Therefore, the present research was carried out to explore the influences of inulin with short and long-chain on the pasting, rheological, and textural properties of SPS. Subsequently, the impact mechanism between inulin and SPS were discussed.

2. Materials and methods

2.1. Materials

Short-chain inulin (DP≤ 10, inulin content was 90.80%) and long-chain inulin (DP>23, inulin content was 100%) was obtained from Beneo-Orafti Company, Belgium. Sweet potato starch (the total starch content was 86.53%) was purchased from Beijing Ershang Company, China. All the other chemical reagents utilized in this paper were analytically pure.

2.2. Preparation of SPS-inulin mixes

SPS-inulin mixes, which were denoted by SPS-SI, and SPS-LI, were obtained by partial replacement of SPS with inulin (0, 2.5%, 5%, 10%, respectively). And the addition of inulin with short and long-chain was shown in Table 1.

| Sample | Inulin (%) | SPS (%) | Total (%) |
|--------|------------|---------|-----------|
| SPS    | 0          | 100     | 100       |
| SPS-SI-2.5 | 2.5 | 97.5    | 100       |
| SPS-SI-5  | 5          | 95      | 100       |
| SPS-SI-10 | 10         | 90      | 100       |
| SPS-LI-2.5 | 2.5 | 97.5    | 100       |
| SPS-LI-5  | 5          | 95      | 100       |
| SPS-LI-10 | 10         | 90      | 100       |

2.3. Pasting properties

Pasting properties of SPS and SPS-inulin mixes were detected by using rapid viscosity analyzer (RVA4500, Perten, Sweden). After 3.0 g samples were blended with 25 mL distilled water in RVA container, the slurries were prepared. The pasting parameters (peak viscosity, trough viscosity, breakdown, final viscosity, setback and pasting temperature) of samples were measured according to the reported method of Wan et al. (2017). The results were the average values of three replications.

2.4. Texture analysis

The texture of SPS-inulin mixes gels was measured according to the method of Zhang et al. (2019). The pastes obtained from RVA analysis of 2.3 were transferred to the plastic containers. After being kept for 24 h at 4°C, the gels were detected under TPA mode by using a texture analyzer (TA-XT2i, Stable Micro System, England). The samples were compressed using P/50 probe at the speed of 4 mm/s to reach 30% strain. The hardness, springiness, cohesiveness, gumminess, chewiness, and resilience was recorded. Results were the average values of three replicates.

2.5. Dynamic rheological properties

2.5.1. Preparation of SPS-inulin mixes paste

The suspension was obtained by simply blending 9 g SPS-inulin mixes with 150 mL distilled water, followed by agitation at 20°C for 20 min, and then heated at 95°C for 30 min in water bath with the stirring rate of 200 rpm. Finally, the paste of SPS-inulin mixes was obtained. During heating, three layers plastic wraps were covered on the mouth of beaker.

2.5.2. Frequency sweep tests

The samples obtained with the method of 2.5.1 were employed to explore the dynamic rheological properties using Haake Mars 60 rheometer (Thermo Fisher Scientific, Germany). Frequency sweep tests were carried out over the frequency of 0.1 to 10 Hz with 1% strain at 25°C. The storage modulus (G’), the loss modulus (G’’), and tan δ (G’/G’’) was obtained.

2.5.3. Temperature sweep tests

The suspension prepared with 6 g samples and 100 mL distilled water was agitated at 20°C for 20 min, and then loaded onto the plate. Dynamic oscillatory properties of temperature sweep were determined according to the published method (Zhang et al., 2019). P60Ti Parallel-plate geometry at gap of 1.00 mm was used. Temperature sweep tests were conducted at a frequency of 1 Hz and the strain of 0.4%. The temperature of samples increased from 25 to 110°C at the rate of 5°C/min, and then decreased to 25°C at the same rate. G’ was obtained, and the maximum value of G’ (G’ Max) was analyzed.

2.6. Measurement of the leaked amylose content

The leaked amylose amount of samples was evaluated according to the published method with some modifications (Zhu et al., 2011). After the slurry was prepared by mixing 2 g SPS-inulin samples with 200 mL distilled water, it was heated
in water bath for 20 min at 95 °C, and then cooled to 25 °C. The supernatant of pastes was collected after being centrifuged at 12 000 × g for 20 min at 25 °C. The obtained supernatant was mixed with 0.5 mol/L NaOH (6 mL), and then heated in water bath for 15 min at 95 °C. After being cooled to 25 °C, the solution was diluted to 100 mL with distilled water in volumetric flask. 1 mL prepared sample solution, 1 mL acetic acid solution (1 mol/L), and 2 mL iodine reagent (0.01 mol/L) was transferred to volumetric flask in turn. Then, the mixes solution was diluted to 100 mL by using the distilled water. Finally, they were stored in darkroom for 20 min at ambient temperature. The absorbance was measured at the wavelength of 620 nm.

2.7. Detection of granule size

The paste was obtained with the method of 2.5.1. The granule size of samples was analyzed with BT-9300 H particle-size analyzer (Bettersize, Dandong, China) according to the published method (W. Kim & Qin, 2014). The solvent was distilled water, and its flow velocity was set at 60 mL/s.

2.8. Interaction force between inulin and SPS

The interaction force was evaluated according to the reported method (Tang, 2013). 6 g SPS-inulin mixes was prepared by blending 5.85 g SPS with 0.15 g SI or LI, followed by dissolving in 100 mL 0.2 mol/L thiourea, or 0.2 mol/L NaCl, respectively. The resulting slurry was heated in water bath for 20 min at 95 °C. After being cooled to ambient temperature (25 °C), G' of SPS-inulin paste was detected according to the method of 2.5.2.

2.9. Analysis of FT-IR spectroscopy

After being prepared with the method of 2.5.1, the samples were freeze-dried, and then characterized by TENSOR 27 FT-IR (Bruker Optics, Billerica) according to the method of Zhang et al. (2019). The scanning range was from 4000 cm⁻¹ to 400 cm⁻¹, and the spectral resolution was set at 4 cm⁻¹.

### 2.10. Statistical analyses

The results were expressed as mean ± standard deviation. All data were subjected to analysis using one-way analysis of variance. Significant differences among the mean was evaluated by LSD test at 5% level.

3. Results and discussion

3.1. Effect of inulin with short and long-chain on pasting properties of SPS

Compared with SPS without inulin, addition of inulin reduced the peak viscosity, final viscosity, trough viscosity, setback and breakdown of SPS mixes. Similar results were found when rice, potato, and wheat starch was replaced or added with inulin (Witczak et al., 2014; Ye et al., 2018). The highest drop of SPS paste viscosity was observed when long-chain inulin was added, while the smaller was short-chain inulin (Table 2).

The breakdown could reflect the stability of starch granules during being heated. The smaller the breakdown, the stronger the thermal stability of SPS. Addition of inulin resulted in the decrease of breakdown of SPS, indicating that inulin improved the heating stability of starch granules. As for inulin with different chain-length, at the lower addition levels (≤5.0%), the influence of short-chain inulin on breakdown was greater than that of long-chain inulin. While, at the higher addition levels (10%), long-chain inulin had much stronger impact on breakdown than that of short-chain inulin. Witczak et al. (2014) reported the similar result.

Addition of inulin decreased the setback values of SPS, which indicated that inulin could improve SPS storage stability. With the increase of short-chain inulin addition amount, the setback of SPS decreased first and then increased slightly, and at the addition level of 5%, the value of setback was the lowest (1383 cP). While this value of SPS decreased all along with the increase of long-chain inulin content. Compared to inulin with long-chain, inulin with short-chain has much smaller molecules that could easily combine with water at room temperature, so that the retrogradation of SPS could be markedly inhibited by short-chain inulin even at smaller addition-level. When

### Table 2. Pasting characteristics of SPS replaced by inulin with short and long-chain.

| Sample  | Peak viscosity (cP) | Trough viscosity (cP) | Breakdown (cp) | Final viscosity (cP) | Setback (cP) | Pasting temperature (°C) |
|---------|---------------------|-----------------------|----------------|----------------------|-------------|-------------------------|
| SPS     | 4325 ± 47 a         | 3486 ± 43a            | 809 ± 37a      | 4986 ± 24a           | 1499 ± 67a  | 81.17 ± 0.97 c          |
| SPS-SI-2 | 4079 ± 91 b         | 3370 ± 97bc           | 708 ± 10 c     | 4774 ± 153bc         | 1403 ± 72b  | 81.77 ± 0.10 c          |
| SPS-SI-5 | 4056 ± 48 bc        | 3355 ± 24            | 702 ± 24 c     | 4377 ± 38 cd         | 1383 ± 60b  | 83.32 ± 0.08b           |
| SPS-SI-10 | 3614 ± 9d           | 2890 ± 22e            | 724 ± 17bc     | 4344 ± 27e           | 1455 ± 26ab | 85.37 ± 0.03a           |
| SI      | 179 ± 1 g           | 171 ± 2g              | 8 ± 1f         | 172 ± 2 g            | 0.7 ± 0.6e  | -                       |
| SI      | 1426 ± 9 a          | 3450 ± 97 ab          | 795 ± 94 ab    | 4891 ± 96 ab         | 1441 ± 38ab | 86.7 ± 0.88 c           |
| LI      | 651 ± 86 f          | 173 ± 4g              | 478 ± 89e      | 174 ± 4 g            | 1 ± 1d      | -                       |

SPS, sweet potato starch; SI, short-chain inulin; SPS-SI-2, sweet potato starch substituted by short-chain inulin with the level of 2.5%; SPS-SI-5, sweet potato starch substituted by short-chain inulin with the level of 5%; SPS-SI-10, sweet potato starch substituted by short-chain inulin with the level of 10%; SPS-LI-2,5, sweet potato starch substituted by long-chain inulin with the level of 2.5%; SPS-LI-5, sweet potato starch substituted by long-chain inulin with the level of 5%; SPS-LI-10, sweet potato starch substituted by long-chain inulin with the level of 10%. Values are means ± standard deviations (n = 3). Different letters in the same column indicate significant differences (p < 0.05).

Ye, S.P.; SPS, almidón de batata; SI, almidón de patata; LI, almidón de patata sustituido por inulina de cadena corta a nivel de 2.5%; SPS-SI-2, almidón de patata sustituido por inulina de cadena corta a nivel de 5%; SPS-SI-10, almidón de patata sustituido por inulina de cadena corta a nivel de 10%; SPS-LI-2, almidón de patata sustituido por inulina de cadena larga a nivel de 2.5%; SPS-LI-5, almidón de patata sustituido por inulina de cadena larga a nivel de 5%; SPS-LI-10, almidón de patata sustituido por inulina de cadena larga a nivel de 10%. Los valores son las medias ± desviaciones estándar (n = 3). Las distintas letras en la misma columna indican diferencias significativas (p < 0.05).
3.2. Effect of inulin with short and long-chain on texture of SPS gel

The influence of short and long-chain inulin on the texture of SPS gel was shown in Table 3. With the increase of inulin content, the hardness of SPS gels showed a downward trend. When addition level of inulin was 2.5%, the hardness of SPS gels replaced by short-chain inulin and long-chain inulin decreased to 3.21 N and 3.55 N, respectively. While their value was not significantly different from that of SPS without inulin (p > 0.05). When the addition amount of inulin increased to 10.0%, the hardness of SPS-SI and SPS-LI mixes gel decreased to 1.85 N and 2.71 N, respectively, and their value was much lower than that of pure SPS gel (p < 0.05). Diao (2015) described the similar result that rice starch gel texture became soft after being mixed with inulin. Inulin addition caused a decrease in the hardness of starch gel, which may be related to that the network structure of inulin gel was much weaker than that of starch gel (Li, 2017).

With the increase of inulin content, both the resilience and springiness of SPS increased first and then decreased. When inulin addition level was 10%, springiness and resilience of SPS-SI mixes gel decreased greatly, while these of SPS-LI declined slowly. Additionally, the gumminess of SPS gel gradually declined with the addition of inulin with both short and long-chain.

Table 3. Texture parameters of gel prepared by SPS and SPS-inulin mixes.

| Sample * | Hardness (N) | Springiness | Cohesiveness | Gumminess (N) | Chewiness | Resilience |
|----------|--------------|-------------|--------------|---------------|------------|------------|
| SPS      | 3.72 ± 0.48a | 0.89 ± 0.03bc | 0.84 ± 0.03a | 3.14 ± 0.42a   | 285.67 ± 38.46a | 0.59 ± 0.02a |
| SPS-SI-2.5 | 3.21 ± 0.26ab | 0.94 ± 0.01ac | 0.85 ± 0.02a | 2.72 ± 0.23bc  | 264.64 ± 25.39ab | 0.65 ± 0.02a |
| SPS-SI-5  | 3.18 ± 0.19ab | 0.94 ± 0.01ac | 0.85 ± 0.02a | 2.70 ± 0.22bc  | 260.17 ± 25.66ab | 0.65 ± 0.02a |
| SPS-SI-10 | 1.85 ± 0.71 c  | 0.81 ± 0.06d  | 0.57 ± 0.06d  | 1.08 ± 0.52d   | 91.74 ± 51.23c   | 0.36 ± 0.10b  |
| SPS-LI-2.5 | 3.55 ± 0.16a | 0.95 ± 0.01a  | 0.84 ± 0.02a | 2.99 ± 0.14ab  | 290.38 ± 16.12a  | 0.66 ± 0.02a  |
| SPS-LI-5  | 3.48 ± 0.08a | 0.94 ± 0.01ac | 0.86 ± 0.02a | 2.98 ± 0.10ab  | 287.43 ± 11.56a  | 0.66 ± 0.02a  |
| SPS-LI-10 | 2.71 ± 0.18b | 0.92 ± 0.02ab | 0.84 ± 0.01a | 2.28 ± 0.18 c  | 218.18 ± 21.11b  | 0.64 ± 0.02a  |

*SPS, sweet potato starch; SI, short-chain inulin; LI, long-chain inulin; SPS-SI-2.5, sweet potato starch substituted by short-chain inulin with the level of 2.5%; SPS-SI-5, sweet potato starch substituted by short-chain inulin with the level of 5%; SPS-SI-10, sweet potato starch substituted by short-chain inulin with the level of 10%; SPS-LI-2.5, long-chain inulin with the level of 2.5%; SPS-LI-5, long-chain inulin with the level of 5%; SPS-LI-10, long-chain inulin with the level of 10%. Values are means ± standard deviations (n = 3). Different letters in the same column indicate significant differences (p < 0.05).

3.3. Effect of inulin with short and long-chain on dynamic rheological properties of SPS gel

3.3.1. Frequency scanning

The results of G’ and G” of SPS-inulin mixes gels varying with the frequency was presented in Figures 1 and 2. G’ and G” of all the SPS-inulin mixes exhibited a slight frequency dependency. Additionally, the values of G’ were much higher than those of G” within the measured frequency (Figures 1 and 2). This result suggested that the gel of SPS-inulin mixes had solid-like property under the measured frequency range.

G’ of inulin-SPS mixes showed a downward trend with the increase of inulin addition, indicating the elastic gel formed by the interaction of inulin and SPS molecules was weak and prone to be out of shape (Kou et al., 2018). Additionally, inulin could also make G’ of SPS gel decrease. When inulin addition amount was the same, both G’ and G” of samples containing short-chain inulin was lower than those of samples containing long-chain inulin.

The tan δ of SPS-inulin mixes gel was larger than those of SPS without inulin (Figure 3), which showed the viscosity of samples with inulin changed faster than elasticity, demonstrating that SPS-inulin mixes gel had stronger liquid-like behavior. Similar result was reported by W. W. Kim and Yoo (2011), who found the tan δ of acorn starch gel became larger with the addition of galactomannan. The tan δ of SPS-inulin mixes gel enhanced with the increase of inulin addition. When addition level of inulin was 2.5%, tan δ of SPS replaced by inulin with short-chain was lower than that did by long-chain inulin. While the tan δ of SPS-LI mixes was higher than that of SPS-SI mixes when inulin addition level was above 2.5%.

3.3.2. Temperature scanning

As shown in Figure 4, in the initial heating period (40–70 °C), the changes in G’ were quite small, and the G’ value was not significantly different between SPS and SPS-inulin mixes. When heating temperature increased from 70 to 97 °C, G’ values were sharply raised until to the maximum. The G’ values dropped with further heating (Figure 4). Similar results were reported by Gonzalez-Reyes et al. (2003), and Singh et al. (2007).

In addition, the temperature of G’ (Max) rose along with the increase of inulin addition. SPS without inulin showed the lowest G’ (Max) temperature with the value of 93.20 °C. SPS-LI with 10% inulin addition had the highest G’ (Max) temperature.
which was 96.04 °C. This behaviour may be due to good water retention ability of inulin (Luo et al., 2012).

As illustrated in Figure 4, at the same addition level, the $G'_\text{Max}$ temperature of SPS-LI mixes was higher than that of SPS-SI blends, which might be related to the fact that the long-chain inulin could absorb more water than short-chain inulin at higher temperature, much easily inhibit the water-swelling of SPS and result in the higher increase of $G'_\text{Max}$ temperature (Luo et al., 2017, 2020).
3.4. Effect of inulin with short and long-chain on amylose content leaked from SPS

During the gelatinization of SPS, amylose more easily leaked out from starch granule than amyllopectin. After being blended with inulin, the leaked amylose content of SPS-inulin mixes fell significantly than that of SPS without inulin (p < .05) (Figure 5). Additionally, the leakage content of amylose dropped remarkably with the increase of inulin addition. Similar results were reported by Li (2017), Zhu et al. (2011), and Li (2017) observed that adding inulin resulted in decrease of the leakage of amylose content of wheat starch. Zhu et al. (2011) described that with the addition of xanthan gum, the leakage content of tapioca starch amylose reduced.

When the addition amount of inulin was less than 5%, the leaked amylose content of SPS mixed with short-chain inulin was significantly lower than that of sample blended with long-chain inulin at the same addition level (p < .05). When the amount of inulin was 10%, the leaked amylose content of SPS-LI mixes was only 17.23%, which was lower.
than that of SPS-SI (17.45%), while the difference between them was not significant ($p > 0.05$).

### 3.5. Effect of inulin with short and long-chain on the granular size distribution of SPS

As compared with SPS alone, the median diameter size of SPS-inulin mixes treated for 20 min at 95 °C became smaller, and decreased with inulin addition level rose (Table 4). With the increase of inulin amount, the volume fraction in the larger range (>45 μm) of SPS granule dropped and was lower than that of SPS without inulin, while those of the smaller (<45 μm) grew. When inulin addition level was 10%, compared to SPS alone, the volume fraction of the smaller sized particle of SPS blended by inulin with short and long-chain increased by 3.16% and 5.26%, respectively (Figure 6, Table 4). These results suggested that the swelling of SPS granules could be inhibited by inulin, and its granules was mostly concentrated in the smaller ones. A similar result was reported by Zhang et al. (2019).

In addition, the median diameter size of SPS-SI was slightly lower than that of SPS-LI when the addition amount of inulin was smaller (<5%), while it was higher than that of SPS-LI when inulin addition level was ≥5%.

### 3.6. Interaction force between SPS and inulin molecules

Generally speaking, the interaction such as electrostatic or hydrophobic force, hydrogen bonding may exist in the non-starch hydrocolloids-starch blended system (Zhang et al., 2019). Sodium chloride (NaCl) mainly influences the electrostatic force in the blended system, and thiourea mainly destroys the action of hydrogen bond (Li, 2017). The G’ of SPS-inulin mixes decreased slightly in NaCl solution, which indicated that it was not electrostatic interaction between inulin and SPS. While, the G’ values of SPS-inulin mixes gel decreased remarkably in thiourea solution. These results suggested that the hydrogen bond was the main interaction force between inulin and SPS. Similar results were found by Li (2017), and Zhang et al. (2019). Additionally, it could be seen from Figure 7 that the gel of SPS-LI was more susceptible to thiourea than that of SPS-SI.

### 3.7. Infrared spectroscopy analysis of SPS replaced by inulin with short and long-chain

The infrared spectra of SPS replaced by inulin with different chain-length were detected in the range of 4000 cm$^{-1}$.
and 400 cm\(^{-1}\), and the results are presented in Figure 8 and Table 5. The peak band at about 3700 cm\(^{-1}\) was related to –OH stretching, which suggested that free OH group existed in the system of SPS partially replaced by inulin. Additionally, at about 3700 cm\(^{-1}\), the peak intensity of SPS-SI was slightly higher than that of SPS-LI, which might be due to the more hydrogen bonds and the stronger hygroscopicity of short-chain inulin (Li, 2017). The peak band at about 3200 cm\(^{-1}\) was attributed to the associative-OH stretching (Li, 2017). This band of SPS
shifted to lower wave number (3200 cm$^{-1}$) after being blended with inulin, which reflected that the hydrogen bond between starch and inulin was strengthened. The hydroxyl stretching vibration band of SPS alone was 3338.67 cm$^{-1}$, while the band of SPS replaced by inulin with short and long-chain was 3330.95 and 3334.81 cm$^{-1}$, respectively. This indicated that the shorter chain-length of inulin was, the stronger the hydrogen bond between inulin and SPS molecules was. Similar result was obtained by Li (2017). Additionally, as shown in Figure 8, compared to SPS alone, there were no new absorption peak bands observed in SPS-inulin mixes.

3.8. Possible influence mechanism of inulin on pasting of SPS

Based on the results obtained in this paper and related published articles, the possible influence mechanism of inulin on pasting of SPS was depicted in the form of schematic diagram (Figure 9).

Inulin, a fructan-type polysaccharide with linear molecular structure, has higher water retention ability, better texture properties of gel, and lower viscosity (Gao et al., 2016; Karimi et al., 2015; Paola & Sancho, 2018). After being blended with SPS and water, inulin could competitively absorb water with
Table 5. Effect of inulin with short and long-chain on absorption peak of SPS.

| Sample          | 1 -OH stretching vibration | 2 O−H Associated stretching vibration | 3 C−H Stretching vibration | 4 -COO- Bending vibration | 5 C−O/C−C Stretching vibration | 6 C−H Bending vibration |
|-----------------|-----------------------------|--------------------------------------|-----------------------------|----------------------------|--------------------------------|--------------------------|
| SPS             | –                           | 3338.67                              | 2927.84                     | 1652.94                    | 1157.25                        | 1020.31                  |
| SPS-SI-2.5      | 3737.92                     | 3338.67                              | 2927.84                     | 1652.94                    | 1157.25                        | 1026.10                  |
| SI              | 3737.92                     | 3338.67                              | 2927.84                     | 1652.94                    | 1157.25                        | 1028.02                  |
| SPS-LI-2.5      | –                           | 3338.67                              | 2927.84                     | 1652.94                    | 1157.25                        | 1022.24                  |
| LI              | 3741.78                     | 3338.67                              | 2927.84                     | 1652.94                    | 1157.25                        | 1028.02                  |

SPS, sweet potato starch; SI, short-chain inulin; LI, long-chain inulin; SPS-SI-2.5, sweet potato starch substituted by short-chain inulin with the level of 2.5%; SPS-LI-2.5, sweet potato starch substituted by long-chain inulin with the level of 2.5%. Values are means ± standard deviations (n = 3). Different letters in the same column indicate significant differences (p < 0.05).

Figure 9. The schematic diagram demonstrating the potential effect mechanism of inulin on pasting of SPS. SPS, sweet potato starch.
SPS granules during pasting, limited the availability and mobility of water, and reduced the amount of water available for SPS. These resulted in the increase of the gelatinization temperature, and the inhibition of both swelling and leakage of amylose of starch granules (Tables 2 and 4, Figures 5, 6, and 9B2). Although SPS granules could absorb the water from the continuous phase during pasting, the viscosity of SPS-inulin mixes decreased (Table 2), this could be attributed to that, (1) The hygroscopicity of inulin molecules caused that the amylopectin of SPS could not absorb enough water to form a completely viscous substance (Li, 2017); (2) The viscosities of inulin were much lower than those of SPS (Table 2).

Simultaneously, inulin could interact with the leached amylose (Li, 2017), and hinder them to diffuse into the solution. Additionally, some of the leached amylose wrapped on the surface of starch granules (Alamri et al., 2012), and the non-leaking amylose could make the molecules inside starch granule more entangled, these resulted in the inhibition of the unwinding of the amylopectin molecules (Figure 9-C2 and 9-D2). Since most of the hydroxyl groups are outside of its molecule structure, inulin possessed larger hydrogen bonding area, and was easy to get close to the amylose through hydrogen bonding. Therefore, the formed hydrogen bonding distance between inulin and starch was short and their binding force was larger.

Compared with long-chain inulin, short-chain inulin had more hydroxyl groups outside the molecule structure, and exhibited stronger ability of binding water (Luo et al., 2012). Additionally, short-chain inulin was more easily inserted into starch molecule than long-chain inulin during heating, which in turn affected the crystallization structure of SPS. Therefore, short-chain inulin could significantly affect the gelatinization temperature and paste viscosity of SPS than long-chain inulin at a lower addition level (<5.0%) (Table 2). At higher temperature (80–90°C), the compact and highly regular crystal structure of long-chain inulin might be destroyed, resulting in the more hydroxyl groups being exposed, which enhanced its hygroscopicity and water retention ability (Li, 2017; Luo et al., 2017, 2012). Therefore, long-chain inulin could significantly affect the viscosity of SPS than short-chain inulin at higher addition level (≥5%) (Table 2).

4. Conclusion

This paper explored the influences of inulin with different chain-length (short, and long-chain) on pasting, texture and rheological properties of SPS. Compared with SPS without inulin, addition of inulin reduced the peak viscosity, final viscosity, trough viscosity, setback and breakdown of SPS samples, and enhanced the GT. With the increase of inulin content, the hardness of SPS gels showed a downward trend, while both the springiness and resilience of SPS first increased and then declined. The G’ and G” of SPS-SI gel was lower than those of SPS-LI samples at the same addition level. The temperature of G’\text{Max} went up with the increase of inulin addition. SPS without inulin showed the lowest G’\text{Max} temperature, while SPS-LI with 10% inulin addition had the highest G’\text{Max} temperature. At the same addition level, the G’\text{Max} temperature of SPS-LI mixes was higher than that of SPS-SI blends. Inulin could inhibit the swelling ability of SPS granules, and made SPS granules concentrate in the smaller. Inulin could make the content of leached amylose decline significantly (p < .05). The hydrogen bond was the interacting force between SPS and inulin. Generally, inulin with different chain-length affected the pasting, texture, and rheological properties of SPS in varying degrees. These results could provide some scientific basis for the use of inulin in SPS-based foods.

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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