https://doi.org/10.17221/52/2025-CJFS

Understanding the role of *Taraxacum mongolicum* polysaccharide for corn starch gel amelioration: Physicochemical and structural properties

Mei Lu, Yining Dou, Jialing Xu, Yuanyuan Zhang*

College of Agriculture and Forestry Technology, Weifang Engineering Vocational College, Qingzhou, P.R. China

**Corresponding author: xyzxujialing20232024@163.com*

Citation: Lu M., Dou Y., Xu J., Zhang Y. (2026): Understanding the role of *Taraxacum mongolicum* polysaccharide for corn starch gel amelioration: Physicochemical and structural properties. Czech J. Food Sci., 44: 251–263.

Abstract: This paper aims to investigate the effects of *Taraxacum mongolicum* polysaccharides (TMPs) on the pasting, rheological, gel properties, and structural properties of corn starch (CS) by using different methods. The results show that TMPs could markedly enhance the peak, breakdown, and setback viscosities. TMPs-CS gels showed shear-thinning behaviour, and TMPs could effectively improve the viscoelasticity of TMPs-CS gels, and TMPs could enhance the gel strength and hardness of TMPs-CS gels. Moreover, TMPs could enlarge the size and increase water holding capacity of TMPs-CS gels, whereas TMPs could decrease the relative crystallinity of TMPs-CS gels. Furthermore, TMPs could be bound to CS through non covalent interactions by infrared spectroscopy analysis, and TMPs could increase the thermal stability, reduce ΔH values of TMPs-CS gels, and reduce its thermal decomposition temperature. The microstructure of TMPs-CS gels exhibited the honeycomb-like porous structure, and TMPs could enhance the pore size and accelerate the destruction of TMPs-CS gels particles. The findings contribute to expanding the application of polysaccharides in starch-based foods.

Keywords: *Taraxacum mongolicum* polysaccharide; corn starch; properties

Starch is one of the main energy sources in daily life and the main storage form of carbohydrates in plants. Starch is not only used as an important ingredient in food, but also widely used as a thickener, stabiliser, substitute in fat processed foods, and adhesive to improve the stability and texture properties of food (Wang et al. 2023; Zhang et al. 2023). Corn starch (CS) resources are abundant, inexpensive, and readily available. Hence, CS is widely used in dairy products, baked goods, starch-based foods, etc. Unfortunately, natural CS has poor retrogradation and thermal stability, low transparency and resistant starch content, weak shear resistance, and easy to aging. This leads to poor taste and quality of the product (Tu et al. 2023; Zheng et al. 2024). To improve the processing properties of CS, the physical, chemical, and biological methods are currently used to modify the structure and physicochemical properties of natural CS (Dey and Sit 2017; Masina et al. 2017; Thakur et al. 2021). The physical modification method is currently the most economical and environmentally method to modify natural starch. In recent years, adding non-starch polysaccharides

Supported by the Weifang Science and Technology Development Plan Project, No. 2023GX084.

https://doi.org/10.17221/52/2025-CJFS

to natural starch could improve the defects of natural starch (Feng et al. 2024). Xiao et al. (2020) found that polysaccharides from *Tamarindus indica* could inhibit the retrogradation of starch paste, improve the pasting characteristics of starch, and reduce water loss during storage. Ren et al. (2020a) found that *Mesona chinensis* Benth polysaccharide (MCP) could effectively enhance the gel properties of sweet potato starch (SPS) and improve the viscoelasticity, strength and water retention of MCP-SPS gels. Polysaccharides from tamarind seed could improve the processing properties of potato starch and significantly reduced its digestibility (Xie et al. 2021). Adding polysaccharide from *Agaricus bisporus* to glutinous rice flour could affect the decomposition, gel and re-aggregation of starch particles, thus affecting the physicochemical properties of food matrix (Sulieman et al. 2019). Besides, previous reports have confirmed that the addition of non-starch polysaccharides could improve the pasting, rheology, gel, and digestive properties of starch-based products (Ren et al. 2020a, 2020b; Bu et al. 2024).

Taraxacum mongolicum is a perennial herbaceous plant composed of roots, stems, leaves, flowers, and seeds. *T. mongolicum* Hand.-Mazz. has abundant natural resources and strong vitality, which can grow in areas with harsh climate conditions. *T. mongolicum* Hand.-Mazz. is widely planted in northeastern, northern, eastern, and northwestern regions of China. Numerous studies have indicated that *T. mongolicum* Hand.-Mazz. contained various active ingredients, such as polysaccharides, polyphenols, flavonoids, triterpenes, etc. (Li et al. 2022; Yue et al. 2024). Polysaccharides are one of the most important active ingredients in *T. mongolicum* Hand.-Mazz. Increasing studies have indicated that *T. mongolicum* Hand.-Mazz. polysaccharides (TMPs) exhibited various biological activities, such as antioxidant, hypoglycaemic, anti-inflammatory, antibacterial, anti-tumour, immune regulation, regulation of gastrointestinal microbiota, and other activities (Li et al. 2021; Liu et al. 2024). In addition, TMPs, as a high molecular viscosity polysaccharide, show strong thickening and gel properties (Li et al. 2022). Therefore, TMPs can be widely used as a thickener, gelling agent, and emulsifying stabilizer in the fields of food and health products.

The influence of polysaccharides on the processing properties of starch depends on the type, structure, molecular weight, and source of the original starch. The great potential of TMPs in the application of starch-based foods is attributed to their excellent thickening and emulsifying properties. Currently, there are few studies on the effects of TMPs on the physicochemical and structural properties of CS. This article explores the effects of TMPs on the pasting, rheological, gel properties, thermal stability, and microstructure of CS by using techniques, including rapid visco analyser (RVA), rheometer, texture analyser, thermogravimetric analysis (TGA), scanning electron microscopy (SEM), etc. The aim of this paper is to explore the interaction between TMPs and CS, and further reveal the dose-effect relationship of TMPs on the quality formation of CS.

MATERIAL AND METHODS

Materials and reagents. CS [CAS:9005-25-8; 11.7% moisture, 0.39% total liquid, 28.5% amylose, 0.21% ash, 0.3% proteins, 0.08% lipids, and 17 mg·(100 g)$^{-1}$ phosphate; average molecular weight 4.06×10^7 g·mol^{-1}; volume-mean diameter 12.95 μm] with purity of 97% was offered from Fangxin Biotechnology Co., Ltd. (China). *T. mongolicum* Hand.-Mazz. was purchased from Qinhuayuan Biotechnology Co., Ltd (China). TMPs were prepared by ultrasound assisted hot water extraction method described by Xue et al. (2024). TMPs with average molecular weight of 5.49×10^4 Da consisted of mannose (39.85%), galactose (52.61%), xylose (27.14%), and arabinose (10.4%), total sugar (18.95%), and protein (0%) (Xue et al. 2024). The all chemical reagents are analytical grade in this experiment.

Sample preparation. CS (12%, *w/v*)-TMPs (0, 0.05, 0.10, 0.20 and 0.40%, *w/v*) mixtures were used to prepare the CS-TMPs gels. The specific steps are as follows: TMPs solution was obtained through diluting different concentrations of TMPs with distilled water and then stirred thoroughly at room temperature to obtain the sample solution of TMPs. Subsequently, CS was dispersed into TMPs sample solution and then put it in a water bath at 95 °C for 20 min to obtain TMPs-CS gels.

Pasting properties. The RVA (RVA-tech, Baosheng Instrument Email Company, China) was used to analyse the effect of TMPs on the pasting properties of CS. The specific operation and related parameter settings of this experiment are described in reference by Ren et al. (2020a). We choose the RVA standard procedure 1 as the heating and cooling procedure. The pasting temperature (PT), peak viscosity (PV), trough viscosity (TV), final viscosity (FV), breakdown (BD), and setback (SB) were recorded after the experiment.

Rheological measurement. The rheological properties of TMPs-CS gel were measured by Rheometer

https://doi.org/10.17221/52/2025-CJFS

(RH-30, Baosheng Instrument Email Company, China). We transferred the prepared TMPs-CS gels samples to the parallel plate, and let the samples balance for 1 min at 25 °C. All determinations were performed three times in parallel plate.

Steady-state rheology. The steady-state rheology of TMPs-CS gels was measured by using Rheometer, and the shear rate range was 0.01 s^{-1} to 10 s^{-1} at 25 °C. We analysed the relationship between apparent viscosity and shear rate to obtain the steady-state rheological properties of TMPs-CS gels.

Dynamic rheology. The Rheometer (RH-30, Baosheng Instrument Email Company, China) is used to determine the dynamic rheological properties of TMPs-CS gel. The preliminary amplitude scanning test results show that the linear viscoelastic regions of all samples were within the 1% strain range. During the testing process, we obtained numerical values of storage modulus (G') and loss modulus (G") to analyse the dynamic rheological properties of TMPs-CS gels.

Water holding capacity (WHC). WHC was measured according to the method described by Wang et al. (2018). Briefly, TMPs-CS mixtures were placed in a refrigerator at 4 °C for 12 h to form TMPs-CS gels. The supernatant was removed to obtain the residue sample and weighed by analytical balance.

Gel strength. The texture analyser (TA.XTC-18, Baosheng Instrument Email Company, China) was used to determine the gel strength of TMPs-CS. The specific steps of this experiment were described by Ren et al. (2020a) with light modifications. TMPs-CS gels were determined through texture analyser with a 30 kg gravity induction source. The P36R probe was selected, and the TPA test mode was used in this experiment. The sample was compressed twice with a time interval of 5 s. The temperature during the measurement period was 25 °C.

Particle size distribution. The malvern laser light scattering (HNB-5001, Senbei Technology Co., Ltd, China) was used to analyse the particle size distribution of TMPs-CS gels. The specific steps of this experiment were described by Liu et al. (2020) with light modifications. In short, 12% (*w/v*) aqueous suspension of CS (0, 0.05, 0.10, 0.20 and 0.40%, *w/v*) of TMPs were heated in a water bath at 95 °C for 20 min and added enough samples to obtain appropriate masking coefficients.

X-ray Diffraction (XRD). XRD experiments were carried out by using the X-ray diffractometer (SPSR-70, Langshan Scientific Instrument Co., Ltd, China) according to the method described by Ren et al. (2020a) with a light modification. TMPs-CS gels were refrigerated at 4 °C for 24 h and then freeze-dried by using vacuum freeze dryer (BK-FD10S, Chengteng Biotechnology Co., Ltd, China), and then the freeze-dried samples were crushed and sieved through the 200-mesh sieve. The samples (0.5 g) were placed in the groove of the glass slide and compacted with a cover glass. The parameters set for this experiment were as follows: Diverging slit of 1.25°, receiving slit of 0.3 mm, scanning surface range from 2° to 60°, step width of 0.02°, and scanning speed of 1°·min^{-1}. Equation 1 was employed to calculate the relative crystallinity (RC) of TMPs-CS gels (Ren et al. 2020a).

$$RC(\%) = \frac{A_c}{A_c + A_a} \times 100\% \quad (1)$$

Where: A_c – crystallization region area; A_a – amorphous region area.

Fourier transform infrared (FT-IR) spectroscopy. The freeze-dried samples were mixed with KBr in a ratio of 1 : 30 (g/g). The samples were ground into powder in an agate crucible and then pressed into thin sheets. The infrared absorption characteristics were measured by using FT-IR (iS50, Jincheng Scientific Instrument Co., Ltd, China) with the wavelength range of 4 000~400 cm^{-1}.

Thermogravimetric analysis (TGA). The freeze-dried gelatinised samples (10 mg) were placed in the platinum plate of the TGA (JB-TGA-1200, Jiubin Instrument Co., Ltd, China). Under an argon atmosphere of 20.0 mL·min^{-1}, the temperature was raised from 40 °C to 600 °C at a heating rate of 10 °C·min^{-1}. Real time data such as temperature, time, and sample quality were recorded during the experiment.

Differential scanning calorimetry (DSC). In this experiment, TMPs solutions with different concentrations (0, 0.05, 0.10, 0.20 and 0.40%, *w/v*) were prepared. CS (2.5 mg) was accurately weighed into the crucible, and 10 μL MCP with different concentrations (0, 0.05, 0.10, 0.20 and 0.40%, *w/v*) was added to form the CS-TMPs complex system. After sealing, the samples were placed at room temperature for 24 h to balance the solution. DSC was used for measurement, and the parameters were set as follows: heating from 25 °C to 95 °C at a rate of 10 °C·min^{-1}. Gelatinisation data was obtained from samples gelatinization curves by using STARe software (version 18, Mettler Toledo, Switzerland).

Confocal laser scanning microscopy (CLSM). The CLSM (STELLARIS 5 Cryo, Carl Zeiss, Germany) was employed to observe the structure of TMPs-CS gels samples based on the method of Liu et al. (2020)

https://doi.org/10.17221/52/2025-CJFS

Table 1. The effect of different concentrations of TMPs on the pasting parameters of TMPs-CS (*Taraxacum mongolicum* polysaccharides-cornstarch) gels

Samples	*PV* (mPa·s)	*TV* (mPa·s)	*BD* (mPa·s)	*FV* (mPa·s)	*SB* (mPa·s)	*PT* (°C)
0% TMPs-CS	2 730 ± 165^{e}	1 870 ± 100^{e}	900 ± 70^{d}	3 220 ± 160^{e}	1 300 ± 62^{d}	78.15 ± 1.38^{b}
0.05% TMPs-CS	3 350 ± 180^{d}	2 130 ± 130^{d}	1 000 ± 80^{c}	3 580 ± 155^{d}	1 520 ± 58^{c}	82.64 ± 1.57^{a}
0.10% TMPs-CS	3 780 ± 182^{c}	2 390 ± 135^{c}	1 150 ± 78^{b}	3 400 ± 150^{c}	1 670 ± 65^{b}	83.71 ± 1.82^{a}
0.20% TMPs-CS	4 000 ± 185^{b}	2 560 ± 115^{b}	1 210 ± 83^{a}	3 900 ± 170^{b}	1 800 ± 73^{a}	82.22 ± 1.75^{a}
0.40% TMPs-CS	4 300 ± 210^{a}	2 700 ± 100^{a}	1 300 ± 95^{a}	4 120 ± 167^{a}	1 820 ± 60^{a}	83.89 ± 1.66^{a}

$^{a–e}$different letters indicate marked differences ($P < 0.05$); *PV* – peak viscosity; *TV* – trough viscosity; *BD* – breakdown; *FV* – final viscosity; *SB* – setback; *PT* – pasting temperature

with light modifications as follows: CS (12%, *w/v*) was mixed TMPs with different concentrations (0, 0.05, 0.10, 0.20 and 0.40%, *w/v*). Then, 500 µL 0.1% FITC solution was added to the CS suspensions. Subsequently, 300 µL of the above samples were dropped onto a laser confocal dish. The ZEN 2009 software (Zeiss Enhanced Navigation, Germany) was used to collect all the CLSM images.

Scanning electron microscopy (SEM). SEM (SU9000, Hitachi Scientific Instruments Co., Ltd, China) was used to observe the effect of TMPs on the microstructure of TMPs-CS gels under the condition of 5.0 kV. The dried TMPs-CS gels were cut into thin slices, fixed on the sample table, and coated with gold for 2 min. All charts were obtained through XT Microscope Control software (version 17.40, Thermo Fisher Scientific, USA).

RESULTS AND DISCUSSION

Pasting properties analysis. Starch pasting refers to the process in which starch particles interact with water molecules in water, leading to particle expansion, crystal structure disintegration or disruption, and linear starch dissolution (Chen et al. 2022). RVA is employed to study the effect of TMPs with different concentrations on the pasting properties of TMPs-CS gels. Figure 1 exhibits the pasting curve of TMPs-CS gels, and Table 1 lists the pasting parameters of TMPs-CS gels. Numerous studies have confirmed that TMPs could compete with starch granules for water, thus improving the PT values of TMPs-CS gels (Lopez-Silva et al. 2022; Li et al. 2023). PT values of TMPs-CS gels gradually increased with increasing of TMPs concentrations. This might be due to the intensified competition for water molecules between TMPs and CS, which in turn led to a decrease in the activity of water molecules (Ren et al. 2020a). Besides, the hydrogen bonds formed between water molecules and CS decreased, and the swelling of CS was inhibited, ultimately leading to an increase in PT values (Xiao et al. 2020).

PV is the maximum viscosity that starch can achieve during pasting and before cooling. The origi-

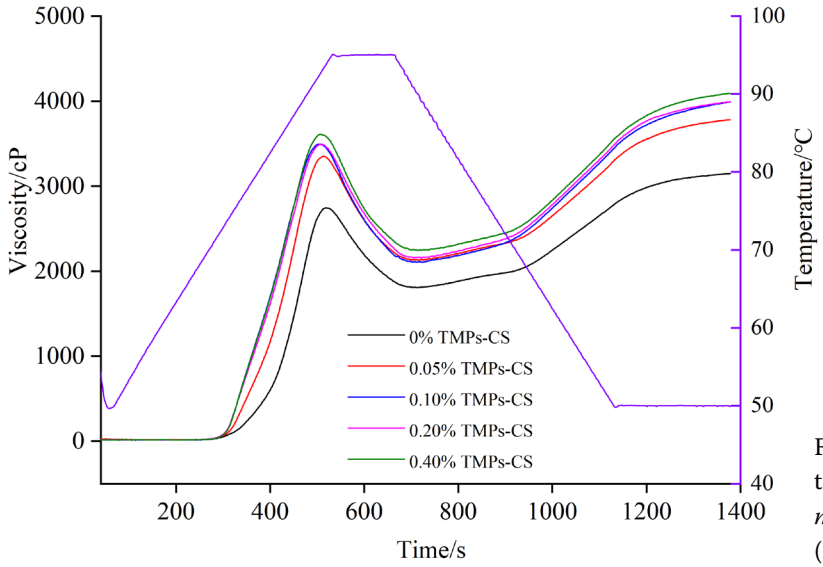

Figure 1. The influence of TMPs on the pasting properties of *Taraxacum mongolicum* polysaccharides-cornstarch (TMPs-CS) gels

https://doi.org/10.17221/52/2025-CJFS

nal CS without added TMPs showed the lowest PV value (2 730 ± 165 mPa·s). PV value increased to 4 300 ± 210 mPa·s after adding TMPs (0.40%). This phenomenon was attributed to the fact that TMPs molecules interacted with CS particles, and the addition of TMPs also exhibited a good thickening effect, which improved the PV values of CS (Wang et al. 2022). In addition, TMPs could increase the swelling volume of CS particles during the pasting process, thereby increasing the PV values of CS (Gao et al. 2021). The results exhibit that the addition of TMPs increased markedly the PV values of CS ($P < 0.05$).

The BD value is an indicator of the thermal and shear stability of starch granules. A higher disintegration value indicates a more significant degree of particle breakage during starch pasting. The addition of TMPs could increase the BD value of CS in a concentration dependent manner. After adding TMPs (0.40%), the BD value of CS increased from the original 900 ± 70 mPa·s to 1 300 ± 95 mPa·s, implying that TMPs affect the expansion and rupture of CS.

The SB value indicates the short-term retrogradation behaviour of starch as well as the molecular reorganisation of linear starch components. The SB value of CS increased to 1 800 ± 60 mPa·s after adding TMPs (0.40%), further implying that the elevating concentration of TMPs is beneficial for improving the SB values of CS and promoting its regeneration. Moreover, TMPs could also markedly increase the TV and FV values of CS ($P < 0.05$). These findings were consistent with the results of Ma et al. (2019) that the addition of konjac glucomannan could increase the TV and FV values of CS.

Steady state rheological analysis. Figure 2A exhibits the change of apparent viscosity of TMPs-CS gels with shear rate. The apparent viscosity of TMPs-CS gels reduced with increasing of shear rate, implying that TMPs-CS gels exhibit shear thinning behaviour and belong to pseudoplastic fluid. The apparent viscosity of TMPs-CS gels increased with the increase of TMPs concentrations. The results were consistent with the conclusion of pasting properties, which might be attributed to the enhanced interaction between CS and TMPs in the gel process, thereby increasing the apparent viscosity of TMPs-CS gels (Huang et al. 2022). In addition, TMPs themselves showed good thickening properties. Hence, adding TMPs can increase the apparent viscosity of TMPs-CS gels. Moreover, TMPs could also wrap around the surface of CS particles and increase the apparent viscosity of TMPs-CS gels system during the compounding process.

Dynamic rheological analysis. The change of modulus can be used as an important indicator of starch gel degree. The rheometer was employed to analyse the dynamic rheological properties of TMPs-CS gels. Figures 2B and 2C exhibit the curve of G' and G" of TMPs-CS gels as a function of angular frequency. The values of G' were always higher than the values of G" in the whole angular frequency range, indicating that the TMPs-CS gels show typical solid like behaviour (weak gel). The G' and G" values of TMPs-CS gels increased with increasing of angular frequency, suggesting that there is an obvious frequency dependence and strong interaction between CS and TMPs. Moreover, the G' and G" values of TMPs-CS gel samples increased with the increase of TMPs concentrations. This was mainly because TMPs could form a relatively stable gel network on the surface of CS particles, improve the gel structure, and enhance the viscoelastic and rheological properties of the mixed gel system (Gao et al. 2021; Wang et al. 2022). Besides, TMPs had good gelling properties, which were conducive to the formation of more molecular connection regions and strengthening of network structures, thereby improving the rheological properties of the mixed gels system. These results were consistent with the results of Chen et al. (2014) exploring the dynamic rheological properties of rice starch-pullulan polysaccharide gel.

WHC analysis. WHC, as an important characteristic parameter of starch gels system, can be reflected by the water evolution of gel. Figure 3A shows the ef-

Table 2. The influence of different concentrations of TMPs on the gel characteristic parameters of TMPs-CS (*Taraxacum mongolicum* polysaccharides-cornstarch)

Samples	Gel strength (g)	Hardness (g)	Springiness (g)	Chewiness (g)	Gumminess (g)
0% TMPs-CS	23.35 ± 0.38^{e}	78.16 ± 1.50^{e}	0.67 ± 0.006^{d}	68.48 ± 1.02^{d}	72.13 ± 1.12^{e}
0.05% TMPs-CS	28.79 ± 0.25^{d}	85.98 ± 3.52^{d}	0.74 ± 0.007^{c}	72.59 ± 1.12^{d}	79.62 ± 1.80^{d}
0.10% TMPs-CS	32.18 ± 0.41^{c}	96.01 ± 2.83^{c}	0.85 ± 0.008^{b}	84.30 ± 0.98^{c}	85.51 ± 2.18^{c}
0.20% TMPs-CS	36.92 ± 0.22^{b}	109.94 ± 2.11^{b}	0.94 ± 0.009^{a}	92.16 ± 1.20^{b}	93.35 ± 1.67^{b}
0.40% TMPs-CS	39.88 ± 0.31^{a}	113.72 ± 2.85^{a}	0.99 ± 0.008^{a}	107.93 ± 2.39^{a}	105.48 ± 2.44^{a}

$^{a–e}$different letters indicate marked differences ($P < 0.05$)

https://doi.org/10.17221/52/2025-CJFS

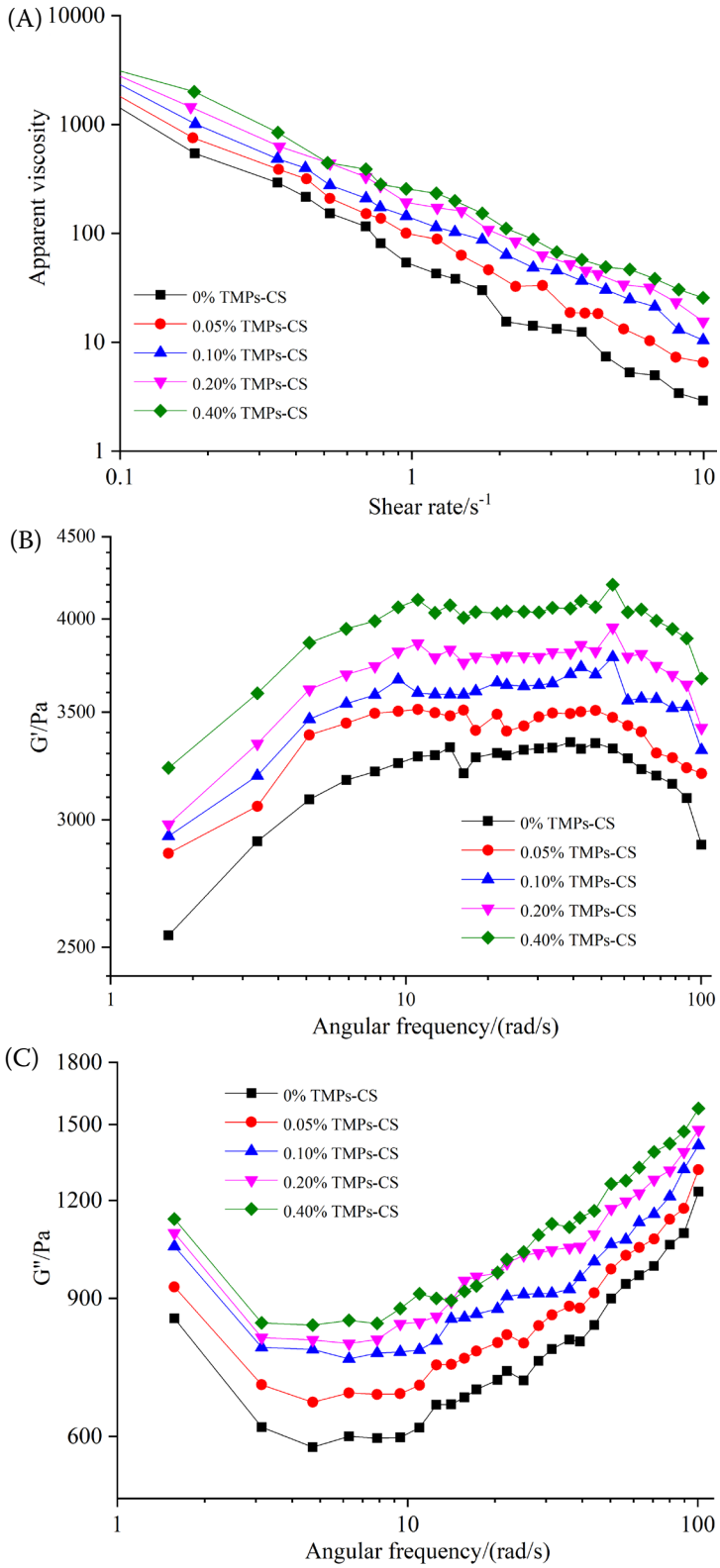

Figure 2. Rheological properties of *Taraxacum mongolicum* polysaccharides-cornstarch (TMPs-CS) gels

(A) Effect of different shear rates on the apparent rate of TMPs-CS gels; (B) G' change at different angular frequencies; (C) G" change at different angular frequencies

fect of TMPs with the different concentrations on the syneresis rate of TMPs-CS gels. The syneresis rate of TMPs-CS gels decreased significantly with the increase of TMPs concentrations (Figure 3A). The syneresis rate of the blank control group (0% TMPs-CS gel) after centrifugation was 22.19 ± 0.35%. The syneresis rate of TMPs-CS gel was 1.02 ± 0.11% when 0.40% TMPs were added, implying that TMPs can improve

https://doi.org/10.17221/52/2025-CJFS

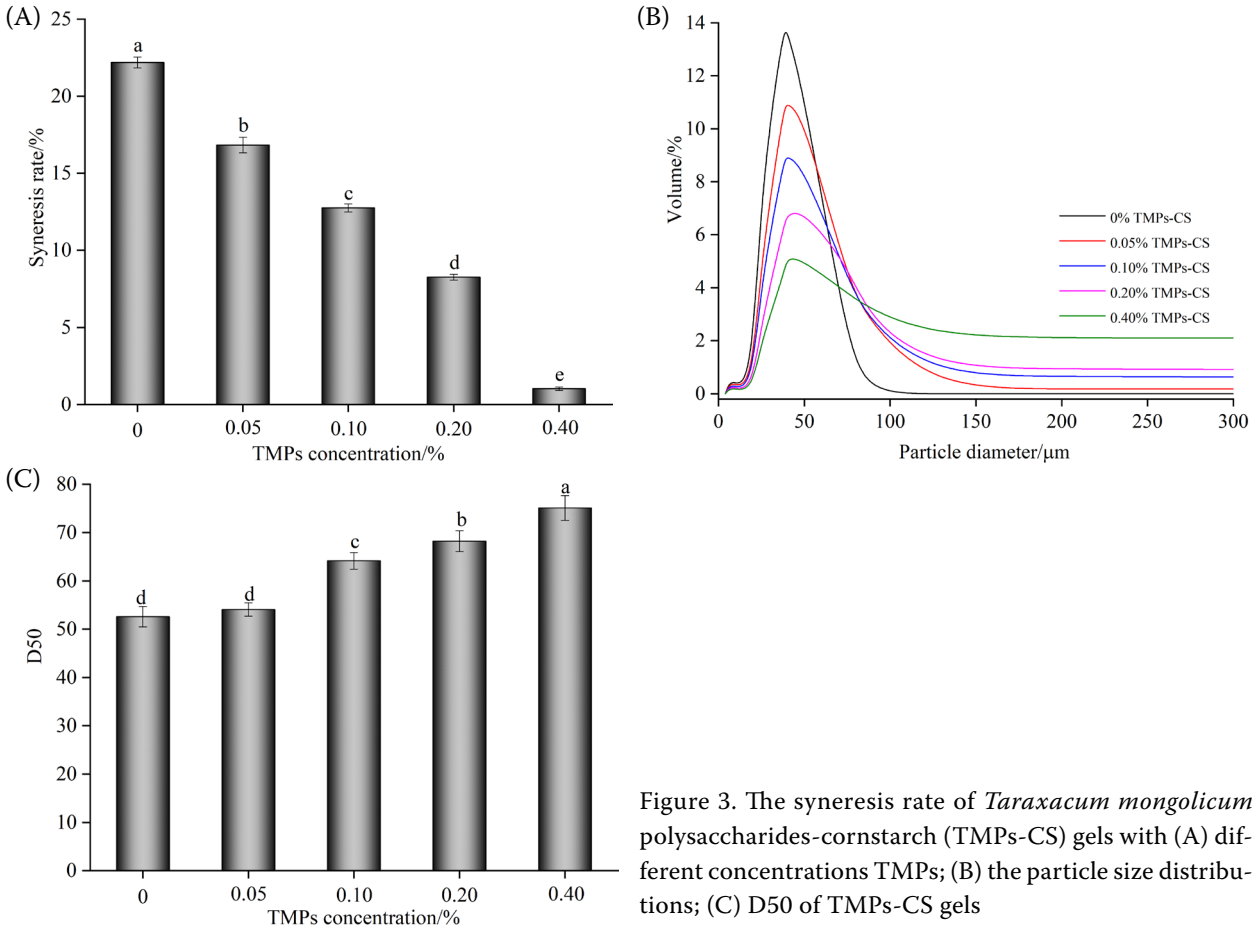

Figure 3. The syneresis rate of *Taraxacum mongolicum* polysaccharides-cornstarch (TMPs-CS) gels with (A) different concentrations TMPs; (B) the particle size distributions; (C) D50 of TMPs-CS gels

WHC of starch based gels. These results were observed in the guar gum/xanthan starch system (Nawab et al. 2016).

Gel strength analysis. Hardness and gel strength, as important evaluation indicators of food gel properties, are mainly employed to reflect the physical properties of food. Table 2 shows the effects of TMPs on the gel characteristic parameters of TMPs-CS. The gel strength of TMPs-CS gels markedly enhanced with increasing of TMPs concentrations ($P < 0.05$). Similarly, the change trend of the hardness of TMPs-CS gels was consistent with that of its gel strength. This phenomenon was not only related to the interaction between TMPs and CS particles, but also to the short-term retrogradation of CS and the re-binding between amylose molecules (Gao et al. 2021). Moreover, the springiness, chewiness, and gumminess values of TMPs-CS gels increased with increasing of TMPs concentration, implying that the adding TMPs improve gel properties of TMPs-CS.

Particle size distribution. The particle size distribution can significantly affect the functional properties of starch particles. Hence, the particle size distribution of TMPs-CS gels was measured by laser particle size analyser to clarify the effect of TMPs on CS particle size in this study. Figure 3C shows that the particle size distribution of TMPs-CS gels had changed markedly with the addition of TMPs. The particle size of CS particles was mainly distributed in the range of 20 μm to 180 μm (Figure 3B). Low concentration (0.05%) TMPs added to CS did not show significant changes in CS particle size ($P > 0.05$), while high concentration (0.10%, 0.20%, 0.40%) TMPs added to CS dramatically increased CS particle size ($P < 0.05$). This phenomenon was mainly attributed to the high concentration of TMPs wrapping around the surface of CS particle to increase its size (Ren et al. 2020a). D50 is an important parameter for measuring the size distribution of CS particle. Figure 3C shows the D50 value of TMPs-CS gels. The D50 values of TMPs-CS gels increased significantly with the increase of TMPs concentration (0.10%, 0.20%, 0.40%). These results were consistent with the particle size distribution of the sweet potato starch gels treated by polysaccharides from *Mesona chinensis* Benth (Ren et al. 2020a).

https://doi.org/10.17221/52/2025-CJFS

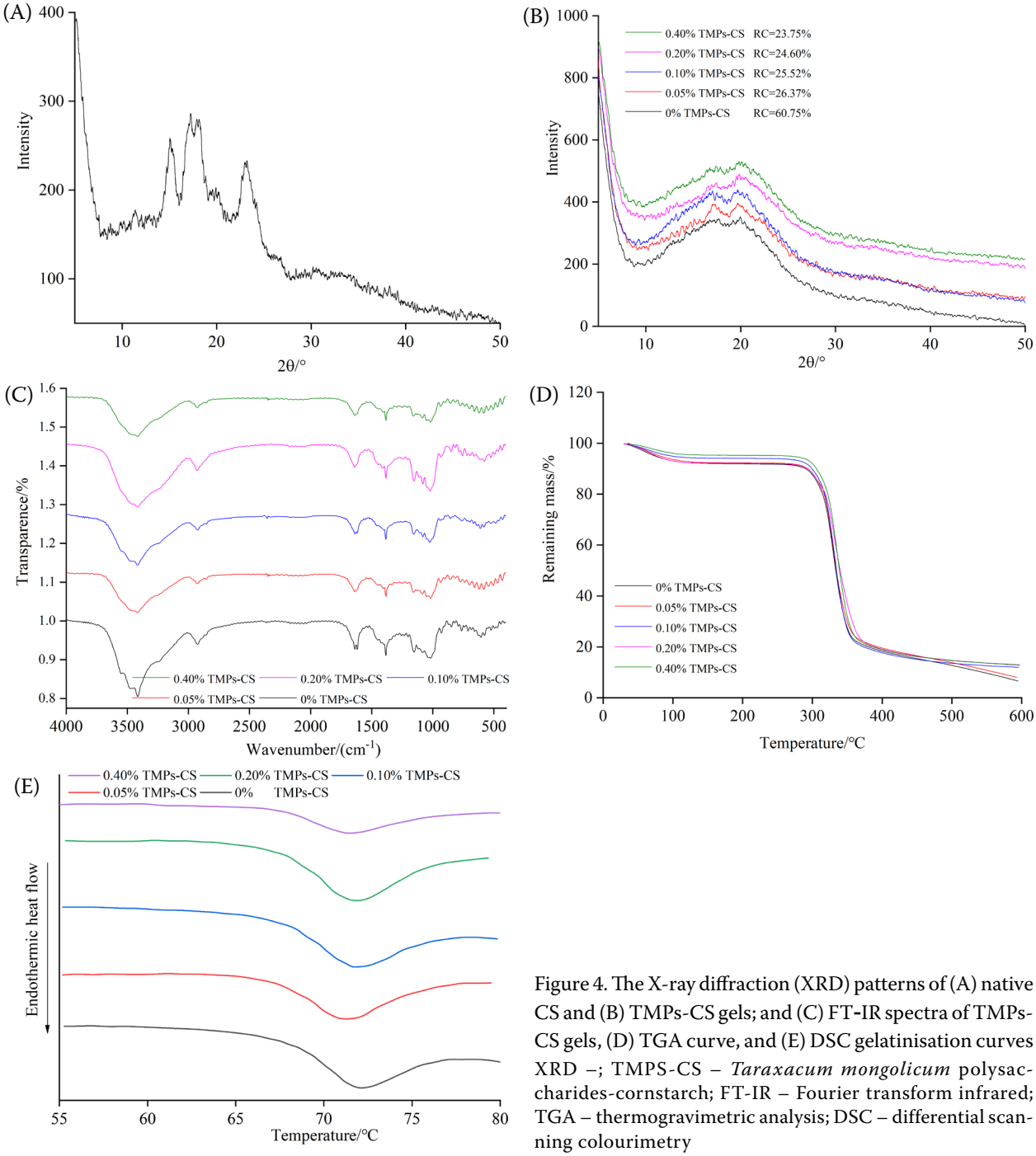

Figure 4. The X-ray diffraction (XRD) patterns of (A) native CS and (B) TMPs-CS gels; and (C) FT-IR spectra of TMPs-CS gels, (D) TGA curve, and (E) DSC gelatinisation curves
XRD –; TMPS-CS – *Taraxacum mongolicum* polysaccharides-cornstarch; FT-IR – Fourier transform infrared; TGA – thermogravimetric analysis; DSC – differential scanning colourimetry

XRD analysis. XRD is an effective method for characterising the crystal structure of starch (Huang et al. 2016). Figure 4A shows the crystal structure of native CS, and Figure 4B exhibits the influence of TMPs on the crystal structure of TMPs-CS gels. The diffraction angles of CS before gelatinisation exhibited characteristic single peaks at 15.2° and 23.1°, respectively (Figure 4A). Moreover, there are characteristic bimodal peaks between 17° and 18°, respectively (Figure 4A). Furthermore, there was a weak diffraction peak at approximately 20°, proving that natural CS is a typical A and V types starch crystal. This structure was related to the complex of single helix or linear glucan with endogenous lipids. Figure 4B shows that the gelatinised CS lose its natural A and V types XRD patterns. Compared with the control group (0% TMPs-CS gel), adding TMPs could more effectively affect the crystal type of TMPs-CS gels, and also change their RC. Adding TMPs could

https://doi.org/10.17221/52/2025-CJFS

significantly reduce the RC of TMPs-CS gels samples ($P < 0.05$), implying that the addition of TMPs can seriously damage CS particles and the crystalline region of CS. TMPs with different concentrations had no significant effect on the RC of TMPs-CS gels ($P > 0.05$), indicating that the effect of TMPs on the crystal structure of TMPs-CS gels is not directly correlated with TMPs concentration.

FT-IR analysis. The infrared spectroscopy (FT-IR) of starch can be used to analyse its molecular structure characteristics, mainly including the following typical absorption peaks: O-H stretching vibration, C-H stretching vibration, and fingerprint region characteristics (Wang et al. 2018). Figure 4C exhibits the FT-IR spectra of TMPs-CS gels. Compared with the control group (0% TMPs-CS gel), no new peak appeared in the infrared spectra of the TMPs-CS gels samples, implying that the binding of TMPs and CS is through non-covalent interactions (Xiao et al. 2020).

The TMPs-CS gel samples showed obvious absorption peaks in both the 3 458 cm^{-1} and 1 613 cm^{-1} regions. These two absorption peaks were mainly related to the O-H tensile vibration and O-H bending vibration in the amorphous region of CS (Wang et al. 2023; Zheng et al. 2024). The hydroxyl absorption band showed red-shift and the peak shape widens with the increase of TMPs concentration. A previous study has indicated that there were intermolecular hydrogen bonds between amylose and pullulan polysaccharides, further suggesting that the main force between CS and TMPs is the hydrogen bond interaction (Gao et al. 2021). The TMPs-CS gels samples showed an absorption peak at 2 934 cm^{-1}. This absorption peak was caused by the stretching vibration of the C-H group (Wang et al. 2022). In addition, the TMPs-CS gels showed a characteristic peak at 1 650 cm^{-1}, which was attributed to the O-H bending vibration of water molecules in the composite system samples (Xue et al. 2023; Wang et al. 2023). Compared with the control group (0% TMPs-CS gel), adding 0.40% TMPs made the TMPs-CS gels sample peaks wider and stronger. However, no new peak of TMPs-CS gels was detected in the infrared spectrum, indicating that there is no covalent interaction between TMPs and CS.

TGA analysis. TGA is employed to measure the thermal degradation performance of TMPs-CS gels. Figure 4D shows the TGA curve of TMPs-CS gels as a function of temperature. The thermogravimetric curve shows three decomposition stages with the increase of temperature (Figure 4D). The first stage was caused by the loss of moisture and volatile substances in the TMPs-CS gels at around 100 °C. In the second stage, the TMPs-CS gels samples experienced obvious weight loss at around 300–340 °C, which was mainly attributed to the thermal decomposition of TMPs and CS. In the third stage, the weight loss of TMPs-CS gels samples was mainly due to the degradation of glycosidic bonds and the further decomposition of some polymer fragments in the range of 400–550 °C (Liu et al. 2020). TMPs could improve the thermal stability of TMPs-CS gels samples and delay its thermal decomposition temperature. In addition, the residual weight of TMPs-CS gels samples system gradually enhanced with increasing of TMPs concentrations, further indicating that the thermal stability of TMPs-CS gels system increases with the increase of TMPs concentration.

DSC analysis. Figure 4E shows that all TMPs-CS gels samples presented a single heat absorption peak, which was the gelatinisation of CS particles and the destruction of crystal structure. The addition of TMPs could markedly increase the initial gelatinisation temperature (T_0), gelatinisation peak temperature (T_p), and final gelatinisation temperature (T_c) of CS (Table 3, $P < 0.05$), implying that TMPs can delay gelatinisation of TMPs-CS gels. This was mainly due to the fact that TMPs and CS competed for water molecules, reduced the activity of the water molecules, hindered water molecules to enter the CS particles, reduced the number of hydrogen bonds formed be-

Table 3. The thermal transition parameters of TMPs-CS (*Taraxacum mongolicum* polysaccharides-cornstarch) mixtures

Samples	T_0 (°C)	T_p (°C)	T_c (°C)	ΔH ($J \cdot g^{-1}$)
0% TMPs-CS	65.15 ± 0.38^{e}	68.39 ± 0.50^{e}	73.08 ± 0.19^{e}	11.43 ± 0.35^{a}
0.05% TMPs-CS	67.03 ± 0.47^{d}	70.05 ± 0.52^{d}	74.69 ± 0.26^{d}	10.24 ± 0.41^{b}
0.10% TMPs-CS	68.81 ± 0.41^{c}	71.18 ± 0.42^{c}	75.83 ± 0.39^{c}	9.11 ± 0.40^{c}
0.20% TMPs-CS	69.91 ± 0.62^{b}	72.89 ± 0.51^{b}	76.92 ± 0.27^{b}	8.35 ± 0.26^{d}
0.40% TMPs-CS	72.03 ± 0.51^{a}	74.05 ± 0.31^{a}	78.53 ± 0.31^{a}	7.39 ± 0.18^{e}

$^{a–e}$different letters indicate marked differences ($P < 0.05$); T_0 – initial gelatinisation temperature; T_p – gelatinisation peak temperature; T_c – final gelatinisation temperature; ΔH – gelatinisation enthalpy

https://doi.org/10.17221/52/2025-CJFS

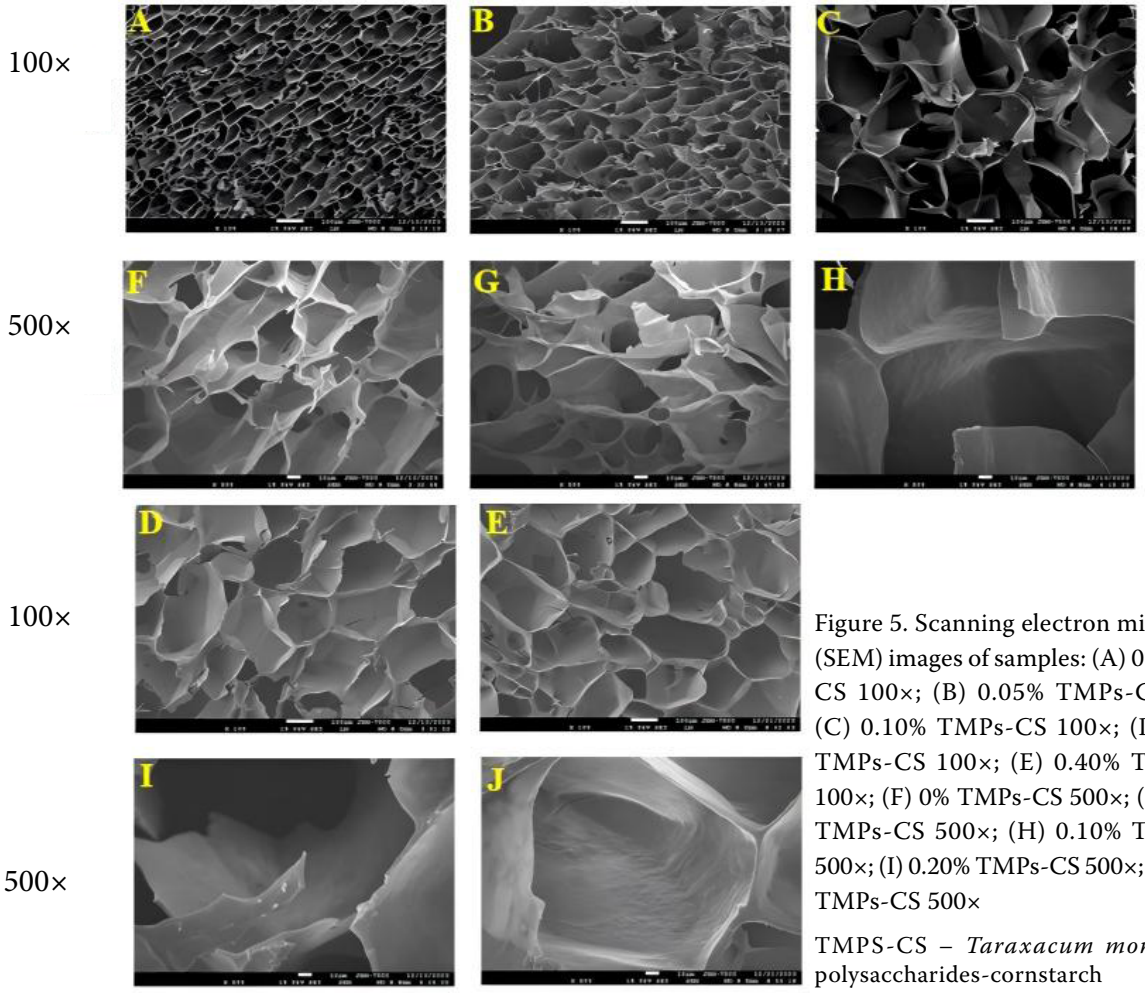

Figure 5. Scanning electron microscopy (SEM) images of samples: (A) 0% TMPs-CS 100×; (B) 0.05% TMPs-CS 100×; (C) 0.10% TMPs-CS 100×; (D) 0.20% TMPs-CS 100×; (E) 0.40% TMPs-CS 100×; (F) 0% TMPs-CS 500×; (G) 0.05% TMPs-CS 500×; (H) 0.10% TMPs-CS 500×; (I) 0.20% TMPs-CS 500×; (J) 0.40% TMPs-CS 500×

TMPS-CS – *Taraxacum mongolicum* polysaccharides-cornstarch

tween water and CS, and inhibited CS swelling, which led to high temperatures required for gelatinisation (Ren et al. 2020a). Gelatinisation enthalpy (ΔH) represents the energy required for gelatinisation of CS, which mainly represents the loss of double helix and the melting of crystal structure. TMPs could significantly reduce the ΔH values of TMPs-CS gels (Table 3). The decrease of ΔH might be attributed to the double helix fracture of the crystalline and amorphous layers of CS particles. Besides, the decrease in ΔH might be due to the gelatinisation of the unstable parts of amylose and amylopectin molecules during the heating process (Ren et al. 2020b).

SEM analysis. Figure 5 exhibits the microstructure of freeze-dried TMPs-CS gels samples at different magnification (100× and 500×). SEM observation showed that the microstructure of TMPs-CS gels was significantly different when TMPs with different concentrations were added TMPs-CS gels. The microstructure of TMPs-CS gels showed a honeycomb-like structure, and their microstructure was similar to those of *Mesona chinensis* Benth polysaccharide-CS gels (Liu et al. 2020) and pullulan polysaccharide-CS gels (Chen et al. 2017).

All TMPs-CS gels samples showed honeycomb-like porous structure. However, their pore size and shape were also different. The microstructure of TMPs (0%)–CS gel showed a small pore size, smooth, and compact. The microstructure of CS paste changed substantially with the increase of TMPs addition. Notably, the pore size and irregular of TMPs-CS gels enhanced with the increase of TMPs concentration. This might be due to the non-covalent interaction between TMPs and CS particles, increasing the repulsive force and the degree of structural irregularity in the MPs-CS gels, thus enhancing the pore size of the gel sample (Ren et al. 2020b). SEM results show that the appropriately increasing the concentrations of TMPs could effectively improve the microstructure of TMPS-CS gel.

CLSM. CLSM is used to study the morphological changes of CS particles after heating and gelatinisation to visually demonstrate the effect of TMPs on the mor-

https://doi.org/10.17221/52/2025-CJFS

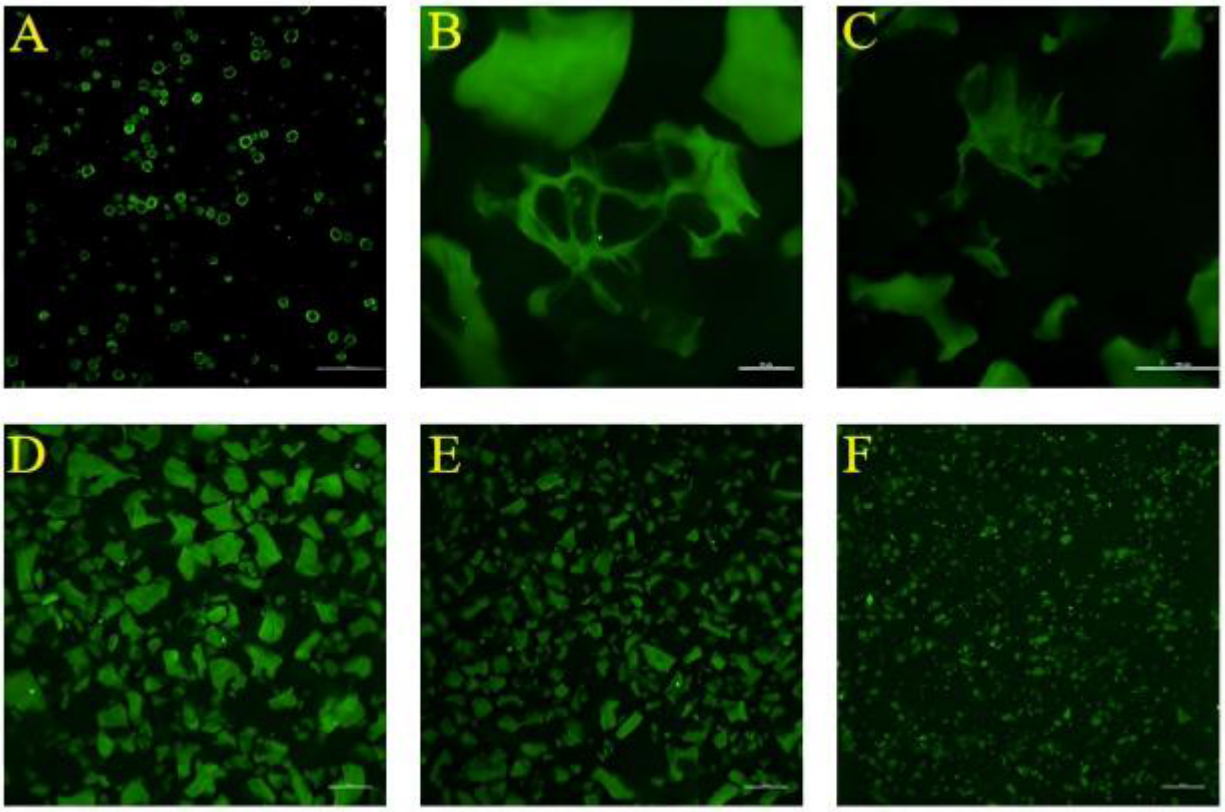

Figure 6. Confocal laser scanning microscopy (CLSM) images of samples: (A) unglued CS; (B) 0% TMPs-CS; (C) 0.05% TMPs-CS; (D) 0.10% TMPs-CS; (E) 0.20% TMPs-CS; (F) 0.40% TMPs-CS

TMPS-CS – *Taraxacum mongolicum* polysaccharides-cornstarch

phology of CS particles. Figure 6 shows that the CS granules without gelatinisation had a distinct shape and were circular or elliptical. After gelatinisation, the morphology of TMPs-CS gels particles was destroyed, which might be due to the rapid gelatinisation of amylopectin in CS, and then lost its original shape (Ren et al. 2020a). Compared with 0%TMPs-CS gel particles, the degree of CS particles structure fragmentation in TMPs-CS gels was more significantly deepened with the increase of TMPs concentration. This phenomenon might be due to the fact that TMPs were wrapped on the surface of TMPs-CS gels, which was conducive to water absorption and swelling of CS particles, accelerating starch gelatinisation and breaking its structure (Liu et al. 2020), implying that TMPs can accelerate the destruction of TMPs-CS gels particles.

CONCLUSION

TMPs could markedly improve the PV, TV, FV, BD, and SB values of TMPs-CS gels. The results of rheological experiments indicate that TMPs-CS gels showed shear-thinning behaviour, and TMPs could improve the viscoelasticity of TMPs-CS gels. Moreover, TMPs could improve gel properties, increase the particle size and water holding capacity of TMPs-CS gels, while TMPs could decrease the relative crystallinity and ΔH values of TMPs-CS gels. TMPs and CS bound through non covalent interactions, and TMPs could improve the thermal stability of TMPs-CS gels and delay its thermal decomposition temperature. The microstructure of TMPs-CS gels showed the honeycomb-like porous structure, and TMPs could increase the pore size and accelerate the destruction of TMPs-CS gels particles, implying that TMPs can improve pasting, rheological, gel, and structural properties of CS. The results can expand the application scope of CS and provide important references for the development of functional CS-based foods.

Acknowledgement. We thank to Dr. Jialing Xu in providing valuable advice on statistical analysis.

REFERENCES

Bu T., Ren Y., Yu Y., Wu W., Zhang Z., Hu W., Lu J., Wang J., Cai M., Yang K., Sun P. (2024): Effect of two different *Flam-*

https://doi.org/10.17221/52/2025-CJFS

mulina velutipes polysaccharides on the physicochemical and digestive properties of rice starch and their interaction mechanisms. Food Bioscience, 59: 104015.

Chen L., Tong Q., Ren F., Zhu G. (2014): Pasting and rheological properties of rice starch as affected by pullulan. International Journal of Biological Macromolecules, 66: 325–331.

Chen L., Tian Y., Tong Q., Zhang Z., Jin Z. (2017): Effect of pullulan on the water distribution, microstructure and textural properties of rice starch gels during cold storage. Food Chemistry, 214: 702–709.

Chen S., Qin L., Chen T., Yu Q., Chen Y., Xiao W., Ji X., Xie J. (2022): Modification of starch by polysaccharides in pasting, rheology, texture and *in vitro* digestion: A review. International Journal of Biological Macromolecules, 207: 81–89.

Dey A., Sit N. (2017): Modification of foxtail millet starch by combining physical, chemical and enzymatic methods. International Journal of Biological Macromolecules, 95: 314–320.

Feng J., Liu S., Sun N., Dong H., Miao L., Wang H., Tong X., Jiang L. (2024): Combining different ionic polysaccharides and pH treatment improved functional properties of soybean protein amyloid fibrils through structural modifications. Food Hydrocolloids, 153: 110027.

Gao J., Zhu L., Huang J., Li L., Yang Y., Xu Y., Wang Y., Wang L. (2021): Effect of dandelion root polysaccharide on the pasting, gelatinization, rheology, structural properties and *in vitro* digestibility of corn starch. Food & Function, 12: 7029–7039.

Huang T.T., Zhou D.N., Jin Z.Y., Xu X.M., Chen H.Q. (2016): Effect of repeated heat-moisture treatments on digestibility, physicochemical and structural properties of sweet potato starch. Food Hydrocolloids, 54: 202–210.

Huang Y., Wu P., Chen X.D. (2022): Mechanistic insights into the influence of flavonoids from dandelion on physicochemical properties and *in vitro* digestibility of cooked potato starch. Food Hydrocolloids, 130: 107714.

Li F., Feng K.L., Yang J.C., He Y.S., Guo H., Wang S.P., Gan R.Y., Wu D.T. (2021): Polysaccharides from dandelion (*Taraxacum mongolicum*) leaves: Insights into innovative drying techniques on their structural characteristics and biological activities. International Journal of Biological Macromolecules, 167: 995–1005.

Li Y., Chen Y., Sun-Waterhouse D. (2022): The potential of dandelion in the fight against gastrointestinal diseases: A review. Journal of Ethnopharmacology, 293: 115272.

Li W., Sun S., Gu Z., Cheng L., Li Z., Li C., Hong Y. (2023): Effect of protein on the gelatinization behavior and digestibility of corn flour with different amylose contents. International Journal of Biological Macromolecules, 249: 125971.

Liu S., Shen M., Xiao Y., Luo Y., Xie J. (2020): Effect of maize, potato, and pea starches with *Mesona chinensis* polysaccharide on pasting, gelatinization properties, granular morphology and digestion. Food Hydrocolloids, 108: 106047.

Liu Y., Shi Y., Zou J., Zhang X., Zhai B., Guo D., Sun J., Luan F. (2024): Extraction, purification, structural features, biological activities, modifications, and applications from *Taraxacum mongolicum* polysaccharides: A review. International Journal of Biological Macromolecules, 259: 129193.

Lopez-Silva M., Agama-Acevedo E., Yee-Madeira H., Bello-Perez L.A., Alvarez-Ramirez J. (2022): Effect of gelatinization degree on emulsification capacity of corn starch esterified with octenyl succinic acid. Food Chemistry, 375: 131657.

Ma S., Zhu P., Wang M. (2019): Effects of konjac glucomannan on pasting an rheological properties of corn starch. Food Hydrocolloids, 89: 234–240.

Masina N., Choonara Y.E., Kumar P., du Toit L.C., Govender M., Indermun S., Pillay V. (2017): A review of the chemical modification techniques of starch. Carbohydrate Polymers, 157: 1226–1236.

Nawab A., Alam F., Haq M.A., Hasnain A. (2016): Effect of guar and xanthan gums on functional properties of mango (*Mangifera indica*) kernel starch. International Journal of Biological Macromolecules, 93: 630–635.

Ren Y., Jiang L., Wang W., Xiao Y., Liu S., Luo Y., Xie J. (2020a): Effects of *Mesona chinensis* Benth polysaccharide on physicochemical and rheological properties of sweet potato starch and its interactions. Food Hydrocolloids, 99: 105371.

Ren Y., Rong L., Shen M., Liu W., Xiao W., Luo Y., Xie J. (2020b): Interaction between rice starch and *Mesona chinensis* Benth polysaccharide gels: Pasting and gelling properties. Carbohydrate Polymers, 240: 116316.

Sulieman A.A., Zhu K.X., Peng W., Hassan H.A., Obadi M., Siddeeg A., Zhou H.M. (2019): Rheological and quality characteristics of composite gluten-free dough and biscuits supplemented with fermented and unfermented *Agaricus bisporus* polysaccharide flour. Food Chemistry, 271: 193–203.

Thakur Y., Thory R., Sandhu K.S., Kaur M., Sinhmar A., Pathera A.K. (2021): Effect of selected physical and chemical modifications on physicochemical, pasting, and morphological properties of underutilized starch from rice bean (*Vigna umbellata*). Journal of Food Science and Technology, 58: 4785–4794.

Tu J., Adhikari B., Brennan M.A., Cheng P., Bai W., Brennan C.S. (2023): Interactions between sorghum starch and mushroom polysaccharides and their effects on starch gelatinization and digestion. Food Hydrocolloids, 139: 108504.

Wang X., Reddy C.K., Xu B. (2018): A systematic comparative study on morphological, crystallinity, pasting, thermal and

https://doi.org/10.17221/52/2025-CJFS

functional characteristics of starches resources utilized in China. Food Chemistry, 259: 81–88.

Wang L., Zhu L., Gao J., Zhang F., Li L., Yang Y., Xu Y. (2022): Effect of dandelion root polysaccharide on structure, rheology and retrogradation properties of corn starch during storage. International Journal of Food Science and Technology, 57: 6522–6530.

Wang X., Fang J., Cheng L., Gu Z., Hong Y. (2023): Interaction of starch and non-starch polysaccharides in raw potato flour and their effects on thickening stability. International Journal of Biological Macromolecules, 242: 124702.

Xiao Y., Liu S., Shen M., Jiang L., Ren Y., Luo Y., Xie J. (2020): Effect of different *Mesona chinensis* polysaccharides on pasting, gelation, structural properties and *in vitro* digestibility of tapioca starch-mesona chinensis polysaccharides gels. Food Hydrocolloids, 99: 105327.

Xie F., Zhang H., Nie C., Zhao T., Xia Y., Ai L. (2021): Structural characteristics of tamarind seed polysaccharides treated by high-pressure homogenization and their effects on physicochemical properties of corn starch. Carbohydrate Polymers, 262: 117661.

Xue H., Gao Y., Wu L., Cai X., Liao J., Tan J. (2023): Research progress in extraction, purification, structure of fruit and vegetable polysaccharides and their interaction with anthocyanins/starch. Critical Reviews in Food Science and Nutrition, 65: 1235–1260.

Xue H., Nima L., Wang S., Tan J. (2024): Ultrasound assisted hot water extraction of polysaccharides from *Taraxacum mongolicum*: Optimization, purification, structure characterization, and antioxidant activity. Journal of Food Science, 89: 2827–2842.

Yue X., Zhong L., Ye M., Luan Y., Zhang Q., Wang Q. (2024): *Taraxacum mongolicum* polysaccharide promotes white adipocyte browning by regulating miR-134-3p via Akt/GSK-3β signalling. International Journal of Biological Macromolecules, 257: 128296.

Zhang S., Yue M., Yu X., Wang S., Zhang J., Wang C., Ma C. (2023): Interaction between potato starch and barley β-glucan and its influence on starch pasting and gelling properties. International Journal of Biological Macromolecules, 253: 126840.

Zheng J., Wang N., Yang J., You Y., Zhang F., Kan J., Wu L. (2024): New insights into the interaction between bamboo shoot polysaccharides and lotus root starch during gelatinization, retrogradation, and digestion of starch. International Journal of Biological Macromolecules, 254: 127877.

Received: April 1, 2025
Accepted: May 7, 2026
Published online: June 23, 2026