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# The effects of *Mesona chinensis* Benth gum on the pasting, rheological, and microstructure properties of different types of starches

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**A B S T R A C T**

The effect of *Mesona chinensis* Benth gum (MCG) on pasting, rheological and texture properties of different types of starches (tubers, cereals, and beans) were investigated. Pasting results showed that the pasting temperatures (PT) of native cereal and beans starch were higher, and MCG decreased the PT of starch granules by competing water with starch granules for water. MCG increased the peak viscosity and breakdown viscosity of native starches except potato starch, and effectively promoted the short-term retrogradation of all kinds of starches. Rheological results also revealed MCG increased apparent viscosity and dynamic modulus of native starch gels, given that the compacter network structures could be formed after adding MCG. The compacter network structures also contribute to the enhancement of gel strength and hardness, and the decreased spin relaxation time of starch gels. The information provided in this paper could help people to understand the different effects of MCG on the various starch, which had certain significance for starch-MCG product development.

## 1. Introduction

As one of the most important energy sources of human beings, native starches were abundance, cheapness, and degradability, and it was widely distributed in the seeds, stems, and root pieces of plants (Zhang et al., 2018). Native starches had been applied in many food fields, such as food thickener, fat replacer, stabilizer, gelling and water retaining agent (Chen et al., 2014). However, with the ever-increasing of people's demand, the practical application of native starch was limited due to some undesired characteristics, such as retrogradation, thermal instability, water indissolubility, and pH sensitivity (Singh et al., 2017).

Physical, chemical, and enzymatic methods were used to modify starch for better physiochemical properties (Tao et al., 2021). Among modified methods, adding hydrocolloids was considered as a safe, efficient and environmentally friendly way. Singh et al. (2017) revealed that gum arabic increased the rheological properties, and decreased peak viscosity (PV) and setback viscosity (SB) of tapioca starch,. Lin et al. (2021) reported xanthan and konjac gums significantly increased the K value and dynamic moduli (G′, G″), and decreased the hydrolysis

rate of mung bean resistant starch. Liu et al. (2021) suggested that Chinese quince seed gum increased freeze-thaw stability of the gum/tigernut tuber starch blends, and prevented the retrogradation by coating the granules of starch and/or influencing the interactions of the amylose.

*Mesona chinensis* Benth polysaccharide (MCP) was extracted from *Mesona chinensis* Benth herb by hot alkali extraction in laboratory (Lin et al., 2017). In recent years, the modification of native starch by MCP has been widely reported. Xiao et al. (2020) reported that tapioca starch/MCP gels exhibited a higher elasticity modulus (G′) and short-range order, and finer structure than that of native tapioca starch gel, while MCP also improve the digestion properties of tapioca starch. Yuris et al. (2019) revealed that freedom of molecular movement of wheat starch was increased with the addition of MCP using solid-state NMR. Liu et al. (2019) reported that the rheological and textural properties of maize starch -MCP gels could be enhanced with the addition of sodium carbonate.

It was concluded that MCP had significant and positive effect on the gel properties of native starches, though scholars tend to study the gel-

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improving effect of MCP on a single starch. It was worth mentioning that the extraction of MCP was time-consuming, ineffective and expensive, which severely limited the practical application of starch-MCP composite products in food industry (Lin et al., 2017). *Mesona chinensis* Benth gum (MCG) was extracted from *Mesona chinensis* Benth without cumbersome process, which was available in Chinese market. MCG contains neutral polysaccharides and acidic polysaccharides (MCP) and is often used to prepare special snacks with *Mesona* chinensis Benth flavor (Rong, et al., 2021). To our knowledge, the works applied in the effects of MCG on the modification of native starch are limited.

We hypothesized that MCG can effectively affect the gel properties and structural characteristics of various starch with some resource dependence. In this way, the object of this paper was to evaluate the effect of MCG on pasting, rheological properties and microstructure of the starch gels from different resource (tubers, cereal and beans), and discussed the correlation of effects of MCG between different starch resources. The information of this work would further understand the effect and interaction between polysaccharides and starches, expanded the practical applications of starch-MCG composites in food industry.

## 2. Materials and methods

### 2.1. Materials and reagent

Potato starch (PS, amylose content: 32.35%), tapioca starch (TS, amylose content: 18.46%), wheat starch (WS, amylose content: 31.23%), corn starch (CS, amylose content: 22.28%), mung bean starch (MBS, amylose content: 41.79%), hyacinth bean starch (HBS, amylose content: 39.75%) was purchased from Enmiao food Co., Ltd. (Henan, China). MCG were provided by Deliyuan food Co., Ltd (Jiangxi, China), the MCG content was 2.4g per 100g MCG stock solution. All other chemicals and reagents were analytical grade unless stated otherwise.

### 2.2. Sample preparation

Native PS and PS-MCG complex gels were prepared as follows: Firstly, 1.25 g PS (5% w/v) were dispersed into 25 mL distilled water, then the PS solution was mixed with corresponding concentration of MCG solution (0%, 0.3% w/v), which was uniformly dissolved in distilled water beforehand. According to the method of Rong et al. (2021), The mixed solution was held at 50 °C for 1min, and heated to 95 °C within 3.5 min, then kept at 95 °C for 2.5 min, after that cooled to 50 °C in 4 min and subsequently held at 50 °C for 2 min using Rapid Visco-Analyzer (RVA, Newport Scientific, NSW). After that the PS and PS-MCG gels were taken out from aluminums pot, 5 mL gel samples were used to be evaluated its rheological properties, and 3 mL gel samples should be applied in the research of moisture migration properties. Approximate 3 mL gel samples stored at 4 °C for 12 h in a 5 mL beaker for the texture testing. 5 mL prepared gels were freeze-dried for the testing of Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and Scanning electron microscopy (SEM). Other native starch and starch-MCG gels were prepared in the same method.

### 2.3. Pasting properties

The pasting properties of starch-MCG gels were determined using a RVA. The specific measurement was carried out refer to the section of 2.2, and the pasting parameters: peak viscosity (PV, cP), pasting temperature (PT, cP), breakdown viscosity (BD, cP), and setback viscosity (SB, cP) were recorded by the program of document (Wang et al., 2020). All tests were carried out in triplicate.

### 2.4. Measurement of zeta potential

The zeta potential of various native starch and starch-MCG gels were measured referring to the method described by Cai et al. (2011) with

some modification. 0.1% (w/v) of native starch and combinations (starch: MCG was 16:1) were thoroughly gelatinized in a boiling water bath. Then these mixed solutions were respectively transfer to the cuvette after cooling to room temperature, and the zeta potential were measured using Malvern Zetasizer Nano ZS90 (Nano ZS, Malvern Instruments Ltd, Worcestershire, UK). All measurements were carried out three times in parallel.

### 2.5. X-ray diffraction (XRD)

A Bruker AXSX ray diffractometer (Bruker AXS Inc., Germany) was used to evaluate the type and degree of crystalloid according to the method of Zhang and Lim (2021). Native starch granules and freeze-dried gels were examined in the 2θ range of 4°–40° with a scanning rate of 4°/min at 40 kV, 40 mA, and 25 °C. The results were obtained and analyzed by the Jade 6.0 and origin software.

### 2.6. Gel strength

Gel strength and hardness of prepared gels in section 2.2 were determined by the texture analyzer (TAXT plus, Stable Co., England) equipped with a P 0.5 probe (Sun and Yoo, 2015). The prepared gel samples in section 2.2 were held at room temperature for 1h before test, and the parameters of instrument were set as follows: the pre-test speed, test speed and the latter test speed were set at 1.0 mm/s, the test distance was 10 mm, the trigger type was automatic and the trigger force was 5 g. All tests were carried out in triplicate.

### 2.7. Rheological measurements

Strain controlled ARES rheometer (TA Instruments, New Castle, DE, USA), equipped with a parallel plate (40 mm diameter, 0.5 mm gap) was used to assess the steady shear and dynamic rheological properties of prepared gels (Li et al., 2021). The gels prepared in section 2.2 was taken and placed on Peltier plate at 25 °C, and the surplus gels were removed with a spatula. Then all gel samples were stabilized at this temperature for 20 s before any measurements. Steady shear experiments were performed to analyze steady shear rheological properties over the shear rate range of 0.1–100 s$^{-1}$ at 25 °C. The frequency sweep test was performed to analyze dynamic rheological properties over the frequency range from 0.1 Hz to 25 Hz at the 1% strain (within the linear viscoelastic region). All measurements were carried out three times in parallel.

### 2.8. Fourier transform infrared spectroscopy (FTIR)

Fourier transform infrared spectrophotometer (IS50, Nicolet, Madison, WI, USA) was used to measure infrared spectra of samples (Wu et al., 2021). Briefly, all freeze-drying gels were mixed with potassium bromide in a ratio of 1:30, then mixtures were measured after pressed to be a sheet by stainless steel cup. All measurements were carried out three times in parallel.

### 2.9. Low-field nuclear magnetic resonance (LF-NMR)

Moisture migration of the native starch and starch-MCG gels were evaluated using a 23 MHz NMR analyzer (EDUUMR20-015V–I, Niumag Co., Ltd., Suzhou, China) followed the method of Luo et al. (2020). In this experiment, approximate 1 mL gels described in section 2.2 were injected into a sample bottle, then the bottle was put in the instrument, respectively. The echoes number was 1024 in the CPMG, scans number was 8, and the spin echo was 1000–2000 ms in the time domain. The spin-spin relaxation time ($T_2$) were obtained by the Carr-Purcell-Meiboom-Gill (CPMG) sequence.

**Table 1**
The pasting parameters of starch and starch-MCG gels.

| Sources | Samples | PV (cP) | BD (cP) | SB (cP) | PT (°C) |
|---------|---------|---------|---------|---------|---------|
| Tubers | PS | 1956.67 ± 29.26i | 747.67 ± 39.55e | 176.00 ± 11.53c | 70.17 ± 0.03a |
| | PS-MCG | 490.33 ± 11.37g | 31.67 ± 11.93 ab | 1596.33 ± 63.13h | 77.68 ± 0.45de |
| | TS | 399.33 ± 2.89f | 77.00 ± 0.00c | 151.00 ± 2.00bc | 72.68 ± 0.06b |
| | TS-MCG | 2086.67 ± 26.73j | 1655.00 ± 29.82f | 761.33 ± 136.00d | 73.93 ± 0.51c |
| Cereals | WS | 86.00 ± 2.00a | 6.67 ± 0.58a | 80.33 ± 3.06abc | \ |
| | WS-MCG | 174.00 ± 9.17cd | 9.00 ± 1.00a | 893.67 ± 57.95e | \ |
| | CS | 190.67 ± 1.53d | 19.00 ± 0.00 ab | 17.00 ± 1.00a | 94.90 ± 0.26g |
| | CS-MCG | 269.33 ± 5.13e | 39.33 ± 1.53b | 925.67 ± 147.55e | 78.28 ± 0.03ef |
| Beans | MBS | 270.67 ± 4.16e | 4.33 ± 0.58a | 153.67 ± 4.04bc | 80.48 ± 0.92g |
| | MBS-MCG | 528.67 ± 9.45h | 162.00 ± 8.54d | 1294.67 ± 55.41g | 78.57 ± 0.51f |
| | HBS | 111.00 ± 1.73b | 3.33 ± 0.58a | 39.33 ± 0.58 ab | \ |
| | HBS-MCG | 155.67 ± 3.06c | 8.67 ± 3.06a | 1091.67 ± 74.04f | 77.47 ± 0.08d |

Results are presented as mean ± SD in triplicate (n = 3). Same letter indicates no significant differences ($p > 0.05$) within column.

### 2.10. Scanning electron microscopy (SEM)

According to the method of Charoenrein et al. (2011), microstructures of freeze-drying gels were examined by SEM (JEOL Ltd., Akishima, Tokyo, Japan) at an operating voltage of 5.0 kV. The freeze-dried gels were cut into slices and coated with gold, then fixed on the sample stage. The micromorphology of samples was observed under a magnification of 100 times. All images were digitally obtained by using XT Microscope Control software.

### 2.11. Statistical analysis

All data were reported as mean ± SD for triplicate measurement. Significance was evaluated by One-way ANOVA and Duncan's multiple range test ($p < 0.05$). And SPSS 25.0 software was used to analyze statistics while. All figures were disposed by Origin Pro (2018) software (Stat-Ease Inc., Minneapolis, USA).

## 3. Results and discussion

### 3.1. Pasting properties

Starch gelatinization refers to the process of water absorption, expansion and rearrangement of starch particles during heating (Ren et al., 2020). The pasting parameters of native starch and starch-MCG gels were recorded in Table 1, it was mentioning that the PT of WS, HBS and WS-MCG mixtures was not recorded by the instrument since their PT was more than 95 °C. Compared with other starches, tuber starch (PS and TS) had the lowest PT of 70.17 °C and 72.68 °C, which indicated that water absorption ability of tuber starches was stronger than the other starch sources, thereby they didn't need high temperature to gelatinize. The PT of tuber starch significantly increased after the addition of MCG ($p < 0.05$), which was consistent with the study of Chen et al. (2015). The water absorption capacity of tuber starch was stronger, the water competition was formed between starch and hydrophilic MCG molecular, therefore the water activity was influenced and pasting process was delayed (Xiao et al., 2020). Compared with tuber starch, MCG clearly decreased the PT of cereal and bean starch ($p < 0.05$), which could be associated with the increase in effective starch concentration in the continuous phase after the addition of MCG. The interaction between starch granules was enhanced, thereby less thermal energy was needed for pasting (Funami et al., 2005; Gałkowska et al., 2014). Similarly, Funami, et al. (2008) suggested that the PT of WS shifted to lower with the addition of soybean-soluble polysaccharide and gum arabic. Lee et al. (2017) reported that compare with control group, the rice starch-tara gum mixtures were characterized by much lower pasting temperatures.

As shown in Table 1, PS had the highest PV of 1956.67 cP, indicating PS granules expanded to a larger volume than other starches during heating. MCG significantly decreased the PV of PS, and increased the PV of other starches, the difference results could be attributed to the difference of expansion capacity. The PV of native starch was increased with the addition of MCG, because MCG covered on the surface of starch granules like a film during pasting, resulting the increase of expanding volume of starch granules (Ren et al., 2020). Differently, PS inherently had strong water-absorption and expansion capacity in the process of pasting, the water-absorption and expansion capacity were inhibited when MCG covered on the surface of PS granules.

The value of BD was used to evaluate the stability of starch during heating. Compared with native cereal and bean starch, tuber starch exhibited a more stable gelatinization process with a higher BD. The BD started to change with the addition of MCG, MCG significantly decreased the BD of PS, and increased that of other starches (Table 1). The results were consistent with the trend of PV, MCG significantly improved the heating stability of PS by inhibiting its expansion, thereby delaying the rupturing and disintegration of PS granules. Meanwhile, it has been
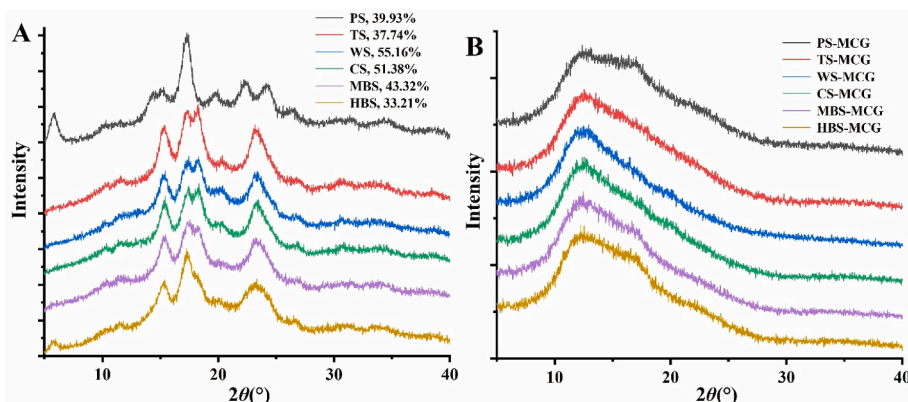


**Fig. 1.** The XRD patterns of starch granules and starch-MCG gels (A) starch granules; (B) starch-MCG gels.

**Table 2**
The texture properties and $T_2$ parameters of starch and starch-MCG gels.

| Sources | Samples | Gel strength (g) | Hardness (g) | 1047/1022 | $T_2$ (ms) |
|---|---|---|---|---|---|
| Tubers | PS | 10.72 ± 2.04a | 14.05 ± 2.46 ab | 0.82 | 1341.65 ± 8.84j |
| | PS-MCG | 27.85 ± 2.9c | 33.96 ± 1.14cd | 0.85 | 197.77 ± 1.36cd |
| | TS | 18.83 ± 4.57b | 24.09 ± 3.03bc | 0.82 | 1257.73 ± 46.12i |
| | TS-MCG | 55.32 ± 2.2f | 68.62 ± 13.23f | 0.85 | 216.71 ± 1.34d |
| Cereals | WS | 6.00 ± 0.51a | 8.01 ± 0.38a | 0.83 | 344.95 ± 13.99e |
| | WS-MCG | 83.44 ± 9.3g | 90.94 ± 12.50g | 0.91 | 148.62 ± 0.20a |
| | CS | 6.42 ± 0.38a | 8.38 ± 0.08a | 0.81 | 551.03 ± 2.25f |
| | CS-MCG | 59.80 ± 2.9f | 70.21 ± 8.48g | 0.91 | 156.80 ± 0.80 ab |
| Beans | MBS | 47.50 ± 3.89e | 53.73 ± 4.37e | 0.86 | 1176.32 ± 6.96h |
| | MBS-MCG | 94.58 ± 5.4h | 105.49 ± 18.93h | 0.89 | 180.99 ± 0.48bc |
| | HBS | 11.75 ± 1.46a | 13.28 ± 0.53 ab | 0.85 | 690.59 ± 6.07g |
| | HBS-MCG | 38.84 ± 3.7d | 39.65 ± 3.75de | 0.91 | 163.32 ± 0.40 ab |

Results are presented as mean ± SD in triplicate (n = 3). Same letter indicates no significant differences ($p > 0.05$) within column.

proved that MCG efficiently increased the PV of other starch by increasing expanding volume, which contributed to the augmenting of surface area under heating, thereby the heating stability was decreased.

SB values was the difference between trough viscosity and final viscosity, which could explain the ability of short-term retrogradation and amylose molecular rearrangement after pasting (Zhang et al., 2018). As shown in Table 1, the native starches have a lower SB value, while

starch-MCG gels exhibited a higher SB after adding MCG, which indicated that MCG effectively promoted short-term rearrangement of released amylose starches. Similar results were obtained in the study of Ren et al. (2020a,b), some interaction could be formed between MCG and amylose starches by hydrogen bond and electrostatic interaction, which had positive effects on the short-term retrogradation of starch gels. The zeta potential was used to evaluated the electrostatic interactions of the starch-MCG system, Table S1 showed that the zeta potential value of complex starch-MCG system was significantly higher than native starch alone ($p < 0.05$), which illustrated that the addition of MCG does enhance the electrostatic interaction of the complex system.

### 3.2. XRD

XRD spectrums of native starches and starch-MCG gels were recorded in the Fig. 1. TS, WS, CS and MBS were typical A-type starch, PS was B-type starch, and HBS was C-type starch, native cereal starch had higher relative crystallinity (RC) than tuber and bean starches (Liu et al., 2020). After gelatinization, the crystalline structures of all samples disappeared, suggesting that gelatinization would destroy the crystalline structure of starch. The results were similar with the study of Liu et al. (2021), who reported that the crystallization of chestnut starch-xanthan gum gel was destructed after gelatinization.

### 3.3. Gel strength

Texture properties were evaluated using gel strength and hardness, Table 2 exhibited most native starches had a lower gel strength ranged from 6.00 to 18.83 g, and hardness ranged from 8.01 to 24.09 g. Differently, the gel strength and hardness of MBS gel were relatively larger than other starches, which could be attributed to its low BD and high SB resulting MBS can be stable in the gelatinization process, and rearrangement after disintegration. As shown in Table 2, MCG significantly increased the gel strength and hardness of all native starch gels ($p$
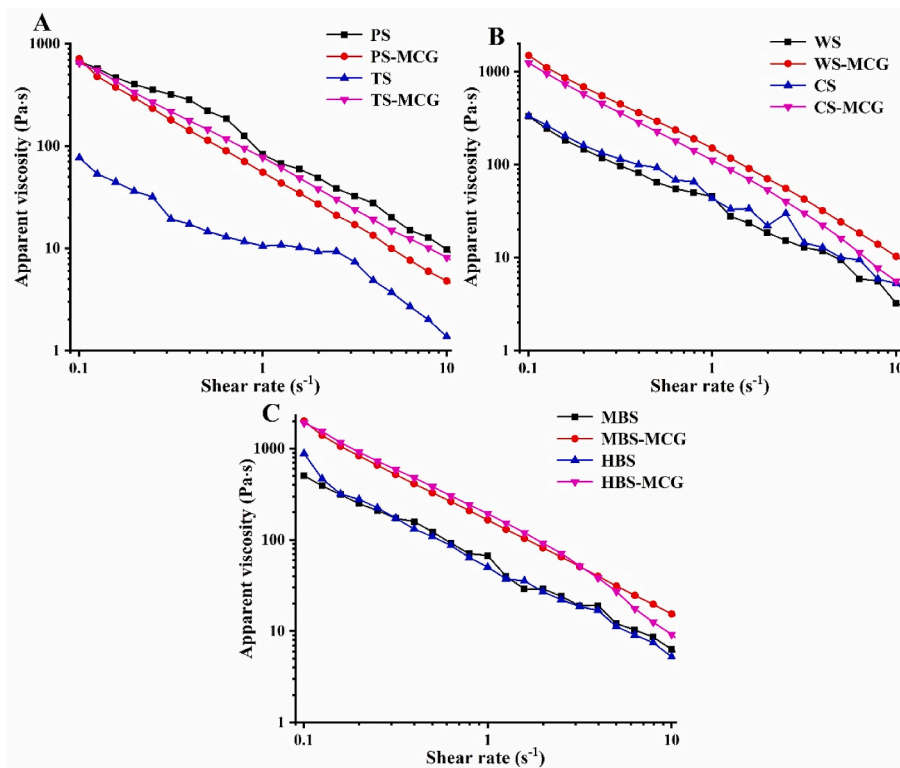


**Fig. 2.** The relationship between apparent viscosity and shear rate. (A) Tuber starch and Tuber starch-MCG gels; (B) Cereal starch and cereal starch-MCG gels; (C) Bean starch and bean starch-MCG gels.
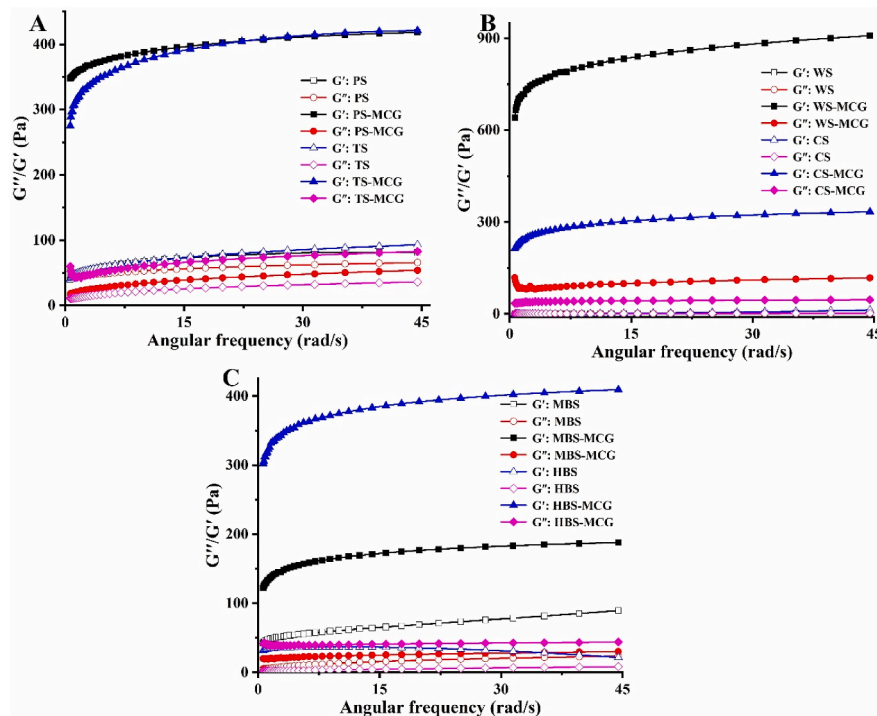
**Fig. 3.** Dynamic viscoelasticity of starch and starch-MCG gels. (A) Tuber starch and Tuber starch-MCG gels; (B) Cereal starch and cereal starch-MCG gels; (C) Bean starch and bean starch-MCG gels.

< 0.05), which could be associated that the short-term retrogradation of starch-MCG gels were promoted with the addition of MCG (Ren et al., 2020). The gel strength of starch gels was closely related to the rearrangement of amylose starch, because the higher the degree of short-term retrogradation, the compacter the network structures of starch gels (Liu et al., 2022). Specifically, the gel strength and hardness of cereal starch increased approximate tenfold after the addition of MCG, and that of tuber and bean starch only increased twofold. The more obvious improvement of MCG on cereal starch could depend on two reasons: on the one hand, compared with tuber and bean starch, the cereal starch had a very low gel strength and hardness with the relatively large growth potential; the amylose content of cereal starch is much higher than tuber starch, which promoting the interaction between amylose and MCG increasing degree of short-term retrogradation.

### 3.4. Rheological properties

Steady shear refers to the flow of a fluid on a plate at a certain shear

rate, and the resistance to flow is the viscosity, and the steady shear rate behaviors of native starch and starch-MCG gels were displayed in Fig. 2. Apparent viscosity of all starch-based gels decreased with the increasing of shear rate, exhibited a shear thinning behavior (the characteristics of pseudoplastic fluid) (Rong et al., 2021b). Similar with the results of PV, the apparent viscosity of PS gel decreased when MCG was added, while the apparent viscosity of other starch gels increased with the addition of MCG.

Fig. 3 exhibited the storage modulus (G′) and loss modulus (G″) of native starch and starch-MCG gels. G′ and G″ of all starch gels increased with the increasing of frequency, and G′ was clearly higher than G″, suggested that all starch-based gels exhibited a solid-like behavior (a typical weak gel), and the viscoelasticity of the gels depended on the angular frequency. G′ and G″ represent the solid-like and liquid-like properties of the starch gel, respectively. It was clear that the dynamic modulus of various native starch was very low, and MCG significantly increased their G′, which suggested that the elastic property of starch-MCG gels was enhanced. The increasing G′ also explained the
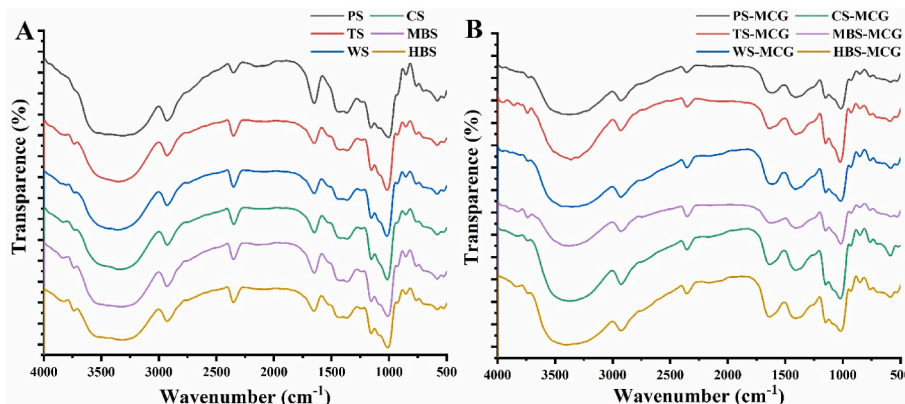


**Fig. 4.** The FTIR curves of native starch and starch-MCG gels. (A) starch; (B) starch-MCG gels.
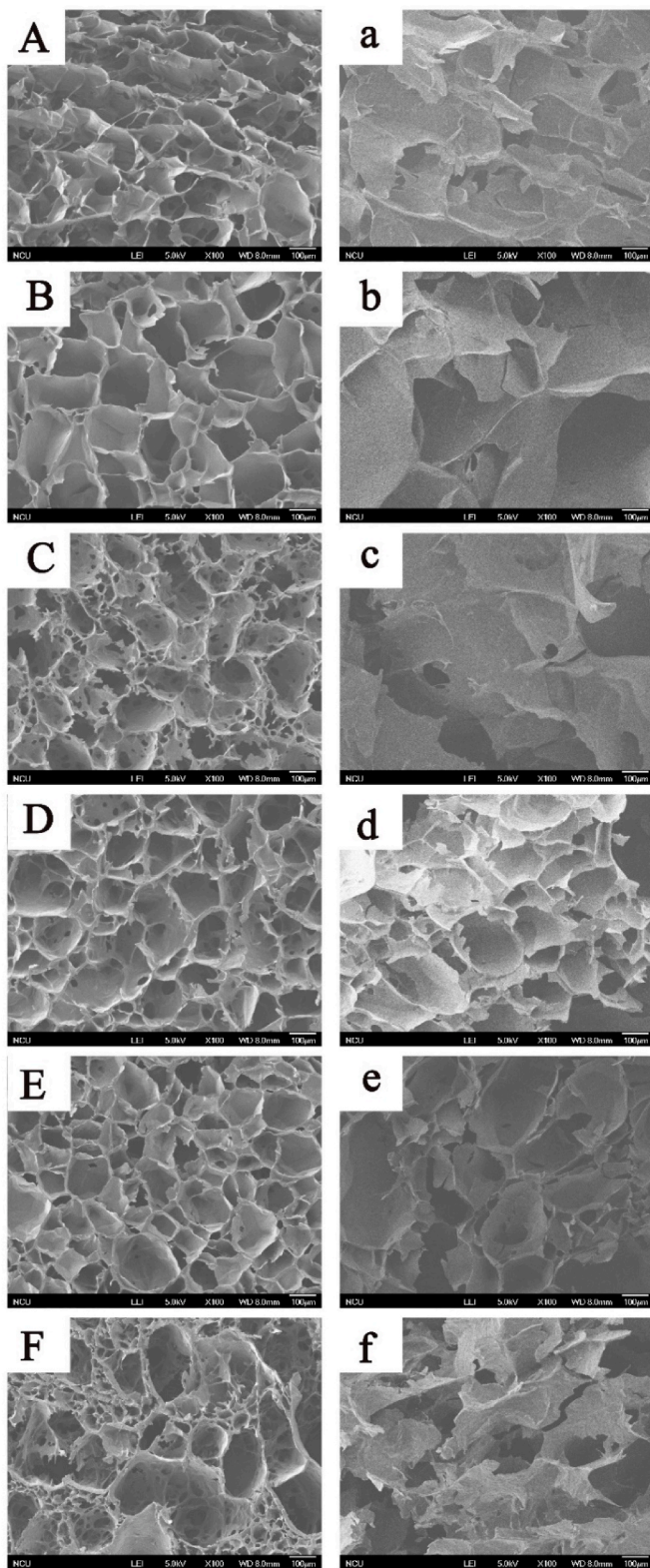
**Fig. 5.** The micrographs of native starch and starch-MCG gels (100 magnification). A → F: native starch gel; a → f: starch-MCG gels.

improvement of gel strength due to the forming of compacter structure.

### 3.5. FTIR

FT-IR spectrums of native starch gel and starch-MCG gels were shown in Fig. 4. Compared with pure starches, there was no covalent bond appeared when MCG existed in the starch gel matrix, given that no new peak and skew peak was observed in the FT-IR spectrums of starch-MCG gels (Anbarani et al., 2021). Furthermore, the band at 3700-3000 cm$^{-1}$ was associated with intermolecular hydrogen bonds and O–H stretching vibrations, and shifted to a higher wavenumber and widened after adding MCG, which confirmed that a stable structure was formed by hydrogen bonding in the starch-MCG matrix. The distinctive spectral features for starch gels were C–O and C–C vibrational modes that are highly coupled from 1300 to 800 cm$^{-1}$, which was sensitive to conformational and crystalline order of starch (Zhang et al., 2013). The ratio of 1047/1022 represented the degree of order (DO), which were obtained after deconvolved gaussian IRF and calculating (Mutungi et al., 2011). Various native starch had a similar DO ranged from 0.81 to 0.86, which indicated there was little difference in the structural order of various native starch gels. The DO increased with the addition of MCG, which illustrated that MCG promoted the formation of order structure in the starch-MCG gel matrix (Ren et al., 2020). The results were similar to that of rheological and FTIR experiments, starch granules assembled to form a more order structure by the mass of hydrogen bond, which increase the elastic property of starch-MCG gels.

### 3.6. LF-NMR

The water migration of starch gels was evaluated by the value of spin relaxation time ($T_2$), while the low $T_2$ suggested the low degree of freedom and mobility of water molecular. All native starch gels had a high $T_2$, and tuber starch had a higher $T_2$ of 1257.73–1341.65 ms than other native starch gels (Table 2). The results suggested that the network structure of native starch gels was poor and the binding degree with water molecules was low, in which tuber starch had the highest degree of free water. The $T_2$ of starch-MCG gels started to decrease with the addition of MCG, which revealed that MCG strengthened the network structure of gels, thereby promoted the combination between matrix and water molecular. Similarly, Luo et al. (2020) reported that MCP strengthened the gel network structure of waxy and normal maize starches-MCP gels, thereby reducing the mobility of water protons.

### 3.7. SEM

The microstructure of freeze-dried native starch and starch-MCG gels were presented in Fig. 5. Native starch gels all exhibited a homogeneous and dense "honeycomb" shape, which was also be found in rice starch-pullulan gels (Chen et al., 2017)). However, it could be observed that the holes of starch-MCG gels were heterogeneous and unconsolidated, while the hole sizes were relative bigger and edges were thicker than that of native starch gels. The "honeycomb" holes were the places of distributing water during the storage process, the large holes and thick edges suggested the entrainment force was strong between starch fragments, which were caused by the difficulty of water evaporation in the process of lyophilization due to its tight network structure (Ren et al., 2020). The results were agreed to the results of LF-NMR experiences, starch-MCG gels had strong water binding capacity, given that the network structure were compacter after adding MCG.

## 4. Conclusion

The present study investigated the effects of MCG on the pasting, rheological and structure properties of tuber, cereal, and bean starch gels. MCG increased the PT of tuber starch because of the water competition between starch and hydrophilic MCG molecular, and MCG inhibited the pasting of cereal and bean starches via increasing the effective starch concentration in the continuous phase. MCG effectively promoted the short-term retrogradation of starch gels associated with interactions were formed between MCG and amylose starches. Based on the promoted rearrangement of amylose starch, the gel strength and

hardness of starch-MCG gels were significantly increased with the addition of MCG. Rheological results suggested that MCG increased apparent viscosity of starch-MCG gels due to it thicken property, and the elastic property of starch-MCG gels were effectively enhanced by MCG, which was associated to that MCG had positive effects on the formation of order network structure. Furthermore, the promoting effect of MCG on ordered starch gel network of various starch-MCG gels were proved and explained by FTIR spectrum and its strong water binding capacity. In summary, the information reported in this paper would further understand the effect of MCG on various starches extracted from different resources, which was beneficial to promote the practical application of starch-MCG complex system in food industry.

## CRediT authorship contribution statement

**Liyuan Rong:** Writing – original draft, Writing – review & editing, Methodology, Validation. **Wenmeng Liu:** Writing – review & editing. **Mingyue Shen:** Writing – review & editing. **Wenhao Xiao:** Writing – review & editing. **Xianxiang Chen:** Writing – review & editing. **Jun Yang:** Writing – review & editing. **Jianhua Xie:** Visualization, Conceptualization, Software, Resources, Writing – review & editing, Supervision.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crfs.2022.11.012.

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