Effects of konjac glucomannan and acetylated distarch phosphate on the gel properties of pork meat myofibrillar proteins

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Abstract The effects of konjac glucomannan (KGM) and acetylated distarch phosphate (ADSP) on properties of pork meat myofibrillar protein (MP) were investigated using rotary rheometer, colorimeter, texture analyzer, Fourier transform infrared spectroscopy (FTIR), scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM). The addition of KGM and ADSP resulted in increase in both storage modulus (G') and water holding capacity. Whiteness of MP gels was not influenced by the addition of KGM or ADSP, but the texture of MP gels changed apparently with the incorporation of KGM or ADSP. The temperature sweep showed that the increase in G' was associated with the gelatinization of ADSP and its synergistic effect with KGM. The FTIR indicated that the addition of KGM and ADSP enhanced the hydrogen bond in the gel system. The addition of KGM and ADSP changed the microstructures of MP gels, indicating the possible interactions among KGM, ADSP and MP. The images of CLSM showed that starch granules filled in the gap in the protein network, meanwhile the KGM evenly dispersed in the protein network structure.

Keywords Myofibrillar proteins · Konjac glucomannan · Acetylated distarch phosphate · Dynamic rheological properties · Water holding capacity · Microstructure

Introduction

Muscle proteins could be divided into three groups: sarcoplasmatic (water-soluble), myofibrillar (salt-soluble) and stromal (insoluble) proteins (Xiong 1997) based on solubility characteristics. MP played an essential role in producing the desirable texture and water-binding in conventional meat products. During the heat gelation process, MP exerted a cohesive force to bind meat particles together and to stabilize fat droplets in the gel system (Acton et al. 1983; Xiong 1997). The functionality of MP and its thermally-induced gel forming ability were influenced by various factors, including pH, salt concentration, pressure and nonprotein polymer ingredients (Grossi et al. 2016; Lesiow et al. 2017). Thus, the knowledge about the interactions of meat proteins with other ingredients would be crucial to the quality of relative foods (Fernández-Ginés et al. 2004).

KGM is a neutral polysaccharide extracted from the *Amorphophallus konjac* tuber. KGM is partially acetylated (1 of every 19 units) and possesses excellent hygroscopic property and water retention capacity (Zhang et al. 2014). The refined KGM powder is used in food and pharmaceutical industries as dietary fiber, affording notable physiological effects as well as unique technical properties. KGM yielded highly viscous pseudoplastic solutions, so it could be used as thickening agents. KGM had a strong water-binding ability and exhibited a synergistic effect on protein gelation in comminuted meat products when combined with other polysaccharides (Kao and Lin 2006). KGM were also used to improve the textural characteristics of low-fat meat emulsion products (Chin et al. 1998). KGM was applied to control rheology and structure of potato starch, cassava starch (Shanavas et al. 2010), and maize starch (Yoshimura et al. 1999), revealing that the behavior

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of KGM was similar to a physical barrier to prevent the association of amylopectin chain (Khanna and Tester 2006). KGM was also found to alter the conformations of gluten proteins upon heating via non-covalent interactions and physical entanglements (Wang et al. 2017).

ADSP is one of the chemically modified starches. It is a kind of composite modified starches, which is esterified by sodium trimetaphosphate or phosphorus oxychloride combined with esterification by acetic anhydride or vinyl acetate (Chen et al. 2018a, b). Usually, ADSP was firstly synthesized by crosslinking starch with POCl_3 , and then starch was esterified with acetic anhydride. It's worth noting that the required amount of acetic anhydride should be slowly added dropwise with agitation to the starch suspension, while simultaneously adding alkali liquor to maintain the pH of the suspension in the range of 8.0–8.4 (Chen et al. 2018a, b; James and Roy 2009). ADSP had been demonstrated to possess the stabilities against acid, thermal and mechanical degradation, and the retrogradation of starch molecules during storage was also inhibited after chemical modifications. ADSP was used widely in salad dressings, canned foods, frozen foods and puddings (Tharanathan 2005).

Starches and non-starch hydrocolloids were often used together in food systems to modify the properties of products. Usually, a weak gel or a stable three-dimensional structure with different interactions between starches and hydrocolloids might form in the hydrocolloid blends (Mohammed et al. 1998; Chen et al. 2017).

Several studies have been performed on the usage of KGM or ADSP to modify gel properties of pork meat salt-soluble proteins. But few studies have been conducted to investigate the gel properties of MP when both of KGM and ADSP are present in the combination system. Therefore, the main objective of present work was to investigate the gel properties of MP–KGM, MP–ADSP, MP–KGM–ADSP, respectively. Furthermore, the water holding capacity, the hydrogen bond interaction and microstructure of combination gels were studied to understand the possible interactions among MP, KGM and ADSP. Such researches were meaningful in exploring the potential utilization of hydrocolloids to improve the product quality, and at the same time reduce the manufacturing cost of MP-based food.

Materials and methods

Materials

KGM was extracted from *Amorphophallus konjac* tuber by Shanghai Brilliant Gum Co., Ltd. (Shanghai, China), which was used without further purification. The moisture content

and molecular weight of KGM were 8.5% and 1, 050, 000 MW, respectively. ADSP was obtained from Hangzhou Starpro Starch Company (Hangzhou, China) with 11.6% moisture. Fresh pork meat was from an eight-month-old Yoykshire pig. The meat was trimmed to remove visible fat and connective tissue, cut into mince, packaged and placed in frozen storage at $-20\text{ }^{\circ}\text{C}$. The meat had an approximate composition of $21.9 \pm 0.2\%$ crude protein, $3.2 \pm 0.4\%$ fat and $1.0 \pm 0.3\%$ ash, as determined using standard procedures (AOAC 2000).

Preparation of myofibrillar proteins (MP)

MP was prepared according to the procedure pointed out by DeFreitas et al. (1997) with some modifications. The subcutaneous and intramuscular fat and connective tissue in meat were removed to prepare lean meat. Then the lean meat mince was homogenized in a blender with four volumes of icy isolation buffer (0.02 M, Na_2HPO_4 , NaH_2PO_4 , pH7.5) for 180 s at 8000 rpm. The slurry was kept at $4\text{ }^{\circ}\text{C}$ for 30 min and then centrifuged at $8000\times g$ at $4\text{ }^{\circ}\text{C}$ using a freezing centrifuge (Sigma, Shanghai Anting Instrument, China) for 20 min. The supernatant fluid was removed and the process was repeated twice. The sediment was resuspended in four volumes (based on initial meat weight) of 0.1 M NaCl solution, filtered with 4 layer of gauze, and then centrifuged at $8000\times g$ at $4\text{ }^{\circ}\text{C}$ for 20 min. The final sediment was the myofibrillar protein.

Preparation of gel solution

The calculated amounts of KGM (0, 0.1, 0.2, 0.3, 0.4 wt%, based on MP weight) or ADSP (0, 0.5, 1.0, 1.5, 2.0 wt%, based on MP weight) were dissolved in distilled water at room temperature for 3 h to obtain a homogenous solution, and then 0.2 g of MP was slurried in KGM or ADSP solutions at room temperature by magnetic stirring for 30 min to get the MP–KGM and MP–ADSP solutions.

MP–KGM–ADSP mixture solutions were prepared with fixed concentration of MP (0.2 g) and ADSP (0.004 g), while different concentrations of KGM (0, 0.1, 0.2, 0.3, 0.4 wt%, based on MP weight) were added in the system.

The slurry was transferred to a plastic centrifuge tube. The air bubbles in the slurry were removed by centrifuging sample at $1000\times g$ at $4\text{ }^{\circ}\text{C}$ for 10 min.

Preparation of heat-induced composite gels

The slurries were coagulated at $80\text{ }^{\circ}\text{C}$ for 30 min in a water bath. After heating, samples were cooled down to room temperature and stored at $4\text{ }^{\circ}\text{C}$ overnight. Multilayer plastic film was used to seal the centrifuge tube mouth with

the purpose of preventing water evaporation during heating.

Determination of rheological characteristics

Dynamic rheological experiments were performed using a Rheometer (TA Instrument Ltd., England). A parallel plate geometry (diameter 20 mm) was used with 1.0 mm of gap. The temperature was controlled by a water bath connected to the Peltier system in the bottom plate. A thin layer of silicone oil was applied on the surface of the samples in order to prevent the evaporation of water. The rheological spectra were obtained using temperature swept from 25 to 90 °C and then swept from 90 to 25 °C at 5 °C/min at a constant frequency of 1 Hz. Storage modulus (G') and $\tan\delta$ were recorded within the linear viscoelastic region.

Color evaluation

The color of gel samples was determined using an UltraScan Pro colorimeter (Hunterlab Instrument Ltd., American). The system was calibrated with a white plate, ($L = +97.83$, $a = -0.43$, and $b = +1.98$). Five measurements for each sample performed and lightness (L), redness (a), and yellowness (b) values were recorded.

Whiteness value was calculated as follows: *Whiteness* =

$$100 - \sqrt{(100 - L)^2 + a^2 + b^2} \text{ (Park 1994).}$$

Textural analysis of gel samples

The textural properties of gel samples were measured by using a TA-XT Plus texture analyzer (Stable Micro Systems, England). The centre cylindrical part of heat-induced gel samples were cut (30 mm in diameter, 40 mm in height) and placed on the platform carefully. The conditions of texture analysis were as follows: pre-test speed 2.0 mm/s, test speed 1.0 mm/s, post-test speed 5.0 mm/s, and force 5 g. The gels were compressed twice to 50% of their original height at a constant speed of 1.0 mm/s. The parameters, namely hardness [peak force on first compression (N)], springiness [ratio of the sample recovered after the first compression], were calculated and analyzed respectively.

Determination of water holding capacity (WHC)

Gel samples were transferred to 50 mL centrifuge tubes and centrifuged at $4000 \times g$ for 15 min at 4 °C. Tubes were inverted to drain away the supernatant fluid for 15 min. WHC (%) was defined as the ratio of the sediment weight to the original gel weight.

Fourier transform infrared spectroscopy (FTIR)

The different samples were subjected to freeze, freeze dehydration and milling. FTIR spectra of the dried powder were recorded with a Nicolet Nexus 670 spectrometer (Thermo Electron Corporation, Waltham, USA) using potassium bromide (KBr) disks, in which the ratio of KBr to sample was 1:50. The spectrum was recorded over the wave number ranging from 400 to 4000 cm^{-1} .

Scanning electron microscope (SEM)

Samples were fixed in 1% (w/w) osmium tetroxide solution at 4 °C. The fixed samples were rinsed in phosphate buffer (pH 7.2, 0.1 M) over 10 times and then dehydrated through a graded series of alcohol solutions (30, 50, 70, 90 and 100%). The samples were then immersed in isoamyl acetate and dried in a critical point drier (model CPD-030, BAL-TEC Company). Consequently, the prepared specimens were stuck on a specimen holder and coated with gold palladium using a sputter coater, and observed in the scanning electron microscope (Quanta-200, FEI company) at an accelerating voltage of 10 kV.

Confocal laser Scanning Microscope (CLSM)

The gel samples were frozen, cut into slices and fixed on microscope slides. The MP was stained with an aqueous solution of 8-Anilino-1-naphthalenesulfonic Acid Sodium Salt (ANS), KGM was stained with an aqueous solution of Rhodamine B (RhB), and ADSP was stained with an aqueous solution of Fluorescein Isothiocyanate (FITC). The MP-ADSP-KGM was stained with a mixture of ANS, FITC and RhB. The excess dye was washed with distilled water, the samples were covered by cover slide. The samples were observed on an inverted Confocal Laser Scanning Microscope (CLSM, LSM-710, Zeiss, Germany). Digital image files were acquired in 1024×1024 pixel resolution. The excitation and emission wavelengths of ANS were 364 and 450 nm, respectively. The excitation of Rhodamine B was performed at 568 nm and the total emission was recorded at 590 nm. Meanwhile, the excitation and emission wavelengths of FITC were 490 and 530 nm, respectively.

Statistical analysis

Statistical significance was assessed by one-way analysis of variance (ANOVA) using SPSS 20 for windows program. The level of significance was set at $p < 0.05$.

Results and discussion

Rheological characteristics

Variation of G' values with temperature for MP, MP-KGM, and MP-KGM-ADSP mixtures during heating from 25 to 90 °C (Fig. 1a₁–a₃) or 90–25 °C (Fig. 1b₁–b₃) at a rate of 5 °C/min were presented in Fig. 1. The gelation curves of pure MP showed a typical curve during heating (Fig. 1), which was ascribed to the thermal denaturation of the myofibrillar proteins (Wang and Smith 1994; Xiong 1997). When KGM was added to the MP suspension, it could be clearly seen that KGM significantly increased G' values when heating temperature was higher than 60 °C (Fig. 1a₁). The higher the KGM concentration used, the higher the G' values increment of the MP-KGM. In addition, the plateau temperature for MP-KGM was 75 °C, while the plateau temperature for MP was 70 °C. This indicated that KGM might enhance the thermal stability of MP. In other words, the degeneration of protein molecules was delayed with the addition of KGM. This might be attributed to the interactions between MP and KGM (Wang et al. 2017). As is known to all, MP possesses some reactive groups, such as $-NH_2$, $-OH$, and $-SH$, as shown in the FTIR diagram in Fig. 5. These functional groups not only participate in crosslinking reactions within protein system, but also interact with groups from other biological molecules. It's worth noting that the biopolymer interactions between protein and polysaccharides, such as hydrogen bond and the steric hindrance effect, usually lead to conspicuous changes in physicochemical properties and therefore regulate the processing and application features of protein (Wang et al. 2017). Similarly, ADSP remarkably increased G' values, this might be attributed to the higher elastic characteristic of ADSP as compared with its native counterpart (Singh et al. 2004a, b). Interestingly, the G' values of MP-ADSP increased with temperature and continued to rise without a plateau (Fig. 1a₂). This might be attributed to the fact that gelatinization temperature of ADSP was higher than the denaturation temperature of protein (Wu et al. 2010). ADSP granules swelled gradually and occupied more space, and then absorbed more water and produced a more compact structure. As a result, the gel's G' values increased with the addition of ADSP. This result was in agreement with Zhang et al. (2013) who pointed out that the effect of acetylated starch on rheological properties of surimi sols and gels was related to the swelling capability of starch granules in the presence of limited water. The G' variation of MP-KGM-ADSP samples was shown in Fig. 1a₃, indicating that KGM (0.3 and 0.4%) and ADSP (2%) had a synergistic effect on the G' values.

Figure 1b₁–b₃ illustrated the gel formation during cooling from 90 to 25 °C at a rate 5 °C/min. Both of KGM and ADSP increased G' value. This was in agreement with Li and Yeh (2003) who suggested that the addition of starch resulted in the increase in G' values of meat protein. These results also indicated that polysaccharides (KGM and ADSP) indeed participated in the gelation process of meat protein.

$\tan \delta$ is the ratio of the energy lost to the energy stored for the deformation, i.e. $\tan \delta = G''/G'$. It is an important indicator of the relative contributions of the viscous and elastic components to the viscoelastic properties of samples (Chen et al. 2018a, b). $\tan \delta$ of the MP gels changed with the addition of KGM (Fig. 2a₁, b₁). The initial $\tan \delta$ value for MP with 0.4% KGM was about 1.1, indicating that the sample showed more viscous than elastic. This might be due to the fact that KGM could quickly absorb water. As could be seen in Fig. 2a₁, $\tan \delta$ value declined with temperature, and KGM changed the $\tan \delta$ markedly. However, ADSP had limited influence on $\tan \delta$ of the MP (Fig. 2a₂).

During the cooling process (Fig. 2b₁–b₃), $\tan \delta$ values increased slightly with the reduction of temperature from 90 to 25 °C. $\tan \delta$ values kept constant at the end of cooling.

Color and texture characteristic of gels

Whiteness is an important index to reflect the exterior quality in gel-based food (Park 1994). As could be seen in Table 1, MP, MP-ADSP, and MP-KGM had similar whiteness values. Namely both ADSP and KGM almost had little or no obvious effect on the color of MP gel. This might be due to the fact that the concentration of KGM and ADSP added in the mixture system was too low to cause the color change observably. Furthermore, the gelatinization of ADSP and gelation of KGM during the formation of heat-induced composite gels might also reduced the color differences between MP and MP gels containing various concentration of ADSP and/or KGM. Therefore, the addition of ADSP and KGM could not bring adverse effect to the color of MP gels.

The effects of ADSP and KGM on the textural property of MP gels are shown in Fig. 3. Both ADSP and KGM affected the hardness and springiness of MP gels effectively and this influence was dependent on hydrocolloids concentration. Generally, the springiness of MP gels increased with the increasing of ADSP or KGM, suggesting the promoting effect of ADSP and KGM on the formation of three-dimensional network. This result was ascribed to the excellent gel forming ability of ADSP and good water holding capacity of KGM (Zhang et al. 2014).

Hardness of gels increased with the increase of ADSP concentration from 0 to 1%, but decreased with the

Fig. 1 Variation of G' values with temperature for MP, MP–KGM, and MP–KGM–ADSP mixtures during heating from 25 to 90 $^{\circ}\text{C}$ (a₁–a₃) or 90–25 $^{\circ}\text{C}$ (b₁–b₃) at a rate of 5 $^{\circ}\text{C}/\text{min}$

Fig. 2 Variation of $\text{Tan}\delta$ values with temperature for MP, MP–KGM, and MP–KGM–ADSP mixtures during heating from 25 to 90 °C (a_1 – a_3) or 90–25 °C (b_1 – b_3) at a rate of 5 °C/min

Table 1 Effect of ADSP and KGM on the whiteness of MP gels^a

Sample	Whiteness
MP	66.37 ± 2.20a
MP + 0.5% ADSP	64.97 ± 1.96a
MP + 1.0% ADSP	64.23 ± 2.00a
MP + 1.5% ADSP	63.80 ± 2.40a
MP + 2.0% ADSP	62.67 ± 2.26a
MP + 0.1% KGM	65.27 ± 2.13a
MP + 0.2% KGM	64.69 ± 2.04a
MP + 0.3% KGM	64.37 ± 2.27a
MP + 0.4% KGM	63.18 ± 2.13a

^aTests were performed in triplicate. Mean ± standard deviation values in the same column for each sample followed by different letters are significantly different ($p < 0.05$)

addition of ADSP when its concentration was higher than 1%. Similarly, KGM caused an increase in the gel hardness at concentration of KGM $\leq 0.2\%$, while caused a sharp

decrease in hardness when the addition levels of KGM were higher than 0.2%. Therefore, it is possible for us to regulate the hardness of MP-based food varying with products features and customer requirements.

Water holding capacity (WHC) of gels

WHC of gels indicated the ability of gel to bind water and was generally used to objectively evaluate the quality and yield of meat and meat products (Trout 1988). The WHC of heat-induced gels with different formulations are shown in Fig. 4.

The WHC of pure meat protein gel in the control was 45%, whereas the addition of ADSP significantly increased the WHC of the gel ($p < 0.05$). For instance, when 2% of ADSP was added into meat protein, the WHC of gel increased from 45% to 68%. The water absorption property of ADSP itself might be a factor to influence the WHC of the protein-ADSP system (Singh et al. 2004a, b). Similar results were reported by Choi et al. (2011) who found that

Fig. 3 Effect of ADSP (a), KGM (b), and the combination of ADSP and KGM (c) on the texture properties of MP gels

Fig. 4 WHC of MP gels with various KGM or ADSP concentrations. Error bars of WHC represented mean values $\pm$ standard deviations of triplicates

rice bran fiber could enhance the WHC of heat-induced meat protein gel.

KGM could also increase the WHC, as could be seen in Fig. 4b. The WHC of blending gel increased from 45 to 77% as KGM increased from 0 to 0.4%. Compared with ADSP, KGM improved the WHC more effectively. The result was in agreement with Verbeken et al. (2005) who found that κ -carrageenan could increase the gel strength and the water holding capacity of salt-soluble meat proteins.

From the results above, both of the ADSP and KGM could enhance the WHC of meat protein gel effectively. The expanded ADSP granules would swell gradually (mainly due to the existence of phosphate group) and occupy more space, producing a squeezing action on the MP–KGM enrichment domains and increasing the effective concentrations of MP and KGM. As a result, the interactions between MP and KGM might be facilitated to form a more compact three dimensional network, which could restrict more water than pure protein gel.

Fourier transform infrared spectroscopy (FTIR)

Figure 5 illustrates the FTIR spectra of different samples. From pure MP gel's FTIR spectrum, typical absorption bands of protein could be identified. The broad absorption bands at 3400–3100 and 3000–2800 cm^{-1} revealed the stretching vibration of the O–H and C–H respectively. The absorption bands at 1630 and 1553 cm^{-1} were assigned to the stretching vibration of the C=O and the bending vibration of the N–H, respectively. A weak absorption band at 1236 cm^{-1} indicated the stretching vibration of the C–N group.

Fig. 5 FTIR spectra of MP, MP–KGM, MP–ADSP, and MP–ADSP–KGM

When ADSP was added in the MP or MP–KGM system, the significant strong absorption bands at 1200–800 cm^{-1} were observed, which could be assigned to the fingerprint region of starch. The absorption band at 1214 cm^{-1} corresponded to the phosphoryl group. These hydrophilic groups would enhance the swelling, water holding capacity of starch granules (Fig. 4). The O–H stretching vibrations at 3300 cm^{-1} significantly enhanced and shifted gradually to a lower wavenumber with the incorporation of KGM in MP. This variation indicated the formation and enhancement of hydrogen bonding between MP and KGM during the heating process. Furthermore, a strong and keen-edged peak at 1658 cm^{-1} could be observed in the samples contained KGM, which could be assigned to C=N

stretching vibration. This result was in accordance with Wang et al. (2014) who elucidated biopolymer interactions between carboxymethyl konjac glucomannan (CMKGM) and soy protein isolate (SPI). The formation of C=N bond indicated the occurrence of Maillard reaction between reducing sugar in polysaccharides and certain amino acid molecules in protein (Su et al. 2010).

The hydrogen bonding interaction among MP, ADSP and KGM. This was attributed to the distribution of different macromolecules. Actually, ADSP granules expanded gradually during heating and increased the effective concentration of MP and KGM. Then the interaction among MP, KGM and ADSP enhanced the structural compactability and structurally associated characteristics of samples, which could be confirmed by the results of WHC property (Fig. 4), SEM observation (Fig. 6) and CLSM image (Fig. 7).

Scanning electron microscopy (SEM)

The morphological characteristics of MP, MP–ADSP, MP–KGM, and MP–KGM–ADSP were observed by scanning electron microscopy (Fig. 6). In the sample of MP alone (Fig. 6a), homogeneous fibrous structures with some macroscopic voids were observed, exhibiting the typical property of meat protein gel. As could be seen from Fig. 6c, the surface and monolithic structure of MP–KGM were relatively homogeneous and continuous. The good structural integrity of MP–KGM confirmed the miscibility between MP and KGM in the combination system. What's more, the holes' size was smaller than those of pure MP. According to Hermansson (1985), a fine and uniform

structure with small pores would result in better absorptive capacity and better retention of water compared to coarse structure with large pores. This partially explained the WHC improvement in MP–KGM or MP–KGM–ADSP system, as could be seen in Fig. 4.

However, in the samples containing ADSP (Fig. 6b, d), intact and swollen starch granules were observed. This was ascribed to phase separation caused by thermodynamic incompatibility between ADSP and KGM. On the one hand, KGM and MP competed with ADSP granules for available water. Consequently, the swelling and gelatinization of starch granules were retarded. On the other hand, the expanded granules would swell gradually and occupy more space, increasing the effective concentration of KGM and MP (as illustrated in the schematic diagrams in Fig. 6). As a result, more compact three-dimensional network structures formed in the region mainly composed of MP–KGM, then the sample was endowed with better water holding capacity. Additionally, acetylation modification could decrease the transition temperature and enthalpy of starch and then increase the swelling power of starch granules (Singh et al. 2004a, b), enhancing the concentration effect in the mixed system contained ADSP.

Confocal laser scanning microscopy (CLSM)

The structural characteristic of MP–KGM–ADSP combination was observed by the means of CLSM, as shown in Fig. 7. Multiple fluorescent dyeing technology was used to confirm the distribution of each component in the MP–KGM–ADSP system (Fig. 7a–c). In the micrographs, blue areas corresponded to the fluorescence of ANS, revealing

Fig. 6 SEM micrographs and schematic diagrams of MP (a), MP–ADSP (b), MP–KGM (c), and MP–ADSP–KGM (d)

Fig. 7 CLSM images of MP–ADSP–KGM stained by different dyes. **a** Blue areas represented MP stained by ANS. **b** Green areas represented ADSP stained by FITC. **c** Red areas represented KGM

stained by RhB. **d** The superposition of **a–c**. Scale bar was 20 μm (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

the presence of MP (Fig. 7a). Green areas corresponded to the fluorescence of FITC, allowing the localization of ADSP in the mixture (Fig. 7b). Red areas corresponded to the fluorescence of RhB, showing the position of KGM in the ternary combination system (Fig. 7c).

In the composite system, MP and KGM nearly located in the same position to form relative homogeneous gels. The colocalization between MP and KGM exhibited purple, which was the superposition of blue (dyed MP) and red (dyed KGM). This phenomenon further indicated the good compatibility between MP and KGM. However, ADSP located in different region, namely ADSP granules were relatively independent of MP and KGM. As a result, a three-dimensional gel structure formed, in which MP and KGM established the network-like structure and ADSP granules were embedded in the network.

Conclusion

The effects of KGM and ADSP on the gel properties of pork meat MP were revealed. The composited system showed improved physicochemical properties compared with pure MP. The addition of KGM and ADSP increased the storage modulus G' and WHC of MP gels. Both ADSP and KGM almost had little or no obvious effect on the color of MP gel, while affected the hardness and springiness of MP gels effectively. The FTIR diagrams indicated the enhancement of hydrogen bonding interaction among ADSP, MP and KGM. The observations of SEM and CLSM further microstructurally confirmed the interactions among MP, KGM and ADSP. The incompatibility between MP/KGM and ADSP, the biological macromolecules interactions such as hydrogen bonding between MP and KGM were hypothesized to be responsible for the above-mentioned results.

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