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The gel properties and microstructure of the mixture of oat β-glucan/soy protein isolates

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ABSTRACT

Oat β-glucan (OG) is a linear non-starch polysacchride which is usually concentrated in the inner aleurone and subaleurone endosperm cell walls, and it exhibits good physiological and functional properties. In this paper soy protein isolate (SPI) which is widely used in the food industry was mixed with OG, then the gel properties and micromechanism of the mixture were studied for a better understanding of the interaction between β-glucan and protein in food. The results showed that, compared with the single OG or SPI, OG/SPI mixture easily formed thermoreversible gels in 4 °C and 25 °C, which reduced the gel forming time; this would be conducive to improve β-glucans application in food production. The glass transition temperature (Tg) and the thermal stability were increased. Scanning electron microscopy (SEM) and confocal laser scanning microscopy (CLSM) were used to analyze the microstructure of the mixture of OG/SPI, and showed that the gathering and interaction of oat β-glucan and soy protein isolate affected the forming of gels. The molecular simulations of the microstructure of OG and OG/SPI mixed system inferred the interaction between OG and SPI were mainly hydrogen bonds.

1. Introduction

Proteins and polysaccharides are important biological macromolecules in foods, and they are also main factors influencing the structure and texture of foods. They often coexist in many systems, for example, there are mixtures of proteins and polysaccharides in mayonnaise (Shen, Luo, & Dong, 2011) and ice cream. When polysaccharides interact with proteins in the same system, some groups of macromolecules can link to each other at the appropriate conditions including temperature, pH value, ionic strength, etc. Soluble or insoluble conjugation would be formed by the interaction (secondary forces; electrostatic attraction, hydrogen bonding, van der Waals forces, hydrophobic interactions and thermodynamic incompatibility between biological macromolecules, etc.) between proteins and polysaccharides. This conjugation of protein-polysaccharides can improve the quality of foods by affecting the interfacial characteristics, solubility and stability of these macromolecular components.

Gel behavior of polysaccharides can improve the quality of foods, so they are widely used in jam and pudding. Oat β-glucans have some physiological functions, such as decreasing cholesterol level, enhancing immunity, improving bowel function, and have other functional properties such as good solubility and high viscosity (Wood, 2004; Qi & Liu, 2007). Gel forming is also thought to be one basic property of cereal β-glucans. The barley β-glucans are used in dairy products, which have a significant impact on gel strength of the hybrid system, it suggests the barley β-glucans have a significant impact on the quality and structure of dairy products (Kontogiorgosa, Ritzoulisa, Biliaderisa, & Kasapis, 2006). In addition, barley β-glucans are added into sausages, rendering more closed protein networks which make the sausages show a higher water-holding ability; the denaturation temperature of protein in the sausage is also increased (Morin, Temelli, & McMullen, 2004). Some research also have found when the molecular weight of oat β-glucans increased from 3.5×10^4 to 6.5×10^4, the required content was reduced from 22.5% (w/w) to 1–1.5% (w/w) (Lazaridou & Biliaderis, 2009). Soy protein isolate (SPI), a high-quality and low cost alternative to animal protein, is the most widely used soy protein product. Isolated soy protein has good functional properties, such as solubility, swelling, gelling, emulsifying, foaming, etc., so in the food industry it has been used extensively (Chi, Zhu, & Ling, 2008). When both of them coexist in a food system, interactions can produce some effects on functional properties and mainly on gel properties and interface properties. Carrageenan can change the denaturation

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and gelling rates of soybean protein through its synergistic effect at a lower pH value than protein isoelectric point (Zhou, 2005); Only 1% xanthan gum was added in the heat-denatured whey protein isolate solution, that significantly increases gel forming and hardness (Bryant & McClements, 2000); when pectin and dextran were added, the gelling critical value of soybean 11s globulin was reduced. Therefore, these kinds of macromolecular components cannot separately form a gel, but after mixing can form a gel, such as gelatin/alginic acid mixture. Besides, there is synergism between soybean protein isolate and k-carrageenan, and one of the mechanisms is increasing the concentration; carrageenan can affect the gel performance of soybean by changing the actual concentration of soybean protein (Zhou, 2005). Polysaccharides can improve the apparent viscosity of protein solution, thus playing a certain stability function. Different combinations of proteins and polysaccharides have different impact on the surface properties of the mixture system. For example, the complexation of β-lactoglobulin and pectin reduces the surface tension, and inhibits the formation of foam (Ganzevles, Stuart, van Vliet, & Jongh, 2006).

Polysaccharides and proteins are essential components in foods, and both of them have gel properties. Therefore, the gelling properties of a mixture have become a hot topic. There were many pieces of research focused on the interaction of proteins, and the effect of interaction in between protein of soybean or lactalbumin and polysaccharides of carrageenan, guar gum (Gong, Xing, Peng, & Liu, 2005; Rocha, Teixeira, Hilliou, Sampaio, & Gonçalves, 2009). However, there is little research about the gel properties of the OG/SPT mixture system. Moreover, textural properties and thermal characteristics in OG/SPI mixtures gel are determined by their microstructure, although there are a lot of methods to study these structures, there is still no effective research of the OG/SPI mixtures microstructure.

This study investigated the gel properties of OG/SPI, by using SEM and CLSM to analyze the micromechanism features. In addition, the molecular simulations of the OG and OG/SPI mixed system were built by using molecular modeling software to discuss the conformational change and gelation mechanism in the process of gelation of OG/SPI mixed gel.

2. Materials and methods

2.1. Materials

Oat β-glucan was kindly supplied by Jinping Technology Co (Zhuhai, Guangdong). The β-glucan content was measured by using the enzyme methods of AOAC 995.16 (McCleary, 1997), the β-glucan was further purified by DEAE Sepharose Fast Flow anion exchange chromatography and Sepharose CL-4B gel column chromatography, and with a test kit from Megazyme Company (Ireland), the purity was 95.7%. The composition of OG was 97.3% total sugar, 0.6% protein, 0.4% fat, 0.6% ash and 1.1% moisture. The soy protein isolate (SPI) from Tong Chuang Yi Sheng Food Co. (Zhengzhou, Henan) was used and the composition was protein 93.2%; total sugar 2.2%; fat 1.3%; ash 0.9% and moisture 2.4%. Congo red solutions were prepared with Congo red (Sigma Chemical Co., St. Louis, MO) dissolved in phosphate buffer solution. Furthermore, concentrated sulfuric acid, redistilled phenol, sodium hydroxide, hydrochloric acid were analytical grade reagents.

2.2. Methods

2.2.1. Preparation of OG/SPI mixed gel and texture properties

2.2.1.1. Preparation. The gels were prepared using the method of van den Berg et al. (2007a, 2007b). OG/SPI were prepared by mixing carefully weighed amounts of stock to obtain the mixed solutions with the mass fraction of 3% at different ratios of OG and SPI was 5:5, 6:4, 7:3, 8:2, 9:1 and 10:0. Then they were stored at 4 °C and the gelation time was investigated. Besides, binary solutions of OG/SPI of the different mass fraction were prepared with a suitable proportion, one group placed at room temperature (25 °C) and other group placed in the refrigerator at 4 °C, while, the same mass fraction of OG solution was prepared, then placed in the refrigerator (4 °C) to observing the gel formation and appearance characteristics. In all cases, the pH was maintained at 7 by the pH meter (pH-10, Sartorias Inc., China). All samples were performed in triplicate.

2.2.1.2. OG/SPI mixed gel texture properties. Textural behavior of OG/SPI mixed gel formed and stored for 48 h was measured using the TA.XT plus (Stable Micro System, Britain) to analysis the effect of mixture ratio on the gel properties of OG/SPI mixed system.

Gel textural properties measurement conditions: p35 probe, the test mode select for the pressure was 5.0 g induction force. Other conditions were: pre-test rate of 3.0 mm/s, test rate 3.0 mm/s, post-test rate of 5.0 mm/s and test distance was 40% (the percentage of the sample thickness).

2.2.2. Thermal analysis (TA)

2.2.2.1. Differential scanning calorimetry (DSC) measurements. OG/SPI (w/w 8:2) mixed gel samples were freeze-dried, and stored for 48 h; the glass transition temperature (Tg) was determined with the differential scanning calorimeter instrument (Q100, TA Inc., USA). The temperature increased from 0 °C to 150 °C and heating rate was 10 °C/min.

2.2.2.2. Thermoanalytical investigations. The OG/SPI (w/w 8:2) mixed gel was freeze-dried and ground into powder, which was analyzed with a Diamond TG/DTA thermal (Perkin Elmer Inc., USA). The scan range was 20 °C ~ 600 °C, heating rate of 10 °C/min, nitrogen 50 mL/min and experimental sample volume was (3 ~ 5) mg.

2.2.3. Scanning electron microscopy (SEM)

Preparation the OG/SPI mixed gel (w/w 8:2, 4%) and OG gel (4%), and were stored for 24th at 4 °C, freeze dried, and studied using scanning electron microscopy according to Meng, Zhang, and Zhao (2006). Freeze-dried gel samples were dispersed on SEM aluminium stabs on to which double-sided adhesive. Samples were then gold coated with an ion sputter coater (Tippetts, Shen, & Martini, 2013), and SEM images were observed with a JSM-6490LV SEM (Olympus Inc., Japan). In all cases, acceleration voltage of 10 kV, beam 5×10^{-9}mA and working distance 15 mm were used.

2.2.4. Confocal laser scanning microscope (CLSM) observations

The FV1000 CLSM (Olympus, Japan) was used to investigate the structural features (van den Berg et al., 2007a, 2007b). The solutions of OG/SPI mixed gel (w/w 8:2, 4%) and OG gel (4%) were formed for 24th at 4 °C, they were prepared at 60 °C with double-distilled water to a final concentration of 1 mg/ml. Gel solution and Congo red solution (80 μmol/L v/v 1:2) were fluorescent labeling reaction for 30 min at room temperature. Sample liquids (40 μL) were placed on clean glass slide with a micro-injector, tomography scanning fluorescence spectroscopy was performed using the FV1000 confocal laser scanning microscope, and the 3D images were rendered by computer (Zhang, Du, & Rao, 2007).

2.2.5. Molecular simulation of microstructure of OG/SPI mixed gel and OG gel

According to the structure of OG and SPI, the molecular simulations of the microstructure of OG and OG/SPI mixed system were built by HyperChem8.0 molecular modeling software (TurnTech