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Influence of konjac glucomannan on gelling properties and water state in egg white protein gel

Jinjin Liu [a,c], Kunkun Zhu [a], Ting Ye [a], Shaolong Wan [a], Yuntao Wang [a], Dan Wang [a], Bin Li [a,c,*], Chao Wang [b,**]

[a] College of Food Science and Technology, Huazhong Agricultural University, Wuhan 430070, China
[b] Research Center of Food Fermentation Engineering and Technology of Hubei, Hubei university of technology, Wuhan 430068, China
[c] Key Laboratory of Environment Correlative Dietology (Huazhong Agricultural University), Ministry of Education, China

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ABSTRACT

The effect of konjac glucomannan (KGM) on nuclear magnetic resonance (NMR) relaxation behavior, water holding capacity (WHC), and gelling properties of egg white gel was studied. It was found that the values of gel strength and WHC reached the summit as the addition of KGM at 0.06 wt.%. Multi-exponential function analysis of the T_2 relaxation revealed that there were at least two categories of water with different states or mobility in egg white gel. Meanwhile, intrinsic T_2 relaxation time of the immobile water in blending gel was longer than the bound water during gelation. The distribution of water in egg white gel was characterized by magnetic resonance imaging (MRI), which corresponded well with the conclusion of WHC. Further, scanning electron micrographs (SEM) suggested that WHC in the protein gel network was related to more porous gel microstructure.

1. Introduction

Egg white protein is extensively used as a food ingredient because of its unique functional properties such as foamability and gelation property (Matsudomi, Takahashi, & Miyata, 2001; Raikos, Campbell, & Euston, 2007). Egg white gels consist of polymers connected to each other in order to form a 3-dimensional network. The quality of the network depends mainly on the physicochemical conditions of the medium (Croguennec, Nau, & Brule, 2002). Kudryashova and de Jongh (2008) have reported that by enhancing the binding affinity between egg white ovalbumin and pectin a strong effect on the adsorption properties of the protein can be accomplished. Furthermore, pectin and guar gum have been verified to enhance the emulsifying activity index, emulsifying stability index, and creaming stability of egg white–polysaccharide mixtures (Erçelebi & Ibanoğlu, 2009). Similar phenomenon that the foam stability was enhanced in the presence of pectin has been shown in Ibanoglu's paper (Ibanoglu & Erçelebi, 2007). Here we report the effect of konjac glucomannan (KGM) on gelling properties and water state in egg white protein gel. These gels may serve as food systems to explore mechanisms of state and distribution of water, and expand the scope of egg white protein applications.

KGM is a high molecular weight neutral polysaccharide obtained from the Konjac plant root powder, is commonly used as a gelling agent in Asia (Chua, Baldwin, Hocking, & Chan, 2010; Wang, Lai, Chen, & Chen, 2008). KGM is a linear random copolymer of (1→4)-β-D-glucopyranose and β-D-mannopyranose, having glucose and mannose units in a molar ratio of 1:1.6 with a low degree of acetyl groups at the C-6 position (Mei et al., 2012). To our knowledge, it has been generally used in food, medical, chemical engineering, and other fields because of its unique physical and chemical properties (Al-Ghazzewi & Tester, 2012; Li, Ji, Xia, & Li, 2011; Li & Xie, 2006). Indeed, the interactions between proteins and polysaccharides are important during many kinds of food systems. The Maillard reaction is one of the most important factors to prepare protein–carbohydrate complexes. It has been reported the stable protein–carbohydrate complexes can be formed using pulsed electric field treatment (Guan et al., 2010).

Indeed, NMR spectroscopes are conventional techniques to characterize the state, mobility and distribution of water in biological macromolecules systems, and have been widely used in previous reports (Mateus, Champion, Liardon, & Voilley, 2007; Tananuwong & Reid, 2004). The general features of proton relaxation are characterized by spin–lattice relaxation time (T_1) and spin–spin relaxation time (T_2) (Lambert & Mazzola, 2003). It has been reported that the thermal denaturation of selected proteins of whey and egg was studied by low resolution NMR (Goetz & Koehler, 2005). Recently, Chen, Wei, and Zhang (2010) used NMR to measure water state and critical water content on textured soybean protein. Moreover, it is worth mentioning that

Abbreviations: KGM, Konjac glucomannan; SEM, scanning electron microscope; NMR, nuclear magnetic resonance; MRI, magnetic resonance imaging; WHC, water holding capacity.

* Correspondence to: B. Li, College of Food Science and Technology, Huazhong Agricultural University, Wuhan 430070, China. Tel.: +86 27 63730040; fax: +86 27 87282966.
** Corresponding author. Tel.: +86 18986138612; fax: +86 27 87282966.
E-mail addresses: libinfood@mail.hzau.edu.cn (B. Li), wangchao5412@163.com (C. Wang).

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pulsed-NMR method has also been successfully used to probe the sol–gel transition during heat-induced gelation of egg white proteins (Goh, Bhat, & Karim, 2009). To assess water dynamics on a macroscale, magnetic resonance imaging (MRI) was used to determine proton density and mobility on the millimeter–centimeter scale (Deka et al., 2006; Lai & Hwang, 2004; Miquel & Hall, 2002).

In previous works, NMR and MRI techniques have been proven to be ideal candidates for determining moisture content. However, the research of egg white-KGM blending gel using NMR has not been reported. Up to present, the relationship between egg white-KGM blending gel structure changes and the changes in water mobility in the gel are still an almost unexplored area. The present paper investigates the effect of KGM on the gelling properties and water proton relaxation behavior of egg white gels by means of NMR, SEM, texture analysis and WHC.

2. Materials and methods

2.1. Materials

Pasteurized liquid hen's egg white was supplied from JiLin Jinyi Egg Products Co., Ltd. (Jilin, China), which produces liquid egg white daily without any processing aids or additives. It was kept at 4 °C until used. KGM was purchased from Shiyan Huaxianzi Konjac Productions Co., Ltd. (Hubei, China), which was used without further purification. Plastic casings were provided by HeBei Licheng Productions Co., Ltd. (Hebei, China). All chemicals used in this study were of analytical grade reagents (Sinopharm Chemical Reagent Co. Ltd., Shanghai, China).

2.2. Preparation of sample

KGM was dissolved in distilled water (1% w/v) at room temperature for 3 h to obtain a homogenous mixture. Based on preliminary experiments, the KGMs were mixed with pasteurized liquid egg white, where the concentrations are given as ratios of components in total 300 g final mixtures. A series of solutions with the same liquid egg (270 g) but different KGM concentrations (0, 0.02, 0.04, 0.06, 0.08, 0.1 wt.%) were prepared by adding different amounts of 1 wt.% KGM solution (0, 6, 12, 18, 24, 30 g). Based on the various concentrations of KGM, the final products were categorized into six groups coded as A (0 wt.%), B (0. 02 wt.%), C (0.04 wt.%), D (0.06 wt.%), E (0.08 wt.%), and F (0.1 wt.%) respectively. The 300 g mixture was stirred thoroughly using a magnetic stirrer at room temperature for 1.5 h to obtain a homogenous mixture.

2.3. Gel texture analysis

The gelling properties of egg white-KGM blending gel were measured according to the method of Koç et al. (2011) with some modifications. Plastic casings (20 mm in diameter) were filled with sample and then tied tightly with ropes. The solution of samples was coagulated at 90 °C for 30 min in a water bath. Immediately, samples were cooled down to room temperature and stored at 4 °C overnight. The cylindrical gel samples (25 mm in height, 20 mm in diameter) were subjected to a compression test at 25 °C by using a 0.5-cm-diameter plate probe integrated with a texture analyzer (TA.XT Plus, Stable MicroSystems, London, UK). Typical parameters were as follows: Sequence Title: 1 Return To Start, Test Mode: Compression, Pre-Test Speed: 1.5 mm/s, Test Speed: 1 mm/s, Post-Test Speed: 1.00 mm/s; Target Mode: Distance, Distance: 10.0 mm; Trigger Type: Auto (Force), Trigger Force: 5.0 g, Advanced Option: Off, and Point per second: 200. Five replicates of each sample were carried out.

2.4. Water holding capacity

Water holding capacity (WHC, %) was determined according to the method developed by Salvador, Toldrą, Saguer, Carretero, and Parés (2009). The cylindrical gel samples were placed into PVC cylinders with filter paper, which were suspended inside centrifuge tubes and then centrifuged at 8000 rpm for 20 min at 4 °C. The results are reported as percentage (w/w) of water retained after centrifugation. Each sample was analyzed in triplicate.

2.5. Microstructural properties

The cylindrical gel samples were cut into small pieces. After that, gel pieces were placed for 12 h in a 10 mM phosphate buffer, pH 7, containing 0.2% glutaraldehyde for fixation. They were thoroughly rinsed with the 10 mM phosphate buffer, pH 7, and were dehydrated by successive 20 min baths of ethanol for 50%, 60%, 70%, 80%, 90%, and 100%. Gel pieces were critical-point-dried with CO_2 as the transition fluid, coated with gold and examined in Scanning Electron Microscope (JSM-6700F on Windows NT, JEOL, Japan) at 6 kV (Croguennec et al., 2002).

2.6. Nuclear magnetic resonance (NMR)

Low-field NMR relaxation measurements (MiniMR-60, Niumag Corporation, Shanghai, China) were performed according to the method of Han, Zhang, Fei, Xu, & Zhou (2009) with minor modification. The cylindrical gel samples (40 mm in height, 20 mm in diameter) were placed in a glass tube and inserted in the NMR probe. Carr-Purcell-Meiboom-Gill (CPMG) sequences were employed to measure spin–spin relaxation time, T_2 (Han, Zhang, Fei, Xu, & Zhou, 2009; Meiboom & Gill, 1958). Typical pulse parameters were as follows: τ-value (time between 90°and 180° pulses) of 100 μs. Data from 5000 echoes were acquired as 8 scan repetitions. The repetition time between subsequent scans was 2000 s. Each measurement was performed in triplicate. The multi-exponential decay curve can be got from NMR relaxation measurement and the mathematical model as follows:

$$A(t) = \sum_i A_{0i} \exp\left(-\frac{t}{T2i}\right)$$

where $A(t)$ is the amplitude size when attenuation to t; t is the decay time; A_{0i} is the amplitude size when the first component balance; and T_{2i} is the relaxation time of the ith relaxation component.

Distributed multi-exponential fitting of CPMG decay curves was performed in MultiExp Inv Analysis software (Niumag Electric Corporation, Shanghai, China). For a better fit, multi-exponential fitting analysis has been performed on the relaxation data in the software algorithm. From such analyses, time constants for each process were calculated from the peak position, and the area under each peak (corresponding to the proportion of water molecules exhibiting that relaxation time) was determined by cumulative integration (Han et al., 2009).

2.7. Magnetic resonance imaging (MRI)

MRI experiments were performed by MiniMR-60 (Niumag Corporation, Shanghai, China) at ambient temperature. Proton density images of the samples were obtained by MSE imaging sequence. MRI is a method with the advantages of non-destructive pre-treatment, and we can get the full image of the sample. Additionally, the sample was divided into eight layers to analysis, and the thickness of each layer was 2.0 mm. The following scanning protocols have been used: FOVRead = 100 mm, FOVPh0061se = 100 mm, Repetition Time (RT) = 1500 ms, Echo Time (TE) = 19 ms, Slice Width = 2.0 mm, Slice Gap = 0.5 mm, NS = 4, and K space size = 256*196. The images ultimately were saved by BMP