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Influence of sugarcane dietary fiber on water states and microstructure of myofibrillar protein gels

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ABSTRACT

The effects of different size particles and contents of sugarcane dietary fiber(SDF) on water state, water holding capacity(WHC), gel strength and microstructure of myofibrillar protein gels was studied. It was found that gel strengths were improved with the increase in SDF particle size and content, and the value of water holding capacity (WHC) reached a maximum with the addition of 80-mesh SDF at 2%. Discrete exponential fitting analysis and multi-exponential function analysis of the T_2 relaxation time revealed that three categories of water, each having different mobility states in the gels, had different effects on the blended gel systems. Also, the intrinsic T_{21} relaxation time of immobile water in gels containing SDF was shorter than that in pure gels. Pronounced differences in myofibrillar gel network structures were observed during heating at 80 °C for 20 min. The fractal dimension which was determined by the box count method and the pore density (diameter < 0.1 μm or < 1 μm) further demonstrated that the homogeneity and compactness of gels increased with higher SDF content. However, the formation of numerous SDF cavities, whose particle size and number was enormously affected by the particle size and ratio of SDF added, is likely to have been responsible for the decrease in WHC and the extension of the intrinsic T_{21} relaxation times of immobilized water.

1. Introduction

The development of healthier food products has become a key target for manufacturers of processed meats, their central aim being to produce nutritious, low energy and low salt products. The main approaches used to achieve this in meat products are generally with the addition of non-animal proteins and water to reduce the amount of fat in the formulation; thus replacing animal fat with lower caloric ingredients and/or water (Colmenero, 1996, 2000; Jimenez-Colmenero, Carballo, & Cofrades, 2001; Mehta, Ahlawat, Sharma, & Dabur, 2015). Dietary fiber, as a fat replacement, had good water holding capability and a low caloric content. The beneficial effects of dietary fiber for human health have been widely reported, and it has been used in processed meat products as a functional ingredient (Colmenero, 2000; Sangnark & Noomhorm, 2003, 2004). In addition to the health benefits, dietary fiber not only possesses hydrocolloidal properties that have positive functional properties for food manufacturing and for ultimate food products, it also can be used as a filler or extender to improve the gel strength. Sugarcane dietary fiber (SDF) is insoluble, neutral in taste and odor and has been researched in baked goods, like bread (Sangnark & Noomhorm, 2003, 2004). Sugarcane bagasse contains a large amount of dietary fiber is an extremely abundant waste product from sugar factories. When treated with alkaline hydrogen peroxide (AHP), its brightness, water-holding capability, oil-binding capability increased sharply (Sangnark & Noomhorm, 2003, 2004).

Low-field NMR spectroscopy is the conventional technique to characterize the state, mobility and distribution of water by measuring the transverse water proton relaxation, and has been widely used for research on meat products (Mehta et al., 2015; Tananuwong & Reid, 2004). Moreover, it is a rapid, non-invasive and non-destructive method to analyze water in foods (Han,

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Wang, Xu, & Zhou, 2014; J. Liu et al., 2013; Tananuwong & Reid, 2004). In the processing system we have studied here, only myofibrillar proteins, sugarcane dietary fiber (SDF) and water were present, so we used a more simplistic approach to investigate how SDF affected the mobility of water in the three-dimensional gel network by low-field NMR spectroscopy. Recently, J. Liu et al. (2013) successfully used NMR to study the effect of konjac glucomannan on the water state in heat-induced gelation of egg white protein. The microstructure of myofibrillar heat-induced gelation was an irregular three-dimension network, which resulted in difficulties with numerical description (Langton, Astrom, & Hermansson, 1996; Marangoni, Barbut, McGauley, Marcone, & Narine, 2000), so only an abstract description is generally obtained. Some research has described it in terms of coarseness and compactness by visualization or has referred to outline the particle size of cavities indirectly (J. Liu et al., 2013; Romero, Cordobes, Guerrero, & Cecilia Puppo, 2011; Romero et al., 2009; Zhou, Zhao, Su, Cui, & Sun, 2014). Fractal analysis, based on image analysis, is a powerful tool for characterizing the irregular geometries and patterns including gel system in quantitative terms (Barrett & Peleg, 1995). Recently, fractal analysis has attracted attention as a quantitative analytical method that can characterize many kinds of disordered shapes (Gibis, Schuh, & Weiss, 2015; Han et al., 2014). In this way, a better description of microstructural changes should be achieved.

However, to our knowledge the research on adding SDF to meat reformulation products is still limited. In the present work, we attempt to study the effect of SDF on the microstructural changes of blending gels by means of scanning electron microscopy (SEM) and by light microscopy of paraffin sections, as well as changes of water mobility in the gels by means of NMR and centrifugation. Through the above methods, we should have a thorough understanding of how the particle size and concentration of SDF affect the gelling properties. Also, the results of this work would contribute to the utilization of SDF for improving the functionality of meat products.

2. Materials and methods

2.1. Materials and chemicals

Fresh pork leg meat (71.58% moisture, 20.27% protein, 6.85% fat) was purchased from a local market. The meat was frozen at 24 h post-mortem and stored at −20 °C until required for the extraction of myofibrillar protein. Triton X 100 was purchased from Amersco (San Francisco, USA). All other chemicals used in this work were from commercial sources and were of analytical grade.

2.2. Sugarcane dietary fiber treatment and preparation with alkaline hydrogen peroxide (AHP)

Sugarcane bagasse (SB) was purchased from a local fruit supermarket. The SB was washed in flowing tap water, dried in a fan-forced air-oven (DHG-90338S-III, Shanghai, China) at 65 °C and stored at room temperature until use. A 50-g sample of washed, dried SB (cellulose 46.34%, hemicellulose 25.94%, lignin 21.13%) was cut into pieces about 0.5 cm length and then treated with 5000 mL of 1% (W/V) AHP solution (pH = 11.5) for 12 h as described by Gould, Jasberg, and Cote (1989) with slight modification. After neutralization with 6 N HCl, the material was collected by filtration and washed with deionized water. The AHP-treated steps were repeated and then the sugarcane dietary fiber (SDF) was placed in a fan-forced air-oven at 55 °C until dry. The composition of SDF was cellulose 59.54%, hemicellulose 26.13%, lignin 9.43%, which was measured as Gould et al. (1989). Then, the treated material was ground in a centrifugal mill (HK-10B, XU LANG Machinery China) fitted with 40-mesh (420 μm) and then an 80-mesh (177 μm) screen. The particle size of SDF was under 80-mesh (termed 80-mesh SDF for convenience) and that between 40-mesh and 80-mesh (termed 40-mesh SDF for convenience).

2.3. Extraction of myofibrillar protein and preparation of gel system

Extraction of myofibrillar proteins was carried out as described by Xu, Han, Fei, and Zhou (2011). The protein concentration of the final pellet was determined by the Biuret method using bovine serum albumin (BSA) as the standard and the pellet was used within 24 h. SDF with either 40 or 80 mesh was added at 3 concentrations: 1, 2 and 3 g/100 g of myofibrillar protein which was diluted to a final protein concentration of 60 mg/mL (in 0.6 mol/L NaCl, 50 mmol/L Na_2HPO_4/NaH_2PO_4 solution, pH 7.0) and stirred with a power whisk (AHM-P125A, Appliance company Co., LTD, China) for about 10 min in order to ensure the homogeneity of the sample. The samples were stored at 4 °C overnight until required for use.

2.4. Gel texture analysis

The physical properties of the blending gels were measured according to the method of J. Liu et al. (2013) with some modifications. Plastic tubes (50 mL) were filled with each sample and then centrifuged (Model 225, Fisher Scientific, Pittsburgh, Pa., U.S.A.) at 800 g for 10 min to remove any bubbles. The sample solutions were heat-coagulated at 80 °C for 20 min in a water bath (TW20, Julabo Co., Ltd., German). Immediately, samples were cooled to room temperature and stored at 4 °C overnight. The cut cylindrical gel samples (20 mm in height, 40 mm in diameter) were penetrated with a 0.5-cm-diameter plate probe (P/5) integrated with a texture analyzer (TA-XT Plus, Stable Micro systems Ltd., Surrey, UK) at a crosshead speed of 1.2 mm/s. The penetrated force, i.e., the peak force required to rupture the gel, was expressed as the gel strength. Five replicates of each sample were carried out.

2.5. WHC

WHC (%) was determined according to the method developed by Salvador, Toldra, Saguer, Carretero, and Pares (2009). The cylindrical gel samples were placed into PVC cylinders with filter paper, which were suspended inside centrifuge tubes and then centrifuged at 10000 g (Model 225, Fisher Scientific, Pittsburgh, Pa., U.S.A.) for 10 min at 4 °C. The results are reported as percentage (w/w) of water retained after centrifugation. Each sample was analyzed four times.

2.6. Low-field NMR

The study of the relaxation times using low-field ^1H NMR was performed on 2 g portions of gel sample placed inside cylindrical glass tubes (15 mm in diameter) after heating at 80 °C for 20 min in a water bath. The measurements of the transverse relaxation time (T_2) were performed on a Niumag Benchtop Pulsed NMR analyzer (Niumag PQ001; Niumag Electric Copporation, Shanghai, China) operating at 22.6 MHz. The T_2 was measured using a Carr–Purcell–Meiboom–Gill (CPMG) with 32 scans, 12,000 echoes, 6.5 s between scans, and 250μs between pulses of 90° and 180° (Carr & Purcell, 1954; Meiboom & Gill, 1958). The lengths of the pulses were 23 μs for the 180 pulse. The NMR data was primarily analyzed by continuous distribution inverse and discrete exponential fitting as described by Shao and Li (2013). The low-field NMR relaxation curves were fitted to continuous distributions with the MultiExp Inv Analysis software (Niumag Electric Copporation, Shanghai, China). Discrete exponential fitting of relaxation