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Effect of dynamic high pressure microfluidization modified insoluble dietary fiber on gelatinization and rheology of rice starch

Cheng-mei Liu, Rui-hong Liang, Tao-tao Dai, Jiang-ping Ye, Zi-cong Zeng, Shun-jing Luo, Jun Chen*

State Key Laboratory of Food Science and Technology, Nanchang University, Nanchang 330047, China

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ABSTRACT

Modification of insoluble dietary fiber (IDF) for facilitating its applications has been encouraged in food industry. IDF from soybean residues was treated by dynamic high pressure microfluidization (DHPM), and effect of modified IDF (MIDF) addition on gelatinization and rheology of rice starch (RS) was investigated. It was found that DHPM could effectively reduce particle size of IDF, induce puffed morphology, and increase their water holding capacity. Addition of IDF/MIDF to RS increased peak and final viscosity of paste, and MIDF decreased breakdown and setback value, indicating MIDF may be a great candidate for increasing stability of paste and restraining short-term retrogradation of starch gels. Dynamic rheology indicated that supplementing MIDF changed rheological properties of RS less than IDF did. The results suggested that DHPM would provide an opportunity to change the physicochemical properties of IDF, and the resulting MIDF may be more suitable for designing fiber-enriched products.

1. Introduction

Dietary fiber (DF) has attracted considerable interest in current researches. It can typically be divided into two categories, soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Many studies have stated that sufficient consumption of DF is beneficial to normal gastrointestinal and physiological functions, including a reduced risk of coronary heart disease, diabetes, obesity, and some cancers (Mann & Cummings, 2009). As such, food processing industries are spending a huge amount of money on developing new generation of food products by incorporating DFs.

IDF were the predominant fiber fraction in byproducts of many major crops such as soybean residue and wheat bran. However, SDF rather than IDF was commonly incorporated into products, partly because introduction of IDF may cause undesirable sensory and unsuitable technological properties of the supplemented foods (Aravind, Sissons, Egan, & Fellows, 2012). Efforts have been made to modify various IDFs using different techniques, such as alkaline hydrogen peroxide treatment (Sangnark & Noomhorm, 2003), micronization (Chau, Wang, & Wen, 2007), enzymatic treatment (Napolitano et al., 2006), microwave cooking (Zia-ur-Rehman, Islam, & Shah, 2003). These processing technologies may effectively improve physiochemical and health-rated properties of various types of DF. For example, reduction of particle sizes of carrot IDF by different micronizing technologies was found to effectively enhance its *in vitro* hypoglycemic potential (Chau et al., 2007) and cholesterol-lowering activities (Chou, Chien, & Chau, 2008). Incorporation of size reduced IDF has decreased loaf volume and softness of bread (Sangnark & Noomhorm, 2003). Therefore, modification of IDF and application of modified IDF (MIDF) in food matrix have drawn a great interest.

Starchy foods are important source of calories in our diet, but it's often suggested that starchy foods are low in essential nutrients and fattening. There were a number of reports concerning supplementation of natural SDF to modify properties of starch (Banchathanakij & Suphantharika, 2009; Zhou, Wang, Zhang, Du, & Zhou, 2008). However, applications of IDF to starchy foods were unpopular. Because adding a high level of IDF to foods may adversely affect color, texture, flavor and taste of the supplemented foods (Robin, Schuchmann, & Palzer, 2012). Studying the effect of IDF or MIDF on starch would definitely help explaining some phenomenon of starchy food that contains IDF, and may widen applications of IDF in food industry, as well as open new possibilities for designing fiber-enriched products.

In this paper, IDF was modified by dynamic high pressure

* Corresponding author. Nanchang University, 235 Nanjing East Road, Nanchang, China.
E-mail address: chen-jun1986@hotmail.com (J. Chen).

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microfluidization (DHPM), which uses combined forces of high-velocity impact, high-frequency vibration, instantaneous pressure drop, intense shear, cavitation, and ultra-high pressures up to 200 MPa with a short treatment time (less than 5 s) (Liu et al., 2009). The unique working mechanism results in powerful energy so that the DHPM would be used to modify properties of many macromolecules such as whey protein (Liu et al., 2011), pectin (Chen et al., 2012) and starch (Kasemwong, Ruktanonchai, Srinuanchai, Itthisoponkul, & Sriroth, 2011). Wang, Sun, Zhou, and Chen (2012) also have suggested that DHPM process would provide an effective method to change physicochemical properties of wheat bran, but the feasibility of this technique on purified IDFs or IDFs from other resources needs to be verified, and application of MIDF also needs to be exploited. Therefore, purpose of this paper is on the one hand to investigate the effects of DHPM on physicochemical properties of IDF from soybean residues, on the other hand to evaluate the potential use of IDF/MIDFs as fiber enriching ingredient in starchy food.

2. Materials and methods

2.1. Materials

Rice starch (RS), bought from Puer Yongji Biological & Technique Co. Ltd., China, contained 9.6% moisture, 28.9% amylose; 0.4% protein, 0.3% ash, and 0.6% fat. IDF isolated from soybean residues were purchased from Lion Biological Technology Co. Ltd., China.

2.2. Purification of IDF

IDF was purified using acid-base method of Selvendran and Susan Pont (1980) with some modifications. 10 g IDF samples were added to 400 mL 1 mol/L sodium hydroxide. The dispersion was subsequently stirred at 1500 rpm, 40 °C for 100 min. Filtration was then carried out, and the obtained solid residues were washed with distilled water to neutral pH, followed by draining to dry. The solid residues were then stirred at 1500 rpm with 400 mL sulfuric acid (pH = 2) at 60 °C for 120 min, filtrated. The resulting residues were washed with distilled water again to neutral pH. Finally, residues were lyophilized and stored in hermetically sealed glass bottles.

2.3. Characterization of IDF

Moisture of IDF was determined using a halogen moisture analyzer (Model HR83, Mettler-Toledo, Switzerland). Proteins were analyzed as total nitrogen content by the Kjeldahl procedure (AOAC, 2002), and the conversion factor used to transform nitrogen into protein was 5.71. Ash content was determined by incineration of samples at 550 °C in a muffle furnace (AOAC, 2002). Sugar composition of IDFs was determined according to our previous procedures adapted for analyzing alcohol insoluble solids from *Premna microphylla* turcz leaves (Chen, Liang et al., 2014).

2.4. Dynamic high pressure microfluidization

Dynamic high pressure microfluidization experiments were performed on laboratory scale microfluidizer M-100EH-30 (channel diameter = 75 μm) (Microfluidics Co., Newton, MA). The purified IDF was dispersed in water to a solid to water ratio 1: 35 and stirred gently at room temperature overnight, and treated under the DHPM pressures of 80, 120 and 170 MPa for 3 passes, respectively, the resultant modified sample (MIDF) was named IDF_{80}, IDF_{120} and IDF_{170} accordingly. 500 mL suspension was used for the first pass, 400 mL for the second pass because initial 100 mL suspension of the first pass was discarded to eliminate the dilution effect of water which was used between passes, 300 mL for the third pass because of the same reason. The temperature of the treated sample was 22–26 °C because there was a machine cooling system on the microfluidizer. Samples just dispersed but without DHPM were taken as control (IDF). Each experiment was done three times in order to verify the repeatability of the DHPM process. Parts of solutions were applied to particle size determination. Others were collected and freeze-dried.

2.5. Determination of particle size

The particle size of IDF and MIDFs was determined by Nicomp 380/ZLS Zeta potential/Particle Sizer (PSS Nicomp, Santa Barbara, USA) based on dynamic light scattering (Chen, Wu et al., 2014). Samples were diluted 1: 10 (v/v) with deionized water. The dispersion was shaken on a vortex mixer for 3 min, and then applied to Particle Sizer immediately. Particle size refers to the corresponding intensity distribution calculated by NICOMP Distribution Analysis. All measurements were carried out at 25 °C.

2.6. Scanning microscopy analysis

IDF and MIDFs were taken after freeze-drying, and samples were prepared by sticking them to one side of double-sided adhesive tape attached to a circular specimen stub at the other end. The samples were viewed using an environmental scanning electron microscope (ESEM) (Quanta200F, FEI Deutschland GmbH, Kassel, Germany) at 30 kV voltages and 3.0 spot size. Low vacuum mode was used while operating the ESEM.

2.7. Water holding capacity

Water holding capacity (WHC) was determined according to the method of Raghavendra, Rastogi, Raghavarao, and Tharanathan (2004). An accurately weighted dry sample (1 g) was hydrated in a graduated test tube with 20 mL distilled water for 18 h. The supernatant was removed by passing through a sintered glass crucible under vacuum. The weight of hydrated residue was recorded after 1 h of draining and then the sample was dried at 105 °C overnight to obtain the residual dry weight. WHC was calculated according to the following Equation (1):

$$\text{WHC (g/g)} = \frac{\text{Residue hydrated weight} - \text{Residue dry weight}}{\text{Initial weight of sample}} \quad (1)$$

2.8. Determination of pasting properties by Rapid Visco-Analyzer (RVA)

Pasting and paste properties of samples were determined by a Rapid Visco-Analyzer (RVA-TecMaster, Newport Scientific Pt. Ltd., Australia) according to Wu et al. (2016) with some modifications. Starch (2.85 g, dry basis) and IDF/MIDF samples (0.15 g, 5 wt.% on a starch basis) were directly weighted into the RVA canister and deionized water was added to obtain a total constant sample weight of 28 g. The heating and cooling cycles were programmed according to an inherent thermal program in the apparatus, namely 'rice rapid', in which the sample was held at 50 °C for 1 min, then heated to 95 °C at a constant rate of 12 °C/min, and held at 95 °C for 2.5 min. It was subsequently cooled to 50 °C with the rate of 6 °C/min and held at 50 °C for 1.4 min. Agitation speed was fixed at 960 rpm for the first 10 s to ensure the uniformity of the dispersion,