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Blasting extrusion processing: The increase of soluble dietary fiber content and extraction of soluble-fiber polysaccharides from wheat bran

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ABSTRACT

In this study, soluble dietary fiber (SDF) content of wheat bran was significantly increased from 9.82 ± 0.16 (w/w, %) to 16.72 ± 0.28 (w/w, %) by a novel blasting extrusion processing with enhanced water retention capacity and the swelling capacity. In addition, a water-soluble polysaccharide (WBP) was isolated and extracted from extruded SDF. WBP was successfully purified from SDF by column chromatography systems with the average molecular weight (Mw) of 4.7×10^4 Da, containing arabinose, xylose, glucose, and galactose. With the molar ratio of 0.76:0.99:1.00:0.12. Our results suggest that WBP owned 1 → 2, 1 → 3, 1 → 2, 6 and 1 → 4, 1 → 4, 6 glycosidic bonds in the absence of 1 →, 1 → 6 glycosidic bonds. *In vitro* antioxidant assays (DPPH, ABTS+ radical scavenging capacities, and ferric ion reducing capacity) demonstrated that WBP possesses good antioxidant capacity, and it could be potentially used as a natural antioxidant for use in functional food, cosmetic and pharmaceutical industries.

1. Introduction

Dietary fiber consists of a mixture of compounds containing carbohydrate polymers and non-carbohydrate components. It has been suggested that high intake of dietary fiber significantly lower the risk of developing coronary heart diseases, strokes, hypertension, diabetes, obesity, and certain gastrointestinal diseases (Elleuch et al., 2011; Huang, Ye, Chen, & Xu, 2013). In particular, it was demonstrated that soluble dietary fiber (SDF) displayed stronger antioxidant activity than insoluble dietary fiber (IDF) (Esposito et al., 2005). In addition, compared to IDF, SDF has a higher capacity to form gels and act as an emulsifier, enabling it to be readily incorporated into food products (Feng et al., 2013, 2014; Jenkins et al., 2006; Mateos-Aparicio, Mateos-Peinado, & Rupérez, 2010; Sozer, Cicerelli, Heiniö, & Poutanen, 2014). There is increasing evidence that the structural features and molecular weight of polysaccharides are of fundamental importance since they are highly associated with the physicochemical and functional properties of polysaccharides.

As a main by-product in flour mills processing, wheat bran is mainly composed of epidermis, peel, seed, nucellus layer, and aleurone layer (Brouns, Hemery, Price, & Anson, 2012), and it is rich in dietary fibers. It has been suggested that wheat bran dietary fiber could reduce diverticulosis and the formation of gallstones, and prevent colon cancer, and it has a positive impact on diabetes. However, wheat bran is generally underutilized, for instance, it is discarded as waste agricultural residues or used in the production of paper and animal feeds because SDF concentration of wheat bran is far less than that of IDF. In addition, insoluble DF (IDF) was detrimental to the sensory characteristics of food products (Robin, Schuchmann, & Palzer, 2012) since IDF could cause changes in the rheological properties and the availability of the amount of free water (Santala, Kiran, Sozer, Poutanen, & Nordlund, 2014). Some attempts have been made to enhance the SDF concentration of corn bran by chemical treatment (Pai, Blake, Hamaker, & Campanella, 2009) and rice bran by enzymatic treatment (Lebesi & Tzia, 2012).

Recently, a novel unit operation, blasting extrusion processing (BEP), was developed by us, which potentially can be used in the food sectors (Chen, Ye, Yin, & Zhang, 2014). In this process, a screw rotates a high-pressure heated barrel at constant speed following Archimedes-type (Chen et al., 2014; Michelangelli, Gaspar-Cunha, & Covas, 2014). After wheat bran containing amounts of water was fed into the extrusion unit, they were subjected to the combination of high temperature and high pressure (10–50 Mpa) and formed semi-fluids in an extruder barrel. When the flow stream of the sample reached the die nozzle, the pressure was suddenly released through a die-shaped hole, resulting in the combination

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effects of high shear, turbulence, cavitation along with temperature. Under these conditions, the bonds of insoluble polysaccharides, for instance, cellulose hemicellulose and the continuous fiber matrix were partially disrupted and released soluble saccharides. In our previous study, it was concluded that this method successfully altered the internal physical structure of soybean residues and improved chemical properties of SDF (Chen et al., 2014). Conventionally, thermal extraction was employed to extract water-soluble polysaccharides from agricultural residues. However, this approach has an evident drawback for extracting bioactive products, which is unfavorable for heat sensitive constituents and the long extraction time at a high temperature, which is detrimental to heat-sensitive bioactive compounds and also results in high energy consumption and low process efficiency (Cheung & Wu, 2013; Feng, Ye, Zhuang, Fang, & Chen, 2012). Recently, enzymatic methods are developed for extraction soluble fiber polysaccharides. Nevertheless, the enzymatic-catalyzed methods still suffer the high cost of enzymes and long reaction time (>24 h) (Yang, Maldonado-Gómez, Hutkins, & Rose, 2013). Of particular significance, this novel *in situ* technique possesses several advantages over other conventional approaches, including low-cost manufacturing, high thermal dynamic efficiency, and retention of heat-sensitive nutritional components. In addition, this unit is operational safe, rapid and environmentally friendly in the absence of by-products.

The primary goal of this study was to employ BEP to increase the concentration of SDF extracted from wheat bran and also, the compositions of extrudes were assessed. It is well-recognized that soluble-fiber polysaccharides are extracted from plant or fungus based SDF due to the potential use of their chemical and biological activities in food, medicine and healthcare products (Dhital, Dolan, Stokes, & Gidley, 2014; Song et al., 2014; van den Brink & de Vries, 2011). Therefore, the secondary purpose of this study was to extract and purify water-soluble polysaccharides (WBP) from wheat bran based SDF treated with BEP. In literature, some water-soluble saccharides achieved from wheat bran, such as arabinoxylans (Hromádková, Paulsen, Polovka, Košťálová, & Ebringerová, 2013; Malunga & Beta, 2015; Prisenžňáková, Nosálová, Hromádková, & Ebringerová, 2010; Yang et al., 2013), and feruloyl oligosaccharides (Yuan, Wang, & Yao, 2006), display antioxidant activities at different degrees. Therefore, the final purpose of this study was to characterize antioxidant activities of WBP by different assays.

2. Material and methods

2.1. Chemicals

Wheat bran was obtained from Flour Mills (Tianjin, China). Sephadex G-75 and DEAE-52-cellulose were purchased from HengHui Co., Ltd. (Tianjin, China). All other chemicals and reagents were purchased from North Yayi Chemicals Co., Ltd. (Tianjin, China). All commercial chemicals were all analytical grade and used without further purification.

2.2. Blasting extrusion processing

The extrusion process parameters (the moisture of wheat bran, temperature, and the rotating speed), were preliminarily optimized with orthogonal experimental design method. Fine wheat bran powder with a moisture content of 45 (w/w, %) was extruded by a laboratory scale twin-screw extruder (SYSLG32-II, Jinan Saibainuo Science and Technology Development Co, Ltd., Jinan, China) at a barrel temperature of 140 °C at a rotation speed of 150 r/min. The extruded sample was then dried at 60 °C in an oven for 48 h. Subsequently, the raw material was carefully ground into a fine powder using a mortar and pestle following pass through mesh screen (1 mm) and stored at −20 °C. The contents of DF and SDF in the extruded wheat bran were determined by AOAC method.

2.3. Proximate composition analysis

Protein content was determined by the Kjeldahl method using a conversion factor of 6.25 (Koch & McMeekin, 1924). Fat content was determined by the Soxlhet method (Sukhija & Palmquist, 1988). Ash content was determined by incineration in a muffle furnace at 550 °C and then weighed. Starch content was determined by enzymatic hydrolysis method. The crude protein content was measured according to the AOAC method. All measurements were performed in duplicate.

2.4. Extraction of SDF

The SDF extraction procedure is displayed in Fig. 1 and the procedure followed the published method (Li, Fan, & Ding, 2011). Briefly, de-oiled wheat bran treated with BEP was soaking in water (1:40, w/w) for 1 h at 120 °C. After the hydrolysis of amylase and protease were centrifuged at 5000 r/min for 15 min at 25 °C. Afterwards, the supernatant was washed by 95% ethanol until no precipitation was achieved. Subsequently, the precipitation was collected after freeze drying.

2.5. Purification of polysaccharide

The purification of polysaccharide was based on the method in literature (Zhang, Guo, & Chen, 2014). In brief, SDF was dissolved in distilled water and then centrifuged to remove insoluble residues. 25 mg of the supernatant was purified through a DEAE-52-cellulose column (2.6 cm × 50 cm) eluted with a linear gradient from 0 to 1.0 M NaCl-eluent at a flow rate of 5 ml/(5 min × tube). Total carbohydrate content was measured by phenol–sulfuric acid colorimetric method at 490 nm; protein absorption at 280 nm was measured for each fraction. Three fractions from the elution step, WBP_1, WBP_2 and WBP_3 were concentrated, dialyzed, and lyophilized. 10 mg of the fraction WBP_2 was purified through a Sephadex G-75 column (1.6 cm × 60 cm) eluted with distilled water at flow rate of 4 ml/(5 min × tube). Two fractions from this step, WBP_{2a} and WBP_{2b}, were collected, and their total carbohydrate contents were then measured. The fraction WBP_{2a} was purified through a Sephadex G-200 column (1.6 × 40 cm) with the same elution as above-mentioned. The fraction containing carbohydrate was concentrated, and then used as the purified polysaccharide (WBP_{2a}).

2.6. Water solubility, water retention capacity (WRC), and swelling capacity

The water solubility was assessed according to a published method (Chen et al., 2014) with minor modifications. 0.5 g of the sample was carefully mixed with 50 ml of distilled water in a beaker. Then, the mixture was gently stirred at 90 °C for 30 min in thermostat water bath followed by centrifugation at 3000 r/min for 15 min. The supernatant was dried until the weight was constant.

The water retention capacity was measured on the basis of the published approach (Chen et al., 2014). A 15 ml aliquot of distilled water was gently mixed with 250 mg of sample at room temperature for 1 h. After centrifugation at 3000 g for 20 min, the residue was collected and weighed. The WRC was expressed as g of water per mg of dry sample.