LWT - Food Science and Technology 75 (2017) 344–351

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Structural characteristics and functional properties of rice bran dietary fiber modified by enzymatic and enzyme-micronization treatments

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ARTICLE INFO

Article history:
Received 25 April 2016
Received in revised form
5 September 2016
Accepted 9 September 2016

Keywords:
Xylanase
Cellulase
Ball-milling
Crystalline structure
Thermal property

ABSTRACT

Using cellulase, xylanase, and ball-milling, the influences of enzyme and enzyme-micronization treatments on the structural and functional properties of rice bran dietary fiber (RBDF) were investigated. Due to the degradation of insoluble dietary fiber, the cellulase, xylanase, micronization, combined enzymes, and enzyme-micronization treatments increased the soluble dietary fiber content by 3.8, 4.7, 3.5, 10.0, and 11.4 fold, respectively. Scanning electron microscopy analysis indicated the enzymatic treatments caused the breakage of RBDF structure, and the enzyme-micronization treatment totally broke the RBDF matrix. Cellulase and xylanase increased RBDF crystallinity because of the hydrolysis of hemicellulose and the amorphous portion in cellulose, while enzyme-micronization reduced RBDF crystallinity due to the destruction of crystalline structure. Infrared spectroscopy indicated the breakage of intra-molecular hydrogen bonding and increased oligosaccharides, and differential scanning calorimetry analysis showed the oligosaccharides melting and reduced water-evaporating peaks because of the enzymatic and enzyme-micronization treatments. Additionally, enzyme and enzyme-micronization reduced the water and oil holding capacity, but increased the swelling capacity, cholesterol and sodium taurocholate absorption capacity of RBDF. The results suggest that cellulase and xylanase can modify the structural and functional attributes of RBDF, and the enzymatic treatments assisted with micronization is more effective in modifying the RBDF properties.

1. Introduction

Previous studies have shown that dietary fiber (DF) provides beneficial effects on maintaining the gastrointestinal function, lowering the postprandial glycemic index, and reducing the risks of cardiovascular diseases, diverticulosis and colon cancer (Abdul-Hamid & Luan, 2000; Kovatcheva-Datchary et al., 2015). DF also possesses many technological functionalities, such as water holding capacity (WHC), oil holding ability (OHC), thickening and emulsifying properties, which have led to its potential uses for regulator and additive in food industry. These characteristics of DF are encouraging more research on fibers from abundant sources. Rice bran, containing approximately 200–350 g/kg of DF, has been reported as a good source of DF by many studies (Abdul-Hamid & Luan, 2000; Gul, Yousuf, Singh, Singh, & Wani, 2015; Qi, Li, et al., 2015; Qi, Yokoyama, et al., 2015). It also has a great potential in food products with high nutritional values (Chinma, Ramakrishnan, Ilowefah, Hanis-Syazwani, & Muhammad, 2015; Saunders, 1986).

Rice bran dietary fiber (RBDF) is mainly composed of cellulose, hemicellulose, lignin, and pectic substances (Chinma et al., 2015; Elleuch et al., 2011). Most DF from rice bran is insoluble and called insoluble dietary fiber (IDF); only a small part is soluble and called soluble dietary fiber (SDF). IDF has shown the physiological functionalities of supporting the growth of intestinal microflora,

Abbreviations: CAC, Cholesterol Absorption Capacity; DSC, Differential Scanning Calorimeter; FT-IR, Fourier Transform Infrared Spectroscopy; IDF, Insoluble Dietary Fiber; OHC, Oil Holding Capacity; RBDF, Rice Bran Dietary Fiber; SC, Swelling Capacity; SDF, Soluble Dietary Fiber; SEM, Scanning Electron Microscopy; STAC, Sodium Taurocholate Absorption Capacity; TDF, Total Dietary Fiber; WHC, Water Holding Capacity; XRD, X-Ray Diffraction.

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http://dx.doi.org/10.1016/j.lwt.2016.09.012
0023-6438/

increasing the faecal bulk, decreasing the intestinal transit, and inhibiting the pancreatic lipase activity (Foschia, Peressini, Sensidoni, & Brennan, 2013; He et al., 2015), but it adversely impacts the color, texture, flavor and taste when supplemented in food products (Robin, Schuchmann, & Palzer, 2012). Compared to IDF, SDF has a greater capacity to promote viscosity, form gels, and act as emulsifier due to its solubility (Abdul-Hamid & Luan, 2000). It also contributes to reduce the glycemic response and plasma cholesterol (Roehrig, 1988). Because of the undesirable sensory qualities that IDF causes, many efforts have been made to modify IDF or DF to improve the physico-chemical properties and technological functionalities (Lebesi & Tzia, 2012; Napolitano et al., 2006; Qi, Yokoyama, et al., 2015; Wang, Sun, Zhou, & Chen, 2012; Yan, Ye, & Chen, 2015). Qi, Li, et al. (2015) and Qi, Yokoyama, et al. (2015) reported that sulfuric acid at low concentrations (2–6 g/L) increased the WHC and swelling capacity (SC) of IDF due to the removals of starch and protein, and increased WHC and SC could enhance the transit time of the food stuff and decrease the cholesterol availability in the small intestine. Therefore, changes in IDF technological properties promoted its application as an antidiabetic and cholesterol lowering functional ingredient. Yan et al. (2015) modified the DF from wheat bran using a blasting extrusion processing and enhanced the WHC and SC of DF by increasing the SDF content.

Enzymatic treatments have been proven to be effective on the quality improvements of DF and bran by modifying the structure or redistributing the composition (Lebesi & Tzia, 2012; Santala, Kiran, Sozer, Poutanen, & Nordlund, 2014). Bran modification by xylanase and cellulase could increase the crispiness and decrease the hardness and piece density of the extrudates containing wheat bran (Santala et al., 2014). The use of xylanase increased the SDF content of oat bran, and reduced the water binding and holding capacity (Lebesi & Tzia, 2012). Laccase and cellulose assisted by a high hydrostatic pressure could increase the SDF content, alter the honeycomb structure of DF, and generate new polysaccharides (Ma & Mu, 2016). The hydrolysis by the complex enzymes including α-amylase, glucoamylase, protease and cellulase significantly increased the total phenolics, flavonoids, ferric reducing antioxidant power, and oxygen radical absorbance capacity of rice bran (Liu et al., 2017). Meanwhile, more attention is being focused on the application of micronization in the processing of cereal grain based food. It has been proven that reduction in raw material particle size not only alters their structural characteristics but also improves the technological properties when used in food development (Raghavendra et al., 2006; Sangnark & Noomhorm, 2003). Chen, Gao, Yang, and Gao (2013) reported that microfluidization effectively reduced IDF particle size to submicron scales and triggered a redistribution of fiber composition. Bran particle size reduction by micronization could increase the perceived smoothness of wheat bran-containing breads (Coda, Kärki, et al., 2014). Extensive ball-mill treatment (120 h, 50% jar volume capacity) could increase the water-extractable arabinoxylan (WE-AX) level by 15.0 fold in wheat and rye bran (Craeyveld et al., 2009). Grinding operation could change the honeycomb structure of fiber matrix to a flat ribbon type structure, thereby providing increased surface area for water and fat absorption (Raghavendra et al., 2006). However, there is little scientific information available on the influences of the combination treatment of enzyme and micronization on the structure and functional properties of cereal bran or DF.

The objective of the study is to investigate the structural characteristics, technological functionalities (WHC, OHC and SC), and In vitro binding capacities (cholesterol absorption capacity and sodium taurocholate absorption capacity) of RBDF modified by enzymatic and enzyme-micronization treatments. It is our hope that the research will contribute to develop a novel and effective method for the modification and application of RBDF.

2. Materials and methods

2.1. Materials

Defatted rice bran was provided by Qing He Oil Group (Gaoan, Jiangxi Province, China). The total dietary fiber, crude protein, total starch, ash, and moisture of rice bran were 384 g/kg, 148 g/kg, 249 g/kg, 98 g/kg, and 102 g/kg, respectively. Xylanase (1.67 millikatal (mkat)/g, originated from *Aspergillus niger*) was bought from Heshibi Biological Technology Ltd. (Yinchuan, Ningxia Province, China). Cellulase (1.30 mkat/g, originated from *Penicillium* sp.) was provided by Guoyao Chemicals Ltd. (Shanghai, China). Other chemicals used in the present study were of analytical grade and provided by local chemical companies.

2.2. Enzymatic and enzyme-micronization treatments

The isolation and purification of dietary fiber were performed as the following steps: defatted rice bran (100 g) was firstly soaked in distilled water (1 L, 50 °C, 1.5 h), followed by centrifugation (1900 g, 15 min). The resulting insoluble material was soaked in a 0.75 mol/L NaOH solution (1 L, 50 °C, 2 h) to remove protein, and the slurry was adjusted to pH 6.5 and gelatinized at 100 °C for 15 min. The treated slurry was incubated with heat-resistant α-amylase at 95 °C for 35 min to remove starch. After washing with distilled water and centrifuging at 1900 g for 5 min, a 250 mL of 950 g/kg ethanol solution was added to precipitate SDF (60 °C, 2 h). The resulting residue (IDF) was then dried at 50 °C for 12 h in an air drying oven, followed by grinding and sieving through a 250 μm mesh. The SDF and IDF were combined to obtain the raw or untreated RBDF.

The enzymatic treatment was conducted as the following steps: RBDF (50 g) was soaked in hot water (600 mL) at 50 °C for 0.5 h, and then cellulase was added at 9.34 nanokatal (nkat)/g (RBDF) and the slurry was incubated for 2 h (50 °C, pH 4.8). The treated slurry was centrifuged at 1900 g for 5 min after the inactivation of enzyme in boiling water bath for 10 min. The resulting insoluble material was washed twice with hot water (pre-heated to 50 °C) and centrifuged (1900 g, 5 min) again. A 200 mL of 950 g/kg ethanol solution was added to precipitate SDF, and the residue was dried at 50 °C for 12 h in an air drying oven, followed by smashing and sieving through a 250 μm mesh. The SDF and the residue were combined to obtain the sample labeled Cel. The xylanase and combined enzymes treatments were conducted by the same process as Sample Cel with some modifications. Xylanase was used at 667 nkat/g (RBDF) with pH at 5.5 to obtain Sample Xyl. Cellulase and xylanase were used at 9.34 nkat/g (RBDF) and 667 nkat/g (RBDF), respectively, with pH at 4.8, to obtain Sample Combined-En.

The combined enzymes plus micronization (enzyme-micronization) treatment was performed by the following method: RBDF (50 g) was added to distilled water (1 L) with the same combined enzymes as Sample Combined-En (pH 4.8). The mixture was evenly divided into four grinding jars, each jar was 750 mL/L filled with zirconia. Then the mixture was wet-milled with a planetary ball mill (Huang Lian Machinery Group Co., Ltd, Lanzhou, Gansu Province, China) at 3000 r/min for 2 h to obtain Sample En-Micro. During the grinding process, the particle size of the sample was reduced by the collision among the zirconia or between the zirconia and the inner wall of the grinding jar. A cooling water bath was applied to avoid the excess high temperature in the grinding jar and the temperature was kept between 45 °C and 55 °C during the experiments. Micronization treatment without enzyme was also conducted as a control group, and the sample was labeled with Micro.