Preparation of Oat Bran Dietary Fiber by Steam Explosion and Its Functional Structure Characteristics

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Abstract [**Objectives**] This study was conducted to investigate the process conditions, function and structural characteristics of oat bran dietary fiber prepared by steam explosion (SE). [**Methods**] With oat bran as the raw material, the technical parameters for preparing dietary fiber by steam explosion were studied, and the functional and structural characteristics of DF before and after modification were discussed. [**Results**] The optimum conditions for extracting DF from oat bran by SE modification were steam explosion pressure of 0.6 MPa and holding time of 4 min. The extraction rate of DF reached 33.9%. The solubility, water holding capacity, oil holding capacity and swelling force of Control-DF were 78.35%, 2.25 g/g, 1.55 g/g and 3.05 ml/g, respectively, and those of SE-DF were 95.69%, 3.28 g/g, 2.18 g/g and 5.98 ml/g, respectively. After SE treatment, the scavenging rates of oat bran DF on DPPH, ABTS, O_2^- · and ·OH were significantly higher than those of untreated samples. The scavenging ability on free radicals was enhanced. The scavenging rates of Control-DF on DPPH, ABTS, O_2^- · and ·OH were 43.72%, 50.26%, 31.02% and 39.25%, respectively, and those of SE-DF were 70.25%, 73.21% and 63.69% 59.32%, respectively. The surface of modified DF showed an obvious honeycomb structure. [**Conclusions**] This study can provide reference for functional modifications and utilization of dietary fiber from oat bran.

Key words Oat bran; Dietary fiber; Steam explosion; Functional and structural property
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Dietary fiber is indispensable for a healthy diet and plays an important role in keeping the digestive system healthy. Meanwhile, taking enough dietary fiber can also prevent cardiovascular diseases, cancer, diabetes and other diseases. It can clean the digestive wall and enhance digestive function, dilute and accelerate the removal of carcinogens and toxic substances in food, and protect the fragile digestive tract and prevent colon cancer. Furthermore, it can slow down digestion and excrete cholesterol most quickly, and control blood sugar and cholesterol at the optimal level[1–6].

Oat bran is the main by-product of oat processing, and the dietary fiber in oat is mainly concentrated in bran. However, oat bran is mainly used as a cheap raw material for fertilizer, feed and other production, with low economic and social benefits, and there are technical problems such as low comprehensive utilization, insufficient in-depth development and few deep-processed products. The preparation of dietary fiber products using remaining oat bran is beneficial to improving the utilization rate of oat resources, enhancing the added value of oat products and promoting the sustainable development of economy.

The principle of steam explosion technique is that when the material suddenly drops from high temperature and high pressure to normal temperature and pressure in an instant, the water inside the material suddenly vaporizes, and the gas suddenly expands, resulting in a blasting effect. Steam explosion pretreatment can make the material tissue spongy and increase its volume, and some structural tissues such as fiber bundles are destroyed and the inclusions are exposed, which is beneficial to the dissolution of target substances and helps to improve the effect of enzymatic hydrolysis of raw materials[7].

In this study, the preparation technique of oat bran dietary fiber by steam explosion and its function and structural characteristics were studied in depth, and it was put forward that modified oat bran dietary fiber, as a functional food ingredient, has a wide development and application prospect in China.

Materials and Methods

Materials, reagents and instruments

Oat bran, provided by Tangshan Runze Cereals Oils and Foodstuffs Co., Ltd.

Control-DF: First, 200 g of oat bran was weighed and added with deionized water according to the material-liquid ratio of 1 : 7 (g/ml). Next, the obtained mixture was stirred evenly, treated with a colloid mill twice, and centrifuged (rotation speed 4 200 r/min, centrifugation time 20 min). The supernatant was concentrated to 1/10 of the original volume by rotary evaporation, precipitated with 4 times of 75% ethanol for 20 min, and vacuum filtered. Finally, the obtained filter residue was dried in a drying box at 40 ℃ at low temperature to obtain DF.

SE-DF: First, 200 g of oat bran was weighed and added with deionized water according to the material-liquid ratio of 1 : 7 (g/ml).

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Next, the obtained mixture was stirred evenly, treated with a colloid mill twice and then with steam explosion equipment at a certain pressure and centrifuged (rotation speed 4 200 r/min, centrifugation time 20 min). The supernatant was concentrated to 1/10 of the original volume by rotary evaporation, precipitated with 4 times of 75% ethanol at 60 ℃ for 20 min, and vacuum filtered. Finally, the obtained filter residue was dried in a drying box at 40 ℃ at low temperature to obtain DF.

Hydrogen peroxide, DPPH and salicylic acid, all analytically pure, Beijing Chemical Reagent Company; JK1002 electronic analytical balance, Shanghai Ohaus International Trading (Shanghai) Co., Ltd.; TD5B desktop centrifuge, Shanghai Anting Scientific Instrument Factory; XD-3000BDQ rotary evaporator, Jiangsu Taicang Experimental Equipment Factory; DR889-1 electrothermal constant temperature blast drying oven, Shanghai Yiheng Technology Co., Ltd.; HH-1 water bath thermostatic oscillator, Jiangsu Guohua Electric Appliance Co., Ltd.; JM-65 colloid mill, Shanghai Duoyuan Machinery Manufacturing Co., Ltd.; steam explosion equipment, made in Beijing University of Chemical Technology; S-4800 scanning electron microscope, Hitachi, Japan.

Experimental methods

Selection of technical conditions for SE preparation of oat bran DF

(1) The steam explosion pressures were 0.5, 1.0, 2.0, 3.0, 4.0, 5.0 and 6.0 MPa, respectively, and the holding time was 4 min. The effects of treatment pressure on the extraction rate of DF were investigated.

(2) The holding time was 1, 2, 3, 4, 5 and 6 min respectively, and the treatment pressure was 4.0 MPa. The effects of holding time on the extraction rate of DF were investigated.

Determination of solubility (WS) and oil holding capacity (OHC) Solubility (WS) and oil holding capacity (OHC) were determined referring to Tang Xiaoqing's methods[8].

Determination of swelling force (SC) and water holding capacity Swelling force (SC) and water holding capacity were determined referring to Li Lun's methods[9].

Determination of scavenging rates of ABTS, ·OH, O_2^-· and DPPH The scavenging rates of ABTS, ·OH, O_2^-· and DPPH were determined referring to Cao Huihui's methods[10].

Microstructure characterization Crushed dietary fiber was adhered to a gold-plated table with double-sided adhesive tape. After coating, it was observed by an S-4800 cold field emission scanning electron microscope under the condition of accelerating voltage of 12 KV.

Data processing

Design-Expert 7.0 was adopted for data analysis, including experimental design and data processing.

Results and Analysis

Effects of steam explosion on DF extraction rate

The effects of steam explosion pressure on DF extraction rate is shown in Fig. 1 - a. The results showed that the extraction rate of DF increased with the increase of pressure in the early stage, and the highest extraction rate was 33.7% when the pressure was 4.0 MPa, and then it began to decline. It could be seen that pressure had a great effect on the extraction rate of DF. When the pressure was lower than 1.0 MPa, the effect of steam explosion was not obvious because of the low pressure. However, when the pressure was higher than 5.0 Pa, the color of oat bran was seriously changed and the effective components were destroyed. Cellulose, lignin and other substances were seriously degraded and became small molecules, which could not be separated by alcohol precipitation, reducing the extraction rate of DF[11]. Therefore, the steam explosion pressure selected in this study was 4.0 MPa.

The effects of holding time on DF extraction rate are shown in Fig. 1 - b. The results showed that the extraction rate of DF increased with the increase of holding time in the early stage, and the highest extraction rate was 33.9% at 4 min, and then, it began to decrease slowly. It could be seen that the holding time was not as long as possible. When the holding time was short, oat bran could not be fully exploded and expanded, and the extraction rate of DF was low. Excessive holding time increased energy consumption, and more importantly, it could lead to severe degradation of substances such as cellulose and lignin into small molecules that could not be separated by alcohol precipitation, thereby reducing the extraction rate of DF. Therefore, the holding time selected in this study was 4 min.

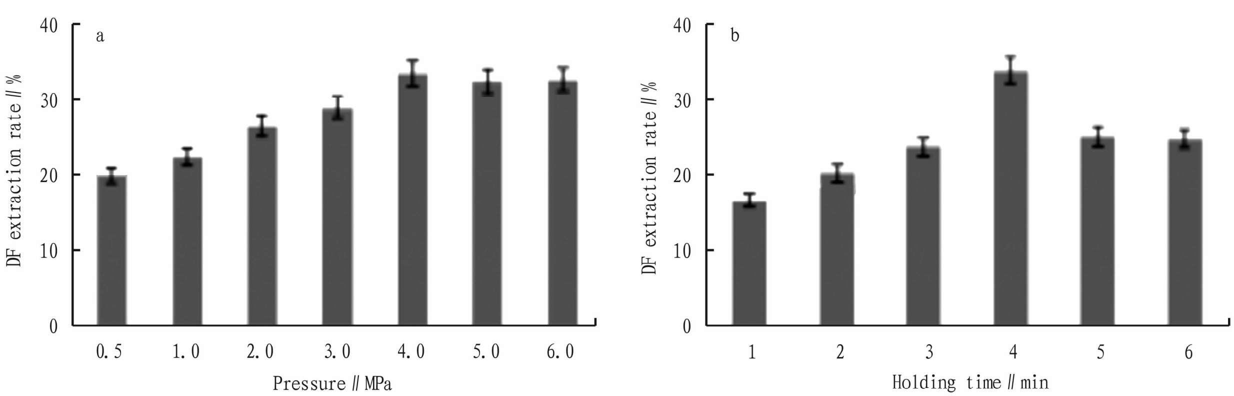


Fig. 1 Effects of steam explosion on extraction rate of oat bran DF

Analysis on functional characteristics of oat bran DF

It can be seen from Table 1 that the functional characteristics of oat bran DF were improved after steam explosion treatment. The solubility, water holding capacity, oil holding capacity and swelling force of Control-DF were 78.35%, 2.25 g/g, 1.55 g/g and 3.05 mL/g, respectively, and the values of SE-DF increased, respectively, to 95.69 %, 3.28 g/g, 2.18 g/g and 5.98 ml/g, which increased by 22.13 %, 45.78 %, 40.65 % and 96.07 %, respectively. During steam explosion treatment, the material structure became spongy and the volume increased. Some structural tissues such as cellulose were destroyed, exposing their contents, which was beneficial for the dissolution of target substances, improving the effects of enzymes on the substrate and enhancing the enzyme hydrolysis efficiency of the raw material. It increased the content of pectin soluble dietary fiber and enhanced its ability to bind with water molecules. After dissolving in water, particles expanded and stretched to produce a larger volume, resulting in an increase in the solubility, water holding capacity, oil holding capacity and swelling force of modified DF[13].

Table 1 Effect of steam explosion treatment on functional characteristics of oat bran DF

Sample	WS//%	WHC//g/g	OHC//g/g	SC//ml/g
Control-DF	78.35	2.25	1.55	3.05
SE-DF	95.69	3.28	2.18	5.98

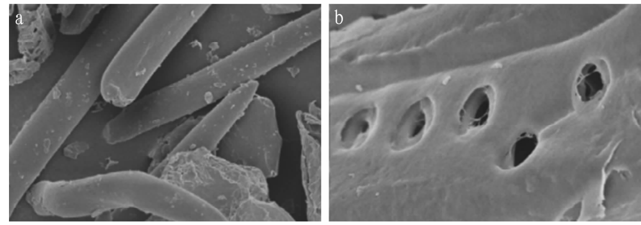
The scavenging rates of DPPH, ABTS, O_2^- ·, and ·OH by oat bran DF after steam explosion treatment are shown in Table 2. The scavenging rates of DPPH, ABTS, O_2^- ·, and ·OH by oat bran DF after steam explosion treatment were obviously higher than those of untreated samples, which might be due to the fact that the average particle size of DF was obviously reduced, and the uniformity and surface area of the sample increased after steam explosion treatment. As a result, the contact surface area between antioxidant components in DF and extractant increased in the process of extracting antioxidant substances. Moreover, after steam explosion treatment, the cell wall of the material was destroyed, and active components were easily dissolved. Many insoluble active components became soluble small-molecule substances, and the extraction rate increased accordingly[14].

Table 2 Effects of steam explosion treatment on antioxidant capacity of oat bran DF %

Sample	DPPH	ABTS	O_2^-	·OH
Control-DF	43.72	50.26	31.02	39.25
SE-DF	70.25	73.21	63.69	59.32

Characterization of structural characteristics of oat bran DF

As can be seen from Fig. 2(a), the particles of DF are large, uniform in size, rod-shaped and flat in surface at first. From Fig. 2(b), it can be seen that the structure of DF was seriously damaged after SE treatment, and it is granular, while the surface structure becomes rough and loose. The reason might be that DF was crushed by high-speed collision. Meanwhile, due to instantaneous pressure loss, a kind of structural collapse similar to expansion was produced, which made the rod-shaped particles smaller and the surface structure coarsened. The surface structure of fiber particles was destroyed, resulting in multi-layer irregular flaky or even porous structure.



a: Control-DF; b: SE-DF.

Fig. 2 Observation of oat bran DF under scanning electron microscope

Conclusions and Discussion

(1) The optimum conditions for extracting DF from oat bran by SE modification were steam explosion pressure of 0.6 MPa and holding time of 4 min. The extraction rate of DF reached 33.9%.

(2) The solubility, water holding capacity, oil holding capacity and swelling force of Control-DF were 78.35%, 2.25 g/g, 1.55 g/g and 3.05 ml/g, respectively, and those of SE-DF were 95.69%, 3.28 g/g, 2.18 g/g and 5.98 ml/g, respectively. After SE treatment, the scavenging rates of oat bran DF on DPPH, ABTS, O_2^- · and OH were significantly higher than those of untreated samples. The scavenging ability on free radicals was enhanced.

(3) Scanning electron microscope observation showed that SE treatment could make long thin rod-shaped fiber curl and break, and expand into flocculent structure, and the surface had concave holes, which fundamentally changed the morphological characteristics of DF.

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