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REGULAR ARTICLE

Physicochemical and functional properties of dietary fiber from Bamboo Shoots (*Phyllostachys praecox*)

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ABSTRACT

Dietary fibers are a necessary component of diet and have positive connection with human health. Dietary fiber extraction and characterization in terms of physicochemical and functional properties of dietary fiber from bamboo shoots are not yet explored. To find the potential applications of dietary fiber from bamboo shoots in food and health products, the effects of chemical, enzymatic methods and particle size distribution on the chemical and structural composition, physicochemical, and functional properties of dietary fibers (DFs) from bamboo shoots were studied. The results showed that BSEDF and BSCDF had higher total DF and higher soluble DF, respectively. The crystalline regions calculated to be higher in latter and both had irregular surfaces and diverse monosaccharide composition. Both fibers showed good functional properties [water retention capacity (WRC) (11.24-15.13g/g), water swelling capacity (WSC) (18.84-28.75 mL/g), oil holding capacity (OAC) (6.71-10.15 g/g), glucose adsorption capacity (GAC) (0.08-6.89 mmol/g) and glucose retardation index (GRI) (3.57-40.92%)]. WRC of BSCDF and BSEDF decreased with the increase in the mesh size (40-200) while, WSC and OAC increased with mesh sizes (40 to 120), followed by decrease above mesh120. Both particle size and extraction methods significantly affected GRI. In conclusion, physico-chemical properties of fibers can be manipulated through treatments (chemical and enzymatic) to improve their overall functionality. Therefore, both BSCDF and BSEDF can find potential applications in food and health products as a functional ingredient in different aspects.

Keywords: Bamboo shoots; Dietary fiber; Particle size distribution; Physicochemical and functional properties

INTRODUCTION

Since time immortal, dietary fibers (DFs) have been consumed and known to contribute almost no energy and impart health benefits (Tungland and Meyer, 2002). Because of their linkage to human health, plants with DFs and bioactive compounds are of great interest to researchers globally (Goyal et al., 2015; Requena et al. 2016). DFs form food components (cellulose, hemicelluloses and lignin), non-digestible constituents in the cell walls of plants, fractions of food (polysaccharides and lignin) as well as non-digestible oligosaccharides (Mccleary et al., 2010). Epidemiological studies suggested that DFs consumption can help in maintaining the functional integrity of the gastrointestinal system, and reducing colon cancer and heart disease (Davidson and Mcdonald, 1998) which are related to physicochemical and functional properties of DFs depending on the food sources, extraction methods, chemical composition, structure, and particle size of DFs (Peerajit et al., 2012; Wuttipalakorn et al., 2009). Therefore, it is recommendable to explore new sources of DFs.

The fractions of fibers, based on their solubility, is classified into insoluble (IDF) and soluble (SDF) dietary fibers (Mudgil and Barak, 2013). IDF with high water retention capacity (WRC) and water swelling capacity (WSC) and SDF with high viscosity attribute have many health benefits (Liu et al., 2016; Macagnan et al., 2016; Sauracalixto, 2011; Tungland and Meyer, 2002; Shiyi et al., 2001).

Chemical and enzymatic methods are currently used to extract DFs from different food sources. Various processing steps also lead to the modification of fiber compositions and microstructure, which in turn, lead to both desirable and undesirable changes in the functional and nutritional properties of the fibers (Peerajit et al.,

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2012). Besides fruits and cereals, vegetables are important part of the diet and also serve as one of the main sources of DFs. Among them, bamboo shoots are commonly used in China and many parts of Asian countries like India (North east regions) (Thakur et al., 2016), and regarded as a highly palatable delicacy as a healthy and nutritious food (Thomas et al., 2016). Recently, there are reports about functional foods from the bamboo shoots (Nirmala et al. 2014).

Luo et al. (2017) prepared the dietary fibers from bamboo shoot shell using multiple enzymes method, and demonstrated that the total dietary fiber from bamboo shoot shell supplement could decrease the body weight, total cholesterol, triglyceride and low density lipoprotein-cholesterol in mice. The current work was designed to evaluate the effects of different extraction methods (chemical and enzymatic hydrolysis) on the chemical composition and structural properties of DFs extracted from BS. Further, the effects of particle size distribution on the physicochemical and functional properties of DFs were also studied with an aim to provide understanding on the potential applications of DFs from BS.

MATERIALS AND METHODS

Materials and reagents

The bamboo shoots were obtained from Ningguo Maosheng Food Co.Ltd. (Anhui, China) followed by drying at 60°C and then fine grinding and passing through a 60-mesh sieve, and then storage in polyethylene bags until use. α-Amylase, protease and amyloglucosidase were purchased from Beijing BAOXING bio-tech CO., Ltd. Glucose assay kit were obtained from Nanjing Jiancheng Bioengineering Institute (Nanjing, China).

Extraction of DFs from bamboo shoots powder (BSP)

The DFs from BSP were extracted through chemical treatment and enzymatic hydrolysis methods according to the descriptions by Chen et al. (2015) and Wang et al. (2016). The obtained products were named as BSCDF and BSEDF, respectively. After freeze drying, BSCDF and BSEDF were grounded into fine powder using a mortar and screened with different stainless steel sieves (mesh No. 40, 80, 120, and 200), and stored in a container with a tight-fitting lid until further analysis.

Component analysis

Moisture, crude protein, crude fat and ash contents were determined by using the appropriate AOAC methods (AOAC, 2000). TDF, IDF and SDF contents were determined according to the AOAC method 991.43 (AOAC, 2000).

Scanning electron microscopy (SEM)

The microstructure of DFs samples and BSP were examined as described by Ma et al. (2016) using SEM (JSM-6490LV, Japan) at 15.kV. Representative micrographs were taken for each sample at 200, 500 and 1000×magnifications.

X-ray diffraction (XRD)

X-ray diffraction of DFs and BSP were carried out as described by Cao and Tan (Cao and Tan, 2005) in an X-ray diffractometer (X'Pert PRO MPD, Netherlands) with minor modification at 40 kV and at 40 mA incident current. The angular region range was scanned from 5° to 70° with a step length of 0.05 and a step rate of 0.21/s. With MDI Jade 5.0 software (Materials Data, Inc., California, USA), the degree of crystallinity was calculated based on the peak area (Ma and Mu, 2016) using the following equation,

$$Dc\ (\%) = Ac \times 100/(Ac+Aa)$$

Where Dc is the degree of crystallinity, Ac is the crystalline area on the X-ray diffractogram, and Aa is the amorphous area on the X-ray diffractogram.

Fourier transform infrared (FT-IR) spectroscopy

FT-IR spectroscopy was conducted to obtain the molecular structure of DFs (Shi et al., 2016). Each sample was measured using a Thermo Nicolet 67 FT-IR spectrometer equipped with a DTGS detector with a resolution of 0.09 cm^{-1} in the range of 400–4000 cm^{-1}. The samples were mixed with potassium bromide (KBr) at room temperature and then pressed into a 1.0-mmthick pellet. Pure KBr was used as control.

Monosaccharide composition analysis

The monosaccharide compositions of fiber fractions were analyzed as described by He et al. (2016) with minor modifications. Approximately 0.1 mL of the resulting supernatant was analyzed by gas chromatography (GC) on a GC equipped with a flame ionization detector and an Rtx@-65 (30 m × 0.32 mmID × 0.25 μmdf) column.

Particle size distribution

The particle size distribution of samples with different sizes was measured using the Laser Particle Size Analyzer (MS-2000, England Malvern) with a He-Ne 632.8 nm laser and 466 nm solid blue light source. Particle size distribution parameters were displayed as Sautermean diameter [D3,2 (μm)] (Ma and Mu, 2016).

Functional group properties

The physico-chemical properties of two types of fiber fractions were determined as the description by Ma et al. (2016).

Glucose adsorption capacity (GAC)

GAC was determined by the method reported by Peerajit et al. (2012).

Glucose retardation index (GRI)

The GRI is used to predict the effect of fiber on the delay of glucose absorption in the gastro-intestinal tract. The measurement of GRI was performed using the method given by Peerajit et al. (2012) with slight modifications.

Statistical analysis

The experimental data were analyzed using the analysis of variance (ANOVA) and are presented as mean ± standard deviation (SD) of triplicates. The differences between mean values were established using Duncan's multiple range tests. Values were considered at a significance level of 95% ($p < 0.05$). Statistical analyses were performed using SPSS statistics 19.

RESULTS AND DISCUSSION

Component analysis

In this study, the DFs were obtained by two different extraction methods. The significant differences in the yields and chemical compositions of bamboo shoot powder (BSP), BSCDF and BSEDF were shown in Table 1. The yield of BSCDF (20.06%) was higher than BSEDF (16.11%), which might be due to the insufficient degradation of starch as Konovalova et al. (2016) had reported that α-amylase could rapidly increase starch hydrolysis. This make chemical extraction more preferable for better yield. Compared to BSCDF, BSEDF had higher TDF content i.e. 67.17 g/100 g and IDF (60.51 g/100 g), while BSCDF had higher content of SDF, which could be partially due to the transformation of some IDF into SDF during acid-alkali treatment (Chen et al., 2015). Thus, BSCDF may find application for various health benefits due to high SDF (Liu et al., 2016). However, both BSCDF and BSEDF had low contents of SDF which could suggest that bamboo shoots extracts contain small molecules which are hard to be precipitated (He et al., 2016). Previous study suggested that the solubilization of the polysaccharides resulted in decreased total fiber content mainly due to loss of SDF (Kutos et al., 2003). Our results showed that chemical compositions of DFs including TDF, IDF, SDF, crude fat and ash content were significantly influenced by processing methods.

Table 1: Chemical compositions of BSP, BSCDF and BSEDF

Component (%)	BSP	BSCDF	BSEDF
Yield	-	20.06±0.57^a	16.11±0.17^b
Moisture	4.81±0.05^c	9.91±0.07^b	12.44±0.11^a
Crude protein	10.42±0.43^a	1.74±0.11^b	2.25±0.10^b
Crude fat	0.15±0.01^a	0.09±0.01^c	0.11±0.01^b
Ash	17.7±0.83^a	10.12±0.43^b	17.53±0.52^a
Total dietary fiber	20.18±0.22^c	40.78±0.53^b	67.17±0.70^a
Insoluble dietary fiber	18.27±0.27^c	28.13±0.34^b	60.51±0.80^a
Soluble dietary fiber	1.91±0.06^c	12.65±0.21^a	6.66±0.26^b

Yield (%) =DF weight/raw BSP weight×100, values in the same lines with different letters are significantly different ($p<0.05$)

SEM

The microstructures of DFs extracted by different methods were observed with SEM and the images presented as micrographs for BSP, BSCDF and BSEDF. (Fig. 1). The microstructures of DFs are related to their hydration, adsorption and binding capacities, such as the characteristic of porosity and available surface lead better adsorption properties (Elleuch et al., 2011) and they can also influence the fermentation of DFs (availability to microbial degradation in the colon)and account for some physiological effects of DFs. On the surface of bamboo shoots powder, lots of oval granules with sizes around 5-50μm were observed (Fig. 1), and assumed to be starch granules according to the description by Chen et al. (2015). Compared to BSP and BSCDF, BSEDF displayed bigger particle sizes, more irregular surfaces with holes and without starch granules. Moreover, the surface morphologies of BSEDF showed a characteristic honeycomb structure with a greater number of holes and cracks which was significantly different to those of BSCDF. This difference corresponds to the residues of some proteins around DFs bundles which were not completely removed after chemical treatment (Ma and Mu, 2016). Larger the pores observed in the cell wall of BSEDF, bonds between the fibrils become more loosened which may contribute for easy diffusion of various components (glucose and other sugars) while BSCDF and BSP may delay the diffusion on the basis of microstructure. After treatment, the microstructural surface of BSEDF were retained, while those of BSCDF were destroyed under strong acid-alkali chemical conditions (Ma and Mu, 2016).

XRD

In order to evaluate the structural differences obtained by using two extraction methods, XRD was performed and diffraction pattern of BSP, BSCDF, BSEDF were shown in Fig. 2. There were numbers of sharp peaks in BSP, and its crystallinity was 85.87%. A sharp XRD peak represents characteristic of crystalline cellulose with an extended crystal line and complete crystal surface, whereas amorphous regions consist of non-crystalline cellulose, hemicellulose, and lignin (Ma and Mu, 2016). Thus, the structure of BSP mostly was orderly crystalline regions. It could be due to cellulose which consists of linear chains of ß (1-4) linked D-glucopyranose units that aggregate to form the core of crystalline cellulose (Wen et al., 2017). BSCDF had regular, broad peaks at 14–25°,

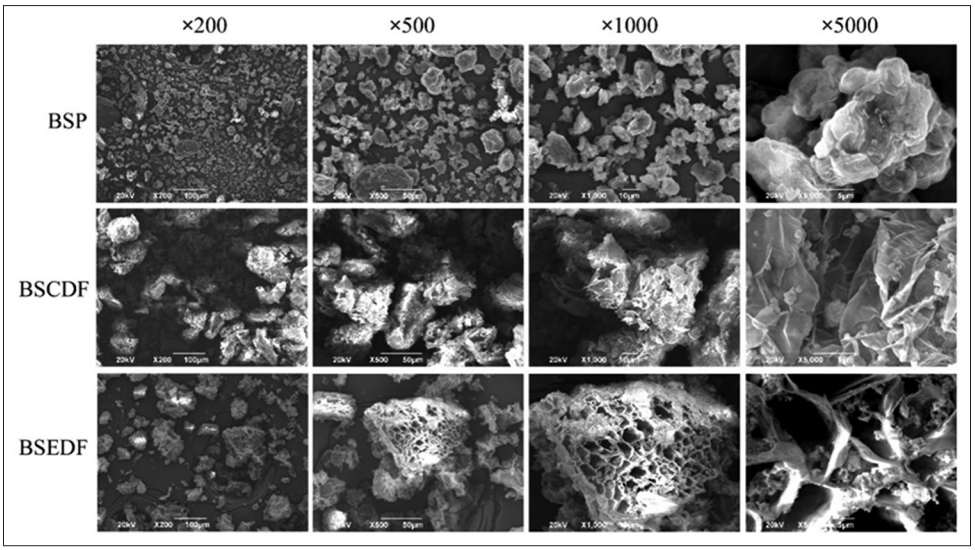

Fig 1. The scanning electron micrographs of BSP, BSCDF and BSEDF. BSP, bamboo shoots powder; BSCDF, dietary fiber obtained by chemical methods; BSEDF, dietary fiber obtained by enzymatic methods.

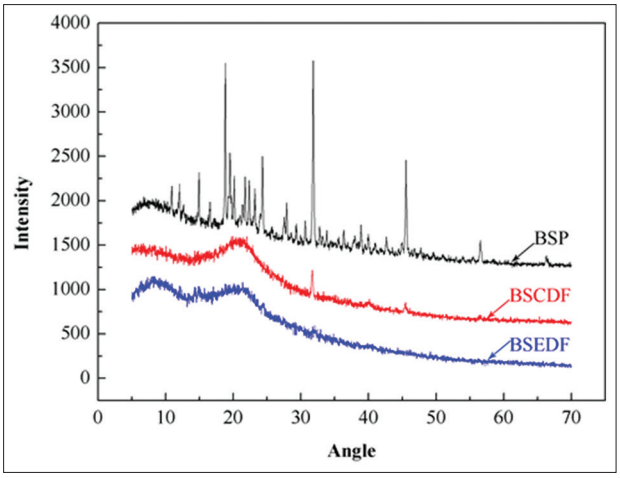

Fig 2. The X-ray diffraction of BSP, BSCDF and BSEDF.

and BSEDF had regular, broad peaks at 16.7–25°and 5-13.5°, respectively. And the crystallinity of BSCDF and BSEDF were 34.42% and 27.01%, respectively. It has been reported that DFs consist of 70% orderly crystalline regions and 30% amorphous regions (Ma and Mu, 2016). However, in our study, the crystallinity of BSCDF was slightly higher than that of BSEDF. Wen et al. (2017) had reported that hemicellulose was generally linked with cellulose microfibers, which has a random and amorphous structure with little strength and could be easily hydrolyzed by various hemicellulases. Based on our results, it can be suggested that the destruction of the hemicellulose and the amorphous portion in cellulose by chemical pretreatment led to the higher crystallinity of BSCDF which make cellulose water insoluble after disruption of hydrogen bonds and lead to more stability which is likely to be actively more stable in the solid state than in solution (Guillon & Champ, 2000).

FT-IR spectroscopy

Fig. 3 displayed the FTIR spectroscopy, which reflected the functional groups of BSP, BSCDF and BSEDF. Similar typical peaks were observed from the spectra, including peaks around 3370, 2930, 1640, 1040 cm-1 for O-H, C-H, C=O, C=C and C-O-C vibrations, respectively (Chen et al., 2015; Zha et al., 2014). As shown in Fig.3, the functional group of BSP, BSCDF and BSEDF displayed some slight differences as compared to each other. Compared to BSP, blue shifts (3378.7 to 3384.6 cm^{-1}) in BSCDF could lead to destruction of hydrogen bonds (Zhang and Wang, 2013). Moreover, obvious differences were appeared in BSCDF, such as the lack of a shoulder peak at 1747.2 cm^{-1} for C=O bending vibration (Zha et al., 2014), red shifts from 3378.7 to 3367.1 cm^{-1}. As compared to enzymatic treatment the chemical treatment seriously destroyed the structure of organic molecules which could break the intramolecular hydrogen bonds of cellulose, hemicellulose and some polysaccharides, resulting in the demolishing of cellulose (Ma and Mu, 2016). The results indicated that chemical extraction method could break the hydrogen bonds and which can alter the functional properties of different components.

Monosaccharide analysis

The DFs were also investigated to identify the main monosaccharides present. Both BSCDF and BSEDF comprised rhamnose, arabinose, xylose, mannose, glucose and galactose (Table 2). The major monosaccharide member of BSCDF was glucose, 68.01% of total components. BSEDF mainly composed of three components, arabinose (24.07%), xylose (24.66%), and glucose (26.02%); Galactose also displayed higher content in BSEDF, up to 14.38% of total members. The above results were in conformity

Table 2: Monosaccharide compositions of BSCDF and BSEDF

Groups	Monosaccharide composition (mol%)					
	Rhamnose	Arabinose	Xylose	Mannose	Glucose	Galactose
BSCDF	1.72	3.83	16.94	2.35	68.01	7.15
BSEDF	3.04	24.07	24.66	7.83	26.02	14.38

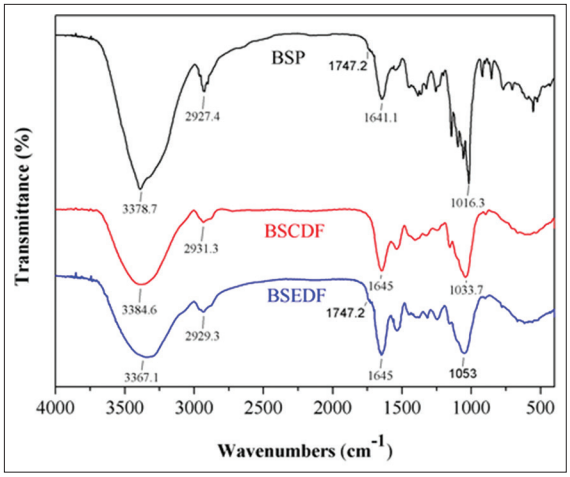

Fig 3. The FT-IR spectra of BSP, BSCDF and BSEDF.

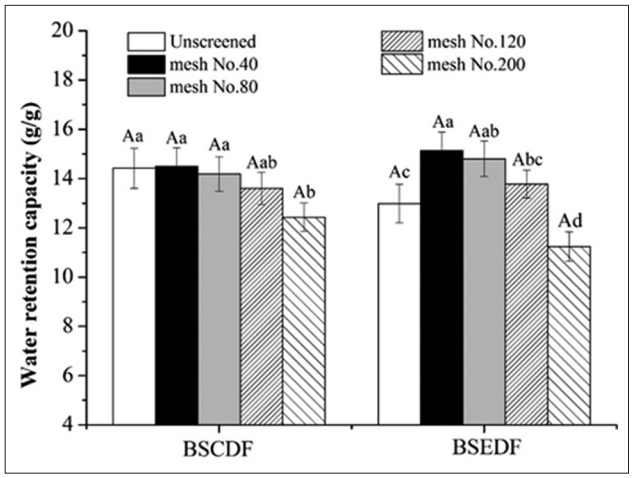

Fig 4. Effects of extraction methods and sieving mesh sizes on the WRC of BSCDF and BSEDF. Values of a–d are significantly different with same extraction method but different sieving mesh sizes, $P < 0.05$; Values of A and B are significantly different with different extraction methods but same sieving mesh size.

to the outcomes of DFs from maca liquor residue (Chen et al., 2015). He et al. (2016) reported that the water-soluble polysaccharides from bamboo shoots were rich in mannose followed by galactose. The above differences indicated that chemical and enzymatic treatment might change the chemical compounds of the carbohydrates.

Functional properties

Particle size plays important roles in physicochemical and functional properties of DFs (Ma and Mu, 2016; Peerajit et al. 2012). The particle sizes of BSCDF and BSEDF

Table 3: Particle size distribution of BSCDF and BSEDF

Sieving mesh sizes	D3,2 (μm)	
	BSCDF	BSEDF
Unscreened	82.36	68.40
40	105.05	96.53
80	101.89	94.52
120	62.38	67.13
200	26.27	39.41

obtained different size of sieves (Table 3). The particle sizes of unsieved BSEDF and BSCDF were 68.40 μm and 82.36 μm, respectively. Different particle size distributions (40, 80, 120, and 200) contributed to particle sizes of 26.27– 105.05 μm in BSCDF and 39.41–96.53 μm in BSEDF, respectively.

Water retention capacity (WRC)

WRC represents the ability of DFs to retain water when the dietary fibers are subjected to an external force (Lan et al., 2012). WRC of sample always depends on the physically trapped water, hydrodynamic water, and the associated water, etc. (Lan et al., 2012; Ma and Mu, 2016). Prior to sieving, WRC of BSCDF (14.42 g/g) was higher than that of BSEDF (12.99 g/g) (Fig. 4). WRC decreased with the increased sieve mesh sizes (40 to 200) both in BSCDF and BSEDF, and the corresponding values of WRC of two samples were12.44-14.49 g/g and 11.24-15.13 g/g, respectively (Fig. 4). Previous studies have reported that WRC of the two DFs (unsieved and sieved) were higher than that of deoiled cumin (7.28 g/g) (Ma and Mu, 2016), defatted rice bran (5.20 g/g) (Hu et al., 2009), tomato peel fiber (6.76 g/g) (Navarro-González, García-Valverde, García-Alonso, & Periago, 2011), but lower than that of maca liquor residue (16.29 g/g) (Chen et al., 2015), Polygonatum odoratum (23.94 g/g) (Lan et al., 2012), Zizyphus mauritiana fruits (25.21 g/g) (Sangeethapriya and Siddhuraju, 2014). Our results indicated that WRC of DFs depends on the particle size, surface characteristics, and processing condition, such as porosity, surface, and microstructure.

Water swelling capacity

WSC is the ratio between the volume of DFs absorbed water after equilibration and the weight of DFs (Ma and Mu, 2016). As shown in Fig. 5, WSC of BSEDF with different treatment was significantly higher than the BSCDF. Moreover, the WSC of sieved BSEDF and BSCDF increased with the sieve mesh sizes (40 to 120),

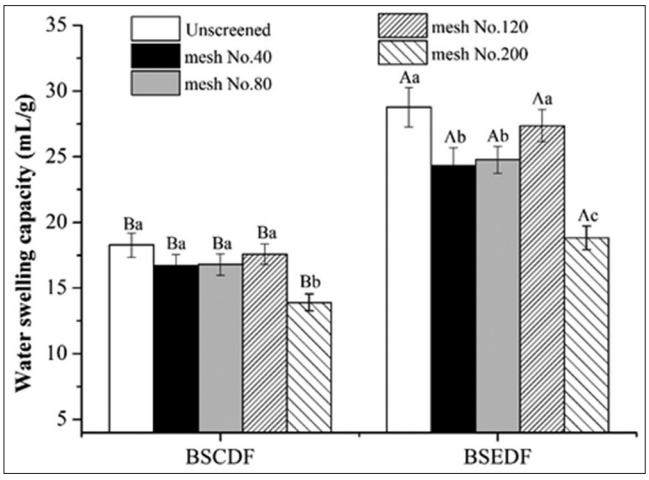

Fig 5. Effects of extraction methods and sieving mesh sizes on the WSC of BSCDF and BSEDF. Values of a–d are significantly different with same extraction method but different sieving mesh sizes, $P < 0.05$; Values of A and B are significantly different with different extraction methods but same sieving mesh size.

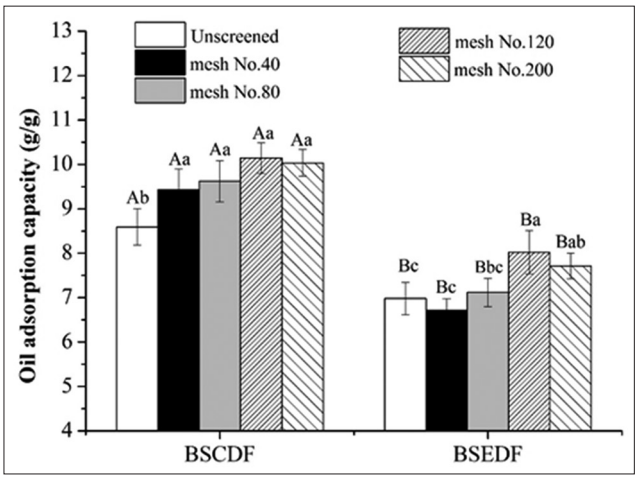

Fig 6. Effects of extraction methods and sieving mesh sizes on the OAC of BSCDF and BSEDF. Values of a–d are significantly different with same extraction method but different sieving mesh sizes, $P < 0.05$; Values of A and B are significantly different with different extraction methods but same sieving mesh size.

but decreased from 120 to 200.The WSC of sieved BSEDF was 18.84–28.75 mL/g, which was higher than that of BSCDF (13.90–16.72 mL/g) (Fig. 5). Our results were in agreement with Ma et al. (2016), who investigated the effects of extraction methods and particle size distribution on the WSC of DFs from deoiled cumin and found that the smallest particle size (mesh No.150) resulted into decreased WRC. Generally, WSC is related to the amount of SDF (especially of pectin); the higher the amount of SDF, the higher the WSC value according to Navarro-González et al. (2011). However, SWC could be related to the amount of insoluble fiber (Figuerola et al., 2005) and as for our results, it was probably due to the higher content of IDF of BSEDF that makes the higher values of WSC. As a result, a reduction in particle size and extraction conditions could affect WSC (Chau et al., 2007). Previous reports revealed that WSC of DFs from bamboo shoots were higher than that of deoiled cumin (7.98 mL/g) (Ma and Mu, 2016) and defatted rice bran (6.08 mL/g) (Hu et al., 2009), but similar to that of *Zizyphus mauritiana* fruits (19.34 mL/g) (Sangeethapriya and Siddhuraju, 2014). Several Studies also suggested that smaller particle size, larger surface area, the content of SDF and IDF and lower bulk density might have contributed to higher WSC (Lan et al., 2012; Wuttipalakorn et al., 2009). Our results indicated that extraction methods also affect the value of WSC.

Oil absorption capacity

The ability of DFs holding oil plays an important part in food applications, such as in preventing fat losses during cooking (Anderson and Berry, 2001). OAC of DFs extracted from BSP was shown in Fig. 6. The OAC of unsieved BSCDF was 8.57 g/g, which was higher than that of BSEDF (6.98 g/g) ($P < 0.05$). Nevertheless, the OAC of sieved BSCDF (9.44–10.15 g/g) was higher than that of BSEDF (6.71–8.00 g/g). The OAC of the two DFs increased when the sieve mesh sizes ranged from 40 to 120, but decreased at 200 mesh. The OAC of our BSCDF and BSEDF (unsieved and sieved) were higher than that of DFs extracted from maca residues (3.91- 5.79 g/g) (Chen et al., 2015) and sweet potatoes in previous studies (1.43–2.48 g/g) (Mei et al., 2010). Furthermore, OAC of BSCDF was higher than BSEDF, indicating extraction method affected the capacity of DFs holding oil. On the basis of previous reports, OAC depended on the surface characteristics, hydrophobic nature of the fiber particle, and overall charge density (Eva et al., 2010; Figuerola et al., 2005). Navarro-González et al. (2011) reported the low values of fat absorption ability found in tomato peel fiber may be owing to the absence or limited presence of lignin in tomato peels.

Glucose adsorption capacity and glucose retardation index

Glucose adsorption capacity and glucose retardation index are very important part *in vitro* indices to predict the effect of DFs on the decrease and delay in glucose absorption in the gastrointestinal tract. Thus, three different concentrations of glucose (50, 100, and 200 mmol/L) were used to assess glucose adsorption capacity (Table 4). The results indicated that both DFs had the ability to adsorb glucose. Moreover, glucose adsorption capacity values were almost proportional to the molar concentration of glucose. Previous reports have shown that DFs from different sources adsorb glucose in a dose-dependent manner (Peerajit et al., 2012). As shown in Table 4, the GAC of BSCDF and BSEDF were 0.08-6.89 mmol/g and 0.13-2.37 mmol/g, respectively. Our results indicated that the relationship between value of GAC and particle

Table 4: Effect of extraction methods and sieving mesh sizes on the glucose adsorption capacity and glucose retardation index of BSCDF and BSEDF

DFs	Sieving mesh sizes (mesh)	GAC (mmol/g)			GRI (%)		
		50	100	200	30 min	60 min	120 min
BSCDF	Unscreened	0.30 ± 0.03^{Ba}	0.75 ± 0.08^{Bb}	6.22 ± 0.27^{Ab}	39.54 ± 0.72^{Aa}	29.10 ± 0.52^{Ab}	11.64 ± 0.35^{Bc}
	40	0.28 ± 0.05^{Aa}	0.12 ± 0.01^{Be}	4.72 ± 0.11^{Ac}	23.20 ± 1.06^{Ad}	26.72 ± 0.95^{Ac}	16.48 ± 1.49^{Ab}
	80	0.18 ± 0.05^{Bb}	1.03 ± 0.07^{Ba}	2.27 ± 0.08^{dA}	26.80 ± 0.21^{Ac}	21.93 ± 1.22^{Ad}	3.57 ± 0.23^{Bd}
	120	0.08 ± 0.07^{Bc}	0.49 ± 0.01^{Bc}	6.89 ± 0.01^{Aa}	33.23 ± 0.30^{Bb}	27.78 ± 0.19^{Bbc}	12.34 ± 0.16^{Bc}
	200	0.18 ± 0.01^{Bb}	0.25 ± 0.01^{Bd}	1.95 ± 0.07^{Ad}	40.92 ± 0.75^{Aa}	34.74 ± 0.73^{Aa}	20.67 ± 0.34^{Aa}
BSEDF	Unscreened	0.13 ± 0.01^{Ac}	1.53 ± 0.01^{Ab}	2.37 ± 0.01^{Ba}	26.95 ± 0.42^{Bb}	25.38 ± 0.14^{Bb}	16.31 ± 0.34^{Aa}
	40	0.17 ± 0.01^{Bbc}	1.79 ± 0.08^{Aa}	2.03 ± 0.01^{Ba}	16.62 ± 0.64^{Bc}	7.95 ± 0.14^{Bd}	0.41 ± 0.11^{Bd}
	80	0.35 ± 0.04^{Aa}	1.57 ± 0.09^{Ab}	2.35 ± 0.02^{Aa}	14.37 ± 0.90^{Bd}	4.73 ± 0.40^{Be}	8.33 ± 0.66^{Ab}
	120	0.20 ± 0.01^{Ab}	0.55 ± 0.03^{Ac}	2.04 ± 0.01^{Bb}	42.22 ± 0.42^{Aa}	30.17 ± 0.68^{Aa}	15.75 ± 0.23^{Aa}
	200	0.33 ± 0.01^{Aa}	1.47 ± 0.02^{Ab}	1.80 ± 0.01^{Ac}	4.86 ± 0.98^{Be}	13.31 ± 0.68^{Bc}	4.87 ± 0.92^{Bc}

Values of A and B are significantly different with different extraction methods but same sieving mesh size while values of a–e are significantly different with same extraction method but different sieving mesh sizes, $p<0.05$

size distribution was not obvious. Our results were in agreement with the study of Peerajit et al. (2012) who reported that the DFs particle size had no significant effect on the GAC. However, our results were in contrast with the study of Chen et al. (2015), who reported that GAC values of DFs increased with 40–150 sieve mesh sizes, which might be due to smaller particle sizes and larger specific surface area, thereby resulting in more adsorbed glucose. Our results have indicated smaller particle size might not have obviously contributed to the slow absorption rate of glucose solutions. The glucose adsorption capacities of bamboo shoots DFs were higher than those of sweet potatoes DFs (540–1270 μmol/g) (Mei et al., 2010), wheat bran DFs (454.2–555.6 μmol/g) (Zhu et al., 2010) and maca residue (764.35-905.91 μmol/g) (Chen et al., 2015). However, compared to the results of Chen et al. (2015) (1.04-60.86 mmol/g), our values of GAC were dropped, which might be due to the higher proportion of SDF in deoiled cumin (11.91 g/100 g) (Ma and Mu, 2016). Since SDF with higher viscosity could potentially contribute to the entrapment of glucose molecules within the fiber network, thereby delaying glucose diffusion (Chau et al., 2007). The values obtained from our results could be used to predict the behavior of DFs on adsorbing of glucose during the gastrointestinal transit time.

The retardation effect of DFs on glucose diffusion was possibly from both soluble and insoluble fractions through increased viscosity and glucose adsorption (Chau et al., 2007; Peerajit et al., 2012). As shown in Table 4, maximum GRI values of bamboo shoots DFs were found mostly at 30 min and then gradually diminished as the time increased. The BSCDF powder with smaller particle sizes possessed higher GRI as presented in Table 4. The similar values (9.92–24.71%) and trends were found in lime DFs earlier previously (Peerajit et al., 2012). The microstructure of DFs powder prepared by different pretreatments was observed with SEM, BSEDF had clear honeycomb structures as presented in Fig. 1. Furthermore, Chau et al. (2004) had reported that IDF could effectively absorb glucose and retard glucose diffusion by chemical adsorption, physical obstacle and entrapment of glucose molecules. Therefore, BSCDF showed GAC and GRI might be due to its high content of IDF, besides its porosity, available surface, and diverse structures. It could be concluded that both particle size and pretreatment methods had significant effects on GRI.

CONCLUSIONS

Our study revealed that BSEDF had higher content of total DFs with a characteristic microstructure and BSCDF had higher soluble DFs which exhibited different microstructure than BSEDF. The monosaccharide component also differentiated in BSEDF and BSCDF, where the major monosaccharide of BSCDF was glucose while BSEDF mainly composed of three components, arabinose, xylose and glucose. WRC of BSCDF and BSEDF had no significant difference and they both decreased with increasing sieve. WSC of BSEDF was significantly higher than BSCDF. While OAC of BSEDF was lower than BSCDF, the OAC and WSC of the two DFs increased with the sieve mesh sizes. The BSCDF powder with smaller particle sizes possessed higher GRI. To conclude, various processing steps led to the modification of fiber compositions and microstructure, which led to some good properties of GAC and GRI in BSCDF and good properties of WSC in BSEDF. Thus, physico-chemical properties of fibers can be manipulated through treatments (chemical and enzymatic) to improve their overall functionality.

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Author contributions

Zhao-Jun Wei designed the experiment and prepared the manuscript; Cai-Hong Wang and Yi-Long Ma performed most of the experiments, and prepared the manuscript; Dan-Ye Zhu performed the component analysis; Hao Wang and Ya-Fei Ren performed the X-ray diffraction; Jian-Guo Zhang was involved in the data analysis; Kiran Thakur was involved in the manuscript preparation.

Abbreviations used

DF, dietary fiber; BSP, bamboo shoot powder; BSCDF, dietary fiber obtained by chemical treatment; BSEDF, dietary fiber obtained by enzymatic method; TDF, total dietary fiber; IDF, insoluble dietary fibers; SDF, soluble dietary fibers; WRC, water retention capacity; WSC, water swelling capacity; OAC, oil holding capacity; GAC, glucose adsorption capacity; GRI, glucose retardation index; ANOVA, analysis of variance; SEM, scanning electron microscopy; XRD; X-ray diffraction; FT-IR, Fourier transform infrared spectroscopy.

REFERENCES

Anderson, E. T. and B. W. Berry. 2001. Effects of inner pea fiber on fat retention and cooking yield in high fat ground beef. Food Res. Int. 34: 689-694.

AOAC. 2000. Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Washington, DC.

Cao, Y. and H. Tan. 2005. Study on crystal structures of enzyme-hydrolyzed cellulosic materials by X-ray diffraction. Enzyme Microb. Technol. 36: 314-317.

Chau, C. F., Y. T. Wang and Y. L. Wen. 2007. Different micronization methods significantly improve the functionality of carrot insoluble fibre. Food Chem. 100: 1402-1408.

Chau, C. F., C. H. Chen and C. Y. Lin. 2004. Insoluble fiber-rich fractions derived from *Averrhoa carambola*: Hypoglycemic effects determined by *in vitro* methods. LWT-Food Sci. Technol. 37: 331-335.

Chen, J., Q. Zhao, L. Wang, S. Zha, L. Zhang and B. Zhao. 2015. Physicochemical and functional properties of DF from maca (*Lepidium meyenii* Walp.) Liquor residue. Carbohydr. Polym. 132: 509-512.

Davidson, M. H. and A. Mcdonald. 1998. Fiber: Forms and functions. Nutr. Res. 18: 617-624.

Elleuch, M., D. Bedigian, O. Roiseux, S. Besbes, C. Blecker and H. Attia. 2011. Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. Food Chem. 124: 411-421.

Nyman , E.M.G. and Svanber S. J. M. 2002. Modification of physicochemical properties of dietary fibre in carrots by mono- and divalent cations. Food Chem. 76: 273-280.

Eva, G., J. Antonio and R. Pilar. 2010. Dietary fibre and physicochemical properties of several edible seaweeds from the Northwestern Spanish coast. Food Res. Int. 43: 2289-2294.

Figuerola, F., M. A. L. Hurtado, A. M. A. Estévez, I. Chiffelle and F. Asenjo. 2005. Fiber concentrate from apple pomace and citrus peel as potential fiber sources for food enrichment. Food Chem. 91: 395-401.

Goyal, R., R. B. Grewal and R. K. Goyal. 2015. Fatty acid composition and dietary fibre constituents of mushrooms of North India. Emirates J. Food Agric. 27: 927-930.

Guillon, F. and M. Champ. 2000. Structural and physical properties of dietary fibres, and consequences of processing on human physiology. Food Res. Int. 33: 233-245.

He, S., X. Wang, Y. Zhang, J. Wang, H. Sun, J. Wang, X. Cao and Y. Ye. 2016. Isolation and prebiotic activity of water-soluble polysaccharides fractions from the bamboo shoots (*Phyllostachys praecox*). Carbohydr. Polym. 151: 295-304.

Hu, G., S. Huang, S. Cao and Z. Ma. 2009. Effect of enrichment with hemicellulose from rice bran on chemical and functional properties of bread. Food Chem. 115: 839-842.

Konovalova, V., K. Guzikevich, A. Burban, W. Kujawski, K. Jarzynka and J. Kujawa. 2016. Enhanced starch hydrolysis using alpha-amylase immobilized on cellulose ultrafiltration affinity membrane. Carbohydr. Polym. 152: 710-717.

Kutos, T., T. Golob, M. Kač and A. Plestenjak. 2003. Dietary fibre content of dry and processed beans. Food Chem. 80: 231-235.

Lan, G., H. Chen, S. Chen and J. Tian. 2012. Chemical composition and physicochemical properties of dietary fiber from *Polygonatum odoratum* as affected by different processing methods. Food Res. Int. 49: 406-410.

Liu, S., W. Luo and H. Huang. 2016. Characterization and behavior of composite hydrogel prepared from bamboo shoot cellulose and β-cyclodextrin. Int. J. Biol. Macromol. 89: 527-534.

Luo, X., Q. Wang, B. Zheng, L. Lin, B. Chen, Y. Zheng and J. Xiao. 2017. Hydration properties and binding capacities of dietary fibers from bamboo shoot shell and its hypolipidemic effects in mice. Food Chem. Toxicol. pii:S0278-6915(17)30075-3.

Ma, M. M. and T. H. Mu. 2016. Effects of extraction methods and particle size distribution on the structural, physicochemical, and functional properties of dietary fiber from deoiled cumin. Food Chem. 194: 237-246.

Macagnan, F. T., D. L. P. Silva and L. H. Hecktheuer. 2016. Dietary fibre: The scientific search for an ideal definition and methodology of analysis, and its physiological importance as a carrier of bioactive compounds. Food Res. Int. 85: 144-154.

Mccleary, B. V., J. W. D. Vries, J. I. Rader, G. Cohen, L. Prosky, D. C. Mugford, M. Champ and K. Okuma. 2010. Determination of total dietary fiber (codex definition) by enzymatic-gravimetric method and liquid chromatography: collaborative study. J. AOAC Int. 93: 221-233.

Mei, X., T. H. Mu and J. J. Han. 2010. Composition and physicochemical properties of dietary fiber extracted from residues of 10 varieties of sweet potato by a sieving method. J. Agric. Food Chem. 58: 7305-7310.

Mudgil, D. and S. Barak. 2013. Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: A review. Int. J. Biol. Macromol. 61: 1-6.

Navarro-González, I., V. García-Valverde, J. García-Alonso and M. J. Periago. 2011. Chemical profile, functional and antioxidant properties of tomato peel fiber. Food Res. Int. 44: 1528-1535.

Nirmala, C., M. S. Bisht and M. Laishram. 2014. Bioactive compounds in bamboo shoots: health benefits and prospects for developing

functional foods. Int. J. Food Sci. Technol. 49: 1425-1431.

Peerajit, P., N. Chiewchan and S. Devahastin. 2012. Effects of pretreatment methods on health-related functional properties of high dietary fibre powder from lime residues. Food Chem. 132: 1891-1898.

Requena, M. C., C. N. A. González, L. A. P. Barragan, M. D. G. Cunha, M. T. D. Correia, J.C.C. Esquivel and R. R. Herrera. 2016. Dietary fiber: An ingredient against obesity. Emirates J. Food. Agric. 28: 522-530.

Sangeethapriya, M. and P. Siddhuraju. 2014. Health related functional characteristics and antioxidant potential of mucilage (dietary fiber) from *Ziziphus mauritiana* fruits. Food Sci. Hum. Wellness. 3: 79-88.

Sauracalixto, F. 2011. Dietary fiber as a carrier of dietary antioxidants: An essential physiological function. J. Agric. Food Chem. 59: 43-49.

Shi, J. J., J. G. Zhang, Y. H. Sun, J. Qu, L. Li, C. Prasad and Z. J. Wei. 2016. Physicochemical properties and antioxidant activities of polysaccharides sequentially extracted from peony seed dreg. Int. J. Biol. Macromol. 91: 23-30.

Shiyi, O., K. Kinchor, Y. Li and F. Liang. 2001. *In vitro* study of possible role of dietary fiber in lowering postprandial serum glucose. J. Agric. Food Chem. 49: 1026-1029.

Thakur, K., C. S. Rajani, S. K. Tomar and A. Panmei. 2016. Fermented bamboo shoots: A riche niche for beneficial microbes. J. Bacteriol. Mycol. 2: 00030.

Thomas, R., N. Jebin, R. Saha and D. K. Sarma. 2016. Antioxidant and antimicrobial effects of kordoi (*Averrhoa carambola*) fruit juice and bamboo (*Bambusa polymorpha*) shoot extract in pork nuggets. Food Chem. 190: 41-49.

Tungland, B. C. and D. Meyer. 2002. Nondigestible oligo-and polysaccharides (dietary fiber): Their physiology and role in human health and food. Compr. Rev. Food Sci. Food Saf. 1: 90-109.

Wang, J., G. Suo, D. M. Wit, R. M. Boom and M. A. I. Schutyser. 2016. Dietary fibre enrichment from defatted rice bran by dry fractionation. J. Food Eng. 186: 50-57.

Wen, Y., M. Niu, B. Zhang, S. Zhao and S. Xiong. 2017. Structural characteristics and functional properties of rice bran dietary fiber modified by enzymatic and enzyme-micronization treatments. LWT-Food Sci. Technol. 75: 344-351.

Wuttipalakorn, P., W. Srichumpuang and N. Chiewchan. 2009. Effects of pretreatment and drying on composition and bitterness of high-dietary-fiber powder from lime residues. Drying Technol. 27: 133-142.

Zha, S., Q. Zhao, J. Chen, L. Wang, G. Zhang, H. Zhang and B. Zhao. 2014. Extraction, purification and antioxidant activities of the polysaccharides from maca (Lepidium meyenii). Carbohydr. Polym. 111: 584-587.

Zhang, J. and Z. W. Wang. 2013. Soluble dietary fiber from *Canna edulis* Ker by-product and its physicochemical properties. Carbohydr. Polym. 92: 289-296.

Zhu, K. X., S. Huang, W. Peng, H. F. Qian and H. M. Zhou. 2010. Effect of ultrafine grinding on hydration and antioxidant properties of wheat bran dietary fiber. Food Res. Int. 43: 943-948.