



Chemical composition and functional characteristics of dietary fiber-rich powder obtained from core of maize straw



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ABSTRACT

A novel dietary fiber (MsCDF) based core of maize straw (Core) was prepared by using high boiling solvent of sodium peroxide by high pressure pretreatment (HBSHP). The composition of MsCDF, and several physicochemical properties for MsCDF related to its nutritional quality were investigated. The results revealed that the MsCDF contains high contents total dietary fiber (TDF), soluble dietary fiber (SDF), insoluble dietary fiber (IDF) and two main monosaccharides, xylose and glucose. Meanwhile, the studies of physicochemical properties of MsCDF indicated that MsCDF performed well water-holding capacity (WHC), oil-holding capacity (OHC), Swelling, solubility (SOL), Glucose dialysis retardation index (GDRI) and adsorption capacity on cholesterol. The results of this study serve as evidence that MsCDF can be used as a functional food additive, Core can be used as a crude material to produce MsCDF and the technology of HBSHP can be used to modify the physico-chemical properties of Core.

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1. Introduction

Dietary fiber (DF) has been shown to have important health implications in the prevention of chronic diseases, such as cancer, cardiovascular diseases, and diabetes mellitus. Not only does dietary fiber help evade hydrolysis and dysfunction in the digestive system and absorb harmful substance in the small intestines, it also increases fecal bulk, stimulates colonic fermentation, and reduces postprandial blood glucose and preprandial cholesterol levels. Based on these benefits, it is pertinent to increase DF intake through high consumption of fruits, vegetables, cereals, legumes, and fiber-enriched food products to sustain a healthy life (Sudha, Vetrinani, & Leelavathi, 2007).

DF is subdivided into insoluble dietary fiber (IDF) and soluble dietary fiber (SDF) according to their solubility in water. The physiological effects of total dietary fiber (TDF), IDF, and SDF of foods play a significant role in human nutrition (Elleuch et al., 2011). Epidemiological and animal experiments indicate that DF protects against the development of colorectal cancer. While IDF appears to be more effective than SDF, and one mechanism by which they may protect is by absorbing dietary carcinogens (Ferguson, Robertson, Watson, Triggs, & Harris, 1995). The absorption capacity

of DF is important in lipid absorption and metabolism, as molecules with ionic groups can easily react with cholesterol and bile acids modifying enterohepatic recycling and, consequently, fecal excretion. Most plant foods contain a combination of both soluble and insoluble fiber.

Cholesterol, an important component of a healthy body, is a part of cell membranes, certain hormones, vitamins, and bile acids and is necessary for other functions. However, high cholesterol is harmful because it combines with low-density lipoprotein (LDL) particles, which are one of the major controllable risk factors for coronary heart disease, heart attacks, and stroke (Lu, Lee, & Patel, 2001). Several dietary fiber sources are known to produce a number of medically beneficial effects, such as decreased plasma cholesterol levels and a reduced glycemic response. The long-term cholesterol-lowering effects of dietary fiber have been fully documented, and their mechanisms of action depend on their physicochemical properties.

Corn is a significant crop all around the world, its annual production is about 520×10^9 kg (Kim and Dale, 2004). The ratio of maize straw to grain is typically assumed to be 1:1 (Wu et al., 2005), thus, maize straw production are very abundant in the world. Moreover, in China, over 600 million tons of crop straw residues, including 250 million tons from maize straw alone, are produced every year (Li, Wei, Duan, Hu, & Zhang, 2014). From the above-mentioned data, maize straw is by far the most readily available biomass residue that contains valuable materials.

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Maize straw is initially composed of leaves, husk fractions, and stalks (Shinners & Binversie, 2007). The stalk is composed of the maize straw cortex (Cortex) and maize straw core (Core), which account for approximately half of the total maize straw content.

The Cortex is mainly composed of cellulose and lignin, while the Core primarily contains hemi-cellulose with a smaller percentage of lignin. Considering their compositions, the Cortex and Core have been used as the material for manufacturing compacting panels and the adsorption material prepared by glycol solvent treatment to be applied in enzyme immobilization, respectively (Lv et al., 2013). To date, no reports exist on using the Core as a raw material for preparing DF.

Due to the favorable effects of DF, it is essential to develop new and effective dietary fibers for human consumption. The general objectives of this study were to examine the feasibility of producing dietary fiber from the Core and to determine the effectiveness of MsCDF as a functional food. The specific objectives of this study included: (a) produce MsCDF from the Core of maize straw; (b) determine the composition and several physicochemical properties of MsCDF; and (c) determine the surface texture of MsCDF. The utilization of MsCDF as a functional food will not only assist in alleviating the symptoms of chronic diseases that are prevalent in most countries, but will also encourage the food and pharmaceutical industries as well as farmers to produce value-added or healthy products from maize straw cores.

2. Materials and methods

2.1. Reagents and instruments

Cholesterol, trifluoroacetic acid, trimethylsilylation, α -amylase, protease, and amyloglucosidase were purchased from Shanghai Richijoint Chemical Reagents CO., Ltd (Shanghai, China). Arabinose, fructose, glucose, galactose, rhamnose, mannose, and xylose were purchased from Sigma (St. Louis, MO, USA). All other chemicals were analytical reagent grade, unless otherwise stated.

A Zealway-GI36DW automatic pressure sterilizer (working pressure: 0.22 MPa, temperature 105–127 °C; volume: 36 L) manufactured by Zealway Instrument Inc., (Xiamen, China), an UV1901 spectrophotometer (Shanghai Phenixsi Light Subject Instrument Co., Ltd, China), a High Speed Pulverizer (DFY-500, Wenlin, China), and a LGJ-18S Freeze-Drier Instrument (Henan brother Instrument Inc., Zhengzhou, China) were used for analyses.

2.2. Sample preparation

Fresh maize straw from a local farm in the Huaian suburb of China was harvested at maturity in 2014. After harvesting, maize straw without visible microbial contamination was collected and washed thoroughly with distilled water. After removing the leaves, husks and Cortex, the Cores were cut into small segments, washed thoroughly with distilled water to remove any adsorbent dust, dried at 90 °C for 3 h, then were pulverized into powder using a High Speed Pulverizer (DFY-500, Wenlin, China). Core powder was processed using a high boiling solvent of sodium peroxide by a high pressure pretreatment (HBSHP), as described by Lv et al. (2013) with slight modifications (sodium peroxide was used instead of NaOH solution).

Briefly, 20 g Core with a 400 mL mixture of dissolvent (composed of 1 mL of 9% sodium peroxide aqueous solution and 20 mL of glycol solution) was put into the automatic pressure sterilizer, then heated to 110–125 °C and held for 30 min. After digestion, the reaction mixture was cooled to 100 °C. The Core solution was acquired by filtering the reaction mixture, and then the filter residue was washed to neutral using HCl-ethanol dissolvent

(composed of one volume of 8% HCl aqueous solution and 8–13 volumes 95% ethanol (food grade)). The washed residue was freeze-dried, powdered, and then sieved through a 120-mesh sieve in order to obtain MsCDF. The MsCDF were then stored at 23 °C in a tightly sealed plastic container for further analyses.

2.3. Proximate analysis

The moisture, ash, protein, and fat contents were determined according to the method described by AOAC (1998).

2.4. Physicochemical properties of MsCDF powder

2.4.1. Water-holding capacity (WHC), oil-holding capacity (OHC), and solubility in water (SOL)

Water-holding capacity (WHC) was determined using the method described by Jiménez et al. (2000) with slight modifications, where centrifugation was combined with the filtration. Oil-holding capacity (OHC) was determined by centrifugation (Jiménez et al., 2000). Either distilled water or sunflower oil (0.86 g/mL density) (15 mL) was transferred into 50 mL centrifuge tubes containing 250 mg MsCDF. The mixture was stirred and left at room temperature for 24 h. After centrifugation at 15000g for 1 h, the mixture containing the supernatants and pulp was filtrated using quantitative filter paper until there were no water drops in order to weigh the hydration fibers weighed for WHC. After centrifugation at 15000g for 1 h, the supernatants and pellets of oil were carefully discarded, and the oily fibers were weighed for OHC. WHC and OHC are expressed as grams of water or oil per gram of fibrous residue, respectively. Hydrated pellets were freeze-dried, and the solubility in water (SOL) was determined as the weight difference between the before and after WHC assay, which is expressed as a percent.

2.4.2. Swelling

Swelling was determined as the method described by Robertson et al. (2000). 100 mg MsCDF was transferred into a calibrated cylinder then distilled water was added to the cylinder. The mixture of MsCDF and water was incubated at room temperature for 24 h. The packed volume was then recorded, and swelling was expressed as milliliters per grams of MsCDF.

2.4.3. Glucose dialysis retardation index (GDRI)

The glucose dialysis retardation index (GDRI) was determined using the method described by Hassan, Ismail, Hamid, Azlan, and Al-sheraji (2011) with slight modifications. Dialysis tubes (10,000–14,000 MWCO, Beijing, China) were loaded with 500 mg of sugar-free MsCDF and 7.5 mL of distilled water, which was used as the control. A UV-Vis spectrophotometer was used to determine the concentration of glucose, and the GDRI was calculated with the following Eq. (1):

$$\text{GDRI} = 100 - \left[\frac{(\text{Total glucose diffusion from sample})}{(\text{Total glucose diffusion from control})} \times 100 \right] \quad (1)$$

2.4.4. Adsorption capacity of MsCDF for cholesterol

The adsorption capacity was determined by placing MsCDF particles into the cholesterol solution.

Preparation of the cholesterol solution and determination of cholesterol was conducted according to the methods of the National Standard of the P.R. China (National Standard of P.R. China, 2003). For each adsorption experiment, 50 mg MsCDF was added to 20 mL of 100 $\mu\text{g/mL}$ cholesterol solution, and adsorption proceeded at 37 °C for 10, 15, 25, 35, 60, and 90 min. After adsorption, these mixtures were filtered using filter paper, which was

treated with the same concentration of cholesterol solution in order to prevent the adsorption of cholesterol from the solution and cause subsequent errors in the calculation of cholesterol concentration in the final solution. The cholesterol concentration of the filtrate was determined by the cholesterol concentrations described previously. The amount of the cholesterol adsorbed onto the MsCDF was calculated according to Eq. (2):

$$Q_e = (C_0 - C_e)V_{CH}/m_{MsCDF} \quad (2)$$

where Q_e is the equilibrium adsorption capacity of MsCDF for cholesterol ($\mu\text{g/g}$ adsorbents); C_0 and C_e are the initial and equilibrium concentration of cholesterol in the aqueous phase of the mixture, respectively ($\mu\text{g/mL}$); V_{CH} is the total volume of the cholesterol aqueous solution (mL); and m_{MsCDF} is the mass of MsCDF (g).

2.5. Composition of MsCDF and the Core

2.5.1. Determination of TDF, IDF, and SDF of MsCDF and the Core

TDF, SDF, and IDF of the MsCDF obtained from the Core were determined according to the method proposed by Prosky, Asp, Schweizer, De Vries, and Furda (1988). Starch and protein in the sample were removed by incubation with amyloglucosidase and protease, respectively, and then the specific operation steps were performed according to the method of Prosky et al. (1988). The amount of klason lignin (KL) was also determined gravimetrically as the amount of acid-insoluble material remaining after a two-stage sulfuric acid hydrolysis. The TDF was determined by adding IDF and SDF.

2.5.2. GC Analysis of the monosaccharide composition of MsCDF

MsCDF (10 mg) was suspended in 1 mL of 2 M trifluoroacetic acid (TFA) in a screw-cap vial. The vial was tightly sealed heated for 3 h at 120 °C and then allowed to cool. The contents were centrifuged for 5 min at 2000g. The TFA in the supernatant was allowed to evaporate off in the fume hood and the remaining mixture was freeze-dried. Derivatization of the released monosaccharides was then carried out using a trimethylsilylation reagent according to the method proposed by Guntas et al. (2001). The pure reference sugars (arabinose fructose glucose galactose rhamnose mannose and xylose) and a mixture containing certain amounts of the pure reference sugars were further analyzed by GC

The trimethylsilylated derivatives were loaded onto a HP-5 capillary column and then analyzed using a GC (GC-14B, SHIMADZU, JAPAN) with a flame ionization detector. The following program was used for analysis: injection temperature and detector temperature were both 230 °C; column temperature was programmed from 130 to 180 °C at 2 °C/min, holding for 3 min at 180 °C, then increasing to 220 °C at 10 °C/min and finally holding for 3 min at 220 °C. N_2 was used as the carrier gas and was maintained at 40.0 mL/min. The speeds of air and H_2 were 400 and 40 mL/min, respectively. The split ratio was set to 10:1.10 μL of samples or standards for injections (Yang, Jiang, Gu, Yang, & Jiang, 2010).

2.6. Analysis of the microstructures of MsCDF and Core

The microstructures of MsCDF and Core were investigated using FTIR and scanning electron microscopy (SEM). The FTIR spectra for the MsCDF and Core were recorded between 4000 and 400 cm^{-1} (AVATAR-360FT-IR, NICOLET, US). The discs were prepared by mixing the dried sample (1 mg) with 100 mg KBr in an agate mortar and then pressing the mixture at 10 MPa for 3 min using an YP-2 tablet press (Shanghai, China).

SEM was conducted to analyze the micro-structural changes and surface characteristics of the MsCDF and Core, which were prepared by attaching samples to a specimen stub with double-coated tape. The samples were sputter-coated with Au Pd prior to

obtaining an image with a S-3000N SEM (S-3000N, Hitachi, Japan) using an acceleration voltage of 2 kV.

2.7. Statistical analysis

All experiments were repeated three times, and data were expressed as mean values $\pm$ standard deviations (sd). Statistical analyses were performed using Excel (Microsoft Office Excel 2003). Data were statistically analyzed using one-way ANOVA. The confidence limits used in this study were based on 95% ($P < 0.05$).

3. Results and discussion

3.1. Preparation of MsCDF

The performance and composition of MsCDF from the Core is crucial in implementing the concept of using maize straw in dietary fiber supplements. Because the presence of lignin may hamper the performance of MsCDF, it should be removed first in order to successfully exploit the Core for MsCDF. Alkaline NaOH pretreatment (Zhu, Wan, & Li, 2010), H_2O_2 pretreatment (Song et al., 2014), and pretreatment with an alkaline/oxidative mixture (NaOH and H_2O_2) (Curreli et al., 1997) have been reported as the effective methods for lignin removal. Furthermore, glycol has been reported as an effective solvent for dissolving lignin (Lv et al., 2013). The goal of these pretreatment methods is to remove hemicellulose and lignin as much as possible while simultaneously keeping enough cellulose intact (Sun & Chen, 2008), which will promote the use of maize straw in the enzymatic hydrolysis of cellulose to obtain fermentable sugars for ethanol production and also to process specific fractions into a supplemental fiber source for paper and other similar products.

However, most of these treatments involve the removal of both lignin and hemicellulose and cause the loss of SOL to obtain only the cellulose content. The purpose of this paper was to dedicate the Core of maize straw as a MsCDF, which should contain greater concentrations of hemicellulose, SDL, and SOL. Therefore, an efficient lignocellulose pretreatment process for producing MsCDF is greatly needed to reduce sugar degradation and improve the cellulose-hemicellulose content. In addition to exploring the interactions between phenolic lignin and other chemicals, the loss of the effective component of MsCDF is also prevented during lignin removal.

In the present HBSHP pretreatment, aqueous sodium peroxide produces sodium hydroxide and peroxide, and a mixed solvent of sodium peroxide solution and glycol have displayed comprehensive effects that can break down and also disrupt the lignin structure in the Core, promoting lignin separation from the hemicellulose and dissolution in glycol. However, hemicellulose and its degradation products are not soluble in glycol. HBSHP pretreatment produced the increased solubility of hemicellulose and its degradation products, while the initial solubility of components in the Core were unchanged, which improved the SDF ($13.3 \pm 1.7\%$) and SOL ($33.8 \pm 5.2\%$) content in MsCDF. The latter mentioned components in MsCDF were higher than SDF ($4.60 \pm 0.22\%$) and SOL ($11.2 \pm 1.3\%$) in the Core, proving that the HBSHP technique can be used to modify the physicochemical properties of the Core.

3.2. Proximate composition

The proximate composition of MsCDF and Core per 100 g sample is shown in Table 1. The protein, fat, and ash contents of the Core were similar to those from a previous report on maize straw core (Yang, Yang, & Yang, 2000).

Table 1
Chemical composition of MsCDF and Core.

Component	Percentage (%)			
	MsCDF	Core	Core ^a	CDF ^a
Moisture	2.32 ± 0.45	2.65 ± 0.35	2.5	3.0
Protein	0.50 ± 0.09	6.52 ± 0.12	6.9	2.7
Fat	0.60 ± 0.07	2.76 ± 0.19	2.8	0.9
Ash	2.15 ± 0.22	6.42 ± 0.38	6.6	4.4
Klason lignin (KL)	0.65 ± 0.25	10.2 ± 0.5	n.d.	n.d.
Total dietary fiber (TDF)	83.5 ± 1.4	81.6 ± 0.6	78.4	78.0
Soluble dietary fiber (SDF)	13.3 ± 1.7	4.60 ± 0.22	n.d.	n.d.
Insoluble dietary fiber (IDF)	70.5 ± 3.3	77.1 ± 0.6	n.d.	n.d.
Solubility in water (SOL)	33.8 ± 5.2	11.2 ± 1.3	n.d.	n.d.

n.d. Represents not detected. Values are means of triplicates ± standard deviations. Results were expressed as % dry mater except for moisture.

^a Yang et al. (2000).

The TDF content in the MsCDF and Core was determined to be 83.5 ± 0.6% dry sample and 83.5 ± 1.4% dry sample, respectively; no significant difference ($P > 0.05$) was found between the MsCDF and Core (Table 1). The SDF content was improved from 4.60 ± 0.22% in the Core to 13.3 ± 1.7% in MsCDF, and IDF was decreased from 77.1 ± 0.6% in the Core to 70.5 ± 3.3% in MsCDF; significant differences ($P < 0.05$) were also found between the MsCDF and Core (Table 1). These results are similar to those from a study on beans and chickpeas using an intense treatment (Tosh & Yada, 2010).

The TDF and SDF contents were determined to be 83.5 ± 1.4% and 13.3 ± 1.7% in MsCDF, respectively, which are both higher than 78.0% TDF content in CDF from the Core, as previously reported (Yang et al., 2000). This difference may be accountable to the different pretreatment process used in the previous study, where the samples were only washed with water. As a result, soluble components were depleted, so the percentages of TDF and SDF decreased in the total composition, and the highest TDF and SDF contents may have been in the form of fibers following treatment with HBSHP. As a consequence, there was no depletion of soluble components and the removal of more lignin, increasing the percentage of TDF in the total composition during processing. During the HBSHP pretreatment process, oligosaccharides were produced and water-soluble sugars in the Core were not dissolved in glycol solution. With the final washing process, neither oligosaccharides nor water-soluble sugars were dissolved in the wash solution containing 8% HCl in 85% ethanol. These measures effectively prevented the loss of soluble sugars and improved the content of soluble dietary fiber.

A balanced ratio of 1:5.2 for SDF and IDF was found in the MsCDF. Hence, the balanced SDF and IDF content may contribute to the enhancement of the functionality and health benefits of MsCDF. Epidemiological studies have suggested that diets high in SDF may protect against CVD risk factors (Theuwissen & Mensink, 2008).

3.3. Physicochemical properties

The important properties of dietary fiber from MsCDF include WHC, swelling, SOL, OHC, GDRI, and adsorption capacity. WHC, swelling, and OHC are suggestive of the possibilities of using fibers as ingredients in food products. Examples of these include: dietary fibers with high OHC allow the stabilization of high fat food products and emulsions; dietary fibers with high WHC avoid syneresis and modify the viscosity of some formulated foods (Elleuch et al., 2011); dietary fibers with high SOL can bind to excessive blood cholesterol delivered by the liver, eventually expelling it from the body (Uskoković, 2008); and dietary fibers with high GDRI absorb glucose and have hypoglycemic activity (López et al., 1996). Table 2 shows that we obtained MsCDF with higher WHC

Table 2
Physicochemical properties of MsCDF.

	MsCDF	CDF ^a
WHC (g/g d.w.)	25.3 ± 2.4	4.5
OHC (g/g d.w.)	2.81 ± 0.23	0.98
Swelling (ml/g d.w.)	23.9 ± 4.5	9.5
SOL (%)	33.8 ± 5.2	No data
GDRI (%)		
10 min	36.2 ± 1.6	No data
20 min	38.2 ± 1.1	No data
30 min	42.0 ± 2.4	No data
40 min	46.7 ± 1.3	No data
50 min	50.5 ± 2.2	No data
60 min	51.9 ± 1.7	No data
Adsorption capacity of MsCDF for cholesterol (μg/g adsorbents)		
10 min	20.45 ± 1.25	No data
15 min	24.65 ± 2.26	No data
25 min	27.94 ± 1.60	No data
35 min	30.25 ± 2.35	No data
60 min	32.28 ± 3.25	No data
90 min	32.21 ± 2.82	No data
120 min	32.25 ± 1.81	No data

Data are presented as mean values ± STD (n = 3).

^a Yang et al. (2000).

and swelling values than those reported for CDF powder from the Core and maize bran in previous studies (Yang et al., 2000). MsCDF powder also exhibited higher WHC values than the agricultural by-products from other fibers, e.g., 12.6 mL water/g from peach pulp fiber (Grigelmo-Miguel and Martín-Belloso, 1999), 5 mL water/g from rice bran (Abdul-Hamid & Luan, 2000), and 11 mL water/g from lemon fiber and cocoa husks (Fuentes-Alventosa et al., 2009). High WHC and swelling may be due to the presence of high-soluble fiber substances (13.3 ± 1.7% SDF and 33.8 ± 5.2% SOL) and the HBSHP treatment (Agustiniano-Osornio et al., 2005). In addition, OHC of the MsCDF powder was similar to the OHC values for bambangan peel but was greater than the agricultural by-products from other fibers (Table 2), e.g., 0.6–2.0 mL oil/g from apple pomace, citrus peel, and unripe banana flour (Hassan et al., 2011).

The GDRI values of MsCDF at different times are showed in Table 2. As the time increased from 10 to 60 min, GDRI values of the MsCDF ranged from 36.2 ± 1.6% to 51.9 ± 1.7%, which are lower values than those from a fiber-rich powder prepared from bambangan peels and higher than those for cellulose (Hassan et al., 2011). The results also show that MsCDF may have potential benefits for controlling postprandial blood glucose and in applications as a low-calorie ingredient for fiber enrichment and dietetic snacks.

The cholesterol homeostasis in the body has a variety metabolic pathways, including cholesterol absorption, cholesterol

biosynthesis, cholesterol secretion, and bile acid synthesis and secretion. Cholesterol absorption in the small intestines plays a pertinent role, where prior to absorption, cholesterol esters of dietary and biliary sources are hydrolyzed to free cholesterol, which is the predominant form that is absorbed into the enterocytes (intestinal absorptive cells). Studies have shown that berberine could lower blood cholesterol levels in which the mechanism for such inhibits intestinal absorption and interferes with intraluminal cholesterol micellarization, decreasing enterocyte cholesterol uptake and secretion (Wang et al., 2014).

In order to confirm that MsCDF can also adsorb cholesterol and reduce cholesterol absorption in the small intestine, experiments on cholesterol adsorption onto MsCDF and the Core were carried out in cholesterol solutions. The adsorption capacity for cholesterol is presented in Table 2, which presents the different cholesterol adsorption abilities of MsCDF and the Core.

Results suggest that the adsorption capacity of the Core is less than MsCDF (32.28 ± 3.25 $\mu\text{g/g}$ powder), suggesting that MsCDF can reduce the concentration of cholesterol. In the experiment, cholesterol dissolved in solution was adsorbed by MsCDF in vitro. SEM images show that MsCDF has a smaller cell room and more surfaces than the Core; thus, cholesterol adsorption was greater. In addition, a gel was found during WHC, and SOL was determined. Uskoković (2008) demonstrated that soluble fiber forms a gel in the small intestines that can bind to excessive blood cholesterol delivered by the action of liver and eventually expel it from the body. The IDF has been related to intestinal regulation, while SDF is associated to the decrease in cholesterol levels and the absorption of intestinal glucose (Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006). The results show that MsCDF from the Core exhibits the potential to control postprandial blood glucose and balance cholesterol in the body and to supply information on physiological functions of dietary fiber. The properties of MsCDF powder also make it useful as thickening, bodying, and emulsifying agents for food applications and as low-calorie ingredients for fiber enrichment and dietetic snacks (Larauri, Rupbrez, Bravo, & Saura-Calixto, 1996).

On the basis of these values, this product could be promoted as a modifier of viscosity, an additive of formulated products for decreasing calories, a sorbent for preventing fat loss upon cooking, and also an absorber or binder of bile acids to increase their excretion, which is associated with plasma cholesterol reduction.

Table 3
Monosaccharide composition of the MsCDF and Core.

Monosaccharide	MsCDF powder (dry weight)	Core powder (% dry weight)
Xylose	89.5 ± 2.2	75.6 ± 4.6
Glucose	11.2 ± 1.5	9.45 ± 1.25

Mean values $\pm$ STD ($n = 3$).

3.4. Composition of MsCDF and the Core

The MsCDF and Core were hydrolyzed by trifluoroacetic acid into individual monosaccharides that were further trimethylsilylated for gas chromatography analysis. The monosaccharide composition was identified by comparison with the retention time of the standards. Table 3 shows the monosaccharide compositions of the MsCDF and Core in which two monosaccharides, xylose and glucose, were identified for both MsCDF and Core.

Analysis of the monosaccharide content in MsCDF show that xylose was the major monosaccharide, which is an interesting finding. Xylooligosaccharides (XOs) are sugar oligomers made up of xylose units, are valuable as food sweeteners and additives, and are used as ingredients in functional foods, cosmetics, pharmaceuticals, and agricultural products. In addition, XOs present interesting physicochemical properties; they are moderately sweet, stable over a wide range of pH and temperatures, and have organoleptic characteristics suitable for incorporation into foods (Hsu, Liao, Chung, Hsieh, & Chan, 2004). The growing commercial importance of these non-digestible oligosaccharides is based on their beneficial health properties, particularly prebiotic activity. In a previous study, a process was developed for producing XOs from bagasse, corncob, wheat bran, and peanut shell agricultural wastes (Yang, Yang, & Liu, 2007). In this study, a process for producing XOs is proposed using MsCDF from Core raw material, which offers economic and ecological benefits, especially since this material is abundant, renewable, and biodegradable.

3.5. Microstructure features of MsCDF and the Core

3.5.1. SEM examination of MsCDF and the Core

Available surface and porosity can influence the fermentation of dietary fiber (availability to microbial degradation in the colon), while the region-specific chemistry of the surface layer may play a role in other physicochemical properties (adsorption or binding of some molecules). Together, these factors account for some of the physiological effects of dietary fiber (Guillon & Champ, 2000). The surface of the Core and MsCDF were analyzed using SEM, and the results are shown in Fig. 1.

Based on SEM results, the surface of the Core is smooth with a sheet-like structure and contains an irregular groove, which appears as a large slice out of the structure (Fig. 1a). The surface of MsCDF in the small slice was concave and exhibits a rough structure (Fig. 1b). HBSHP treatment resulted in damage to the groove structure and increased the exposure of the internal structure of the Core, the irregular groove of the Core was destroyed, and more flakes, hole, and cracks appeared on the surface of the MsCDF, increasing the external surface area. HBSHP treatment disrupted recalcitrant structures and orderly hydrogen bonds in the Core, leading to an increase in the accessibility of cholesterol to MsCDF.

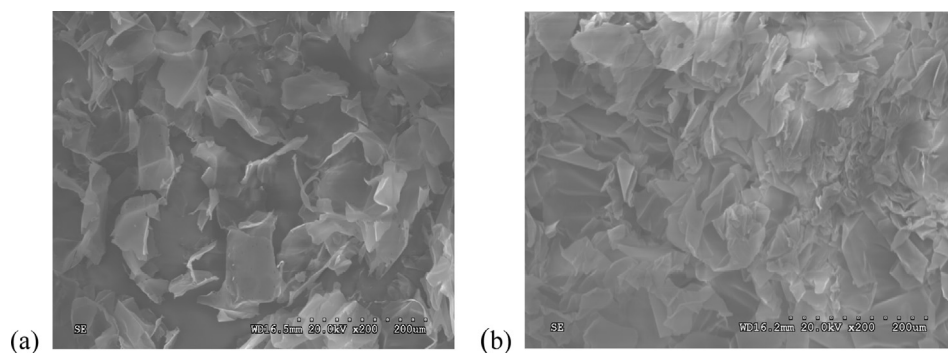


Fig. 1. SEM of (a) Core, (b) MsCDF.

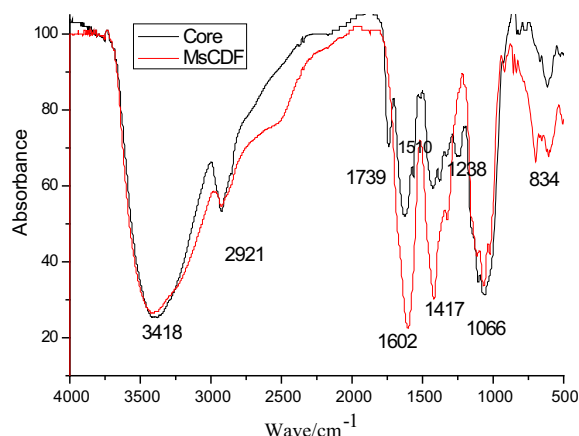


Fig. 2. FT-IR spectra of Core and MsCDF.

3.5.2. FTIR spectra of MsCDF and the Core

FTIR spectroscopy is an analytical method that is frequently used to investigate the structure of constituents and chemical changes that occur during the treatment of lingo-cellulosic biomass. The FTIR spectra of the MsCDF and Core are presented in Fig. 2. The band positions at 3418–3422 cm^{-1} and 2920 cm^{-1} are attributed to OH and C–H stretching, respectively. The intensity of the two peaks did not significantly change for the MsCDF or Core after treatment, which indicates that hydrogen bonds and the methyl and methylene components of the Core were not disrupted during HBSHP treatment (He, Pang, Liu, Li, & Wang, 2008). In the carbonyl-stretching region, a band at 1739 cm^{-1} is attributed to linkages between lignin and ester hemi-cellulose ferulic and p-coumaric acid carboxylic groups (Sun et al., 2005). This bond nearly disappeared in the spectra of MsCDF in comparison to the stronger absorbance spectra of the Core; the peak at 1510 cm^{-1} also disappeared in the MsCDF spectra. These results suggest that HBSHP treatment could degrade lignin in the Core and increase the relative amount of hemicellulose in MsCDF. This also indicates that HBSHP treatment could disrupt most ether linkages and some ester linkages between lignin and carbohydrates. HBSHP treatment for the Core reduced the intensity of the 1238 cm^{-1} band attributed to the cleavage and/or alterations of acetyl groups (Kumar, Mago, Balan, & Wyman, 2009; Sun et al., 2005). A small sharp band at 900 cm^{-1} is characteristic of β -glycosidic linkages, which demonstrates the presence of β -glycosidic linkages between the sugar units in hemicellulose (Kumar et al., 2009; Sun et al., 2005). Absorbance of hydroxyl groups mainly occurred in three bands, 1417, 1066, and 834 cm^{-1} , due to the bending of the OH group in C-OH in hemicellulose.

4. Conclusion

From the obtained results, we can conclude that: (a) the core of maize straw (Core) is a valuable resource that can be processed by HBSHP treatment to produce dietary fiber (MsCDF); (b) MsCDF contains high content of TDF ($83.5 \pm 1.4\%$), SDF ($13.3 \pm 1.7\%$), IDF ($70.5 \pm 3.3\%$), two main monosaccharides, xylose ($89.5 \pm 2.16\%$), and glucose ($11.2 \pm 1.5\%$). Thus, it has potential use as a high dietary fiber and material to produce xylooligosaccharides (XOs). (c) The physicochemical properties of MsCDF, including WHC ($25.3 \pm 2.4 \text{ g/g d.w.}$), OHC ($2.81 \pm 0.23 \text{ g/g d.w.}$), swelling ($23.9 \pm 4.5 \text{ mL/g d.w.}$), SOL ($33.8 \pm 5.2\%$), GDRI (60 min, $51.9 \pm 1.7\%$), and adsorption capacity for cholesterol ($32.28 \pm 3.25 \text{ } \mu\text{g/mg}$), make it a suitable product to be used in the preparation of a low-calorie, high fiber diet, as well as thickening, bodying, emulsifying agents and binder of excessive blood

cholesterol for food applications. (d) The results of this study also serve as evidence that the Core can be used as a crude material in functional food additives and that the HBSHP technology can be used to modify the physicochemical properties of the Core from to maize straw. Therefore, maize straw is a valuable resource that can be processed for use as a prime candidate for biomass fiber diet production. Maize straw serves many purposes in today's agricultural economy and will continue to do so in the future.

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