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RESEARCH

Functional Properties of Insoluble Dietary Fiber Obtained from Ceylon Cinnamon (*Cinnamomum zeylanicum* or *Cinnamomum verum*) Spent Bark Waste

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ABSTRACT

Cinnamon spent bark waste (CBW) is the residue resulted after cinnamon oil extraction. It is accumulated in high quantities in cinnamon oil distillation plants and creates disposal problems. The aim of this study was to extract dietary fiber (DF) from CBW using aqueous, chemical and enzymatic methods and evaluate the functional properties of resulted fiber. CBW reported a very low content of soluble dietary fiber (SDF) but significantly higher ($p<0.05$) insoluble dietary fiber (IDF) content (0.84 % and 78.86 % respectively). Therefore, only the IDF fraction was extracted and functional properties including water holding capacity (WHC), water swelling capacity (WSC), oil holding capacity (OHC) and glucose adsorption capacity (GAC) were determined. Chemical and water extraction methods resulted the significantly lowest (70.92 %) and highest (93.87 %) DF yields ($p<0.05$) respectively. Chemical extraction produced DF with significantly higher ($p<0.05$) WHC (3.91 g/g) compared to CBW (3.29 g/g). Moreover, DF obtained by enzymatic extraction reported significantly higher ($p<0.05$) WSC (0.90 mL/g) than CBW (0.17 mL/g). All the extraction methods produced fiber with significantly higher ($p<0.05$) OHC compared to the original samples. Chemically extracted fiber reported the significantly highest ($p<0.05$) OHC (3.6 g/mL) compared to the other fiber products. GAC of fiber extracted by chemical (0.86 mmol/g) and enzymatic (0.35 mmol/g) treatments were significantly higher ($p<0.05$) than that of water (0.08 mmol/g) extracted fiber and original samples. Results suggested that though the yield of DF was low, functional value of DF obtained by chemical extraction is better than enzymatic and water extraction methods.

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INTRODUCTION

Dietary fibers (DF) are considered as indigestible carbohydrate polymers in food which resist the enzymatic digestion in the gastrointestinal tract, but completely or partially fermented by the microorganisms in the large intestine (Chu et al., 2019). The most common classification of DF is based on its solubility in water as insoluble (IDF) and soluble (SDF). Cell wall contents such as cellulose, hemicellulose and lignin make the IDF fraction whereas SDF is made of non-cellulosic polysaccharides in plant cells such as pectin, oligosaccharides, mucilage and gums (Chu et al., 2019; Hua et al., 2019). Compared to IDF, SDF makes highly viscous aqueous solutions which are fermentable. Thus, it acts as a prebiotic and contributes in lowering blood glucose and cholesterol levels (López-Vargas et al., 2013; Tejada-Ortigoza et al., 2016). IDF is known to have physiological functionalities such as adding fecal volume, facilitating gastrointestinal transition, absorption of heavy metals and toxic substances, and modulating microbial populations in the intestine(López-Vargas et al., 2013) (López-Vargas et al., 2013; Tejada-Ortigoza et al., 2016; Hua et al., 2019; Huang et al., 2021). Consumption of DF in adequate amounts has led to decreased incidence of diseases such as cardiovascular diseases, type II diabetes, colon cancer, bowel disease, Crohn's disease and diverticulosis (Singh et al., 2012; Zhang and Wang, 2013; Hua et al., 2019). IDF is reported to decrease disease conditions such as constipation, obesity and colon cancer (Ma and Mu, 2016). Despite the proven benefits, worldwide average daily consumption of DF doesn't meet the recommended levels (Zhang and Wang, 2013). More importantly, 50-75% of whole portion of DF should be IDF to achieve the optimal activity of DF. Thus, the importance of IDF in maintaining human health should not be overlooked (Hua et al., 2019).

Cinnamon bark is used to extract essential oil which is rich in cinnamaldehyde (Ranasinghe et al., 2003). The world cinnamon market is dominated by *Cinnamomum cassia or* Chinese cinnamon supplied mainly by China. However, the *Cinnamomum verum* or *Cinnamomum zeylanicum* which is known as true cinnamon with the aromatic bark and ultra-low level of carcinogenic coumarin is mainly supplied by Sri Lanka (Baker and Grant, 2013; Suriyagoda et al., 2021). Cinnamon spent bark waste (CBW) is the byproduct resultings after the oil distillation. It is accumulated in large quantities in cinnamon oil distillation plants creating disposal problems. Plant food processing industries create byproducts with disposal problems; thus, can be transformed to value-added products and recover important nutrients, phytochemicals and biomass (Ng et al., 2010; Domingo et al., 2015). Transformation of these byproducts into valuable products not only generates additional income but also contributes to the sustainable development and environmental conservation (Domingo et al., 2015).

Fiber extracts are obtained by separating the fiber fraction from the original plant source (Garcia-Amezquita et al., 2018). Enzymatic, chemical and enzymatic-chemical methods are commonly used to extract DF from the original food/ plant source (Ma and Mu, 2016). Moreover, there is a possibility of modifying the DF from new origins through physical, chemical and enzymatic treatments to widen their fields of application (Ng et al., 2010). However, these treatment conditions can alter the microstructure of DF which directly affects the quality and functional properties of extracted DF (Ma and Mu, 2016). In a previous research, we evaluated the effects of supplementation of IDF from CBW in the diets of *Oreochromis niloticus* (Nile thilapia) as a functional ingredient. Supplementation of IDF obtained by aqueous extraction method affected the gut microbial populations and the hematological parameters of fish without adversely affecting growth performance (Lansakara et al., 2024).. Therefore, the scope of the current study was to evaluate the effects of different extraction methods on the functional properties of DF extracted from CBW. Additionally, cinnamon quillings (CQ) before being subjected to steam distillation to produce essential oil was used as a reference sample.

METHODOLOGY

Sample collection and preparation

Cinnamon spent bark waste and CQ samples were collected from HDDES Extracts (Pvt) Ltd., Colombo, Sri Lanka. First, the samples were cleaned to remove inert materials. Cleaned samples were dried in a drying oven (DX 600, YAMATO Scientific Co., Ltd., Japan) at 60 °C until a constant weight was achieved. Then, the samples were ground into a powder form using a laboratory grinder (ZM 200, YAMATO Scientific Co., Ltd., Japan). Ground samples were sieved, packed under airtight conditions and stored in a desiccator until analysis.

Chemical composition analysis

Proximate composition was determined according to the Association of Official Analytical Chemists (AOAC) International (1995) procedures. Determination of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were carried out as described by Van Soest *et al*. (1991). Hemicellulose and cellulose contents were calculated based on the NDF, ADF and ADL values. Total dietary fiber (TDF), SDF and ADF contents were determined by enzymatic gravimetric method, which was described by Prosky *et al*. (1992).

Chemical extraction method

The IDF fraction was isolated using neutral detergent solution (NDS) as described by Van Soest *et al*. (1991) with slight modifications. A sample of CBW/CQ and neutral detergent solution were mixed in a tall form beaker at a ratio of 1:100 g/mL and boiled for 60 min. The residue was separated by filtering the solution under vacuum using fritted crucible. Then, the residue was washed with hot water (80 °C) and with 30 mL of acetone. The crucible with residue was then dried at 60 °C in a drying oven (DX 600, YAMATO Scientific Co., Ltd., Japan) until the weight was constant. Dried residue was collected, packed under airtight condition and stored until further analysis. The IDF of CBW and CQ obtained from the chemical method were labeled as CCBW and CCQ respectively.

Aqueous extraction method

The extraction of IDF using water was performed according to the method described by Benitez *et al*. (2019). The CBW/CQ was mixed with deionized water (1:40 g/mL) and incubated in a water bath (BW100, Yamato Scientific Co., Ltd., Japan) at 60 °C for 60 min. Then, it was incubated further at 100 °C for 30 min. and the content was filtered through a fritted glass crucible under vacuum. The obtained IDF residue was washed with hot water and with 30 mL of acetone, and dried at 60 °C in a drying oven (DX 600, YAMATO Scientific Co., Ltd., Japan) until the weight becomes constant. Dried residue was collected, packed under airtight condition and stored until further analysis. The IDF of CBW and CQ obtained from the water extraction were labeled as WCBW and WCQ respectively.

Enzymatic extraction method

The enzymatic extraction of IDF was performed according to the method described by Prosky *et al.* (1992). First, the sample was mixed with 0.08 M (pH 6), phosphate buffer (1:50 g/mL). Then, the pH was adjusted to 6.0± 0.2 with 0.325 N HCl or 0.275 N NaOH and incubated with α-amylase (3000 IU/mL, Sigma- A3306, St. Louis, USA) at a rate of 0.1 mL/g at 100 °C for 30 min in a water bath (BW100, Yamato Scientific Co., Ltd., Japan). Then, after cooling to 60 °C, the pH was adjusted to 7.5± 0.1 with 0.275 N NaOH. Next, protease solution (350 IU/mL, Sigma- P3910, St. Louis, USA) was added (0.1 mL/g) to each beaker and incubated for 30 min at 60 °C with agitation in a shaking water bath (YCW-010E, Gemmy Industrial Corporation., Taiwan) set at 60 rpm. Then, the pH was adjusted to 4.0 - 4.6 with 0.325 N HCl. After that, amylo-glucosidase (3300 IU/mL, Sigma- G5003, St. Louis, USA) was added (0.3 mL/g) and incubated for 30 min at 60 °C under continuous agitation in a shaking water bath (YCW-010E, Gemmy Industrial Corporation., Taiwan) set at 60 rpm. Then, the enzyme digest was filtered under suction through a fritted crucible. The residue was washed with two 10 mL portions of water, 95% ethanol and acetone. The crucible with residue was dried overnight in a drying oven (DX 600, YAMATO

Scientific Co., Ltd., Japan) at 105 °C until a constant weight was achieved. Dried residue was collected, packed under airtight condition and stored until further analysis. The IDF of CBW and CQ obtained from the enzymatic extraction were labeled as ECBW and ECQ respectively.

Analysis of yield of dietary fiber

The yields of the IDF obtained from the three methods were calculated as follows (Benitez et al., 2019). Where,
Yield (%) = (Final weight)× 100/Initial weight

Bulk Density

Bulk density was measured as described by Kurek et al., (2018). The ratio of mass to volume was calculated and values were expressed as g/mL.

Water Holding Capacity (WHC) and Oil Holding Capacity (OHC)

Water holding capacity and OHC of extracted IDF samples were determined according to the method described by Mora *et al*. (2013). Five hundred (500) mg from each sample was stirred with 10 mL of distilled water in a 50 mL centrifuge tube. After keeping for 18 h at 28 °C, it was centrifuged at 3000 ×*g* for 20 min (CUR-1A, Hitachi Koki Co, Ltd., Japan). Then, the supernatant was discarded and weight of the residue was recorded. In the determination of OHC, the water was replaced by vegetable oil (Marina®). WHC/ OHC was calculated using following equations.

Water holding capacity (g/g) = Weight of water held by dietary fiber (g)/ Dry weight of the sample (g)

Oil holding capacity (%) = Weight of oil held by dietary fiber (g) ×100/ Dry weight of the sample (g)

Water swelling capacity (WSC)

Water swelling capacity was determined according to the method described by Mora *et al.* (2013). Five hundred (500) mg from each sample was added into a 10 mL measuring cylinder with 0.1 mL graduations. Then, 10 mL of deionized distilled water was added to each measuring cylinder and the initial volume occupied by each sample was measured. Next, it was stirred and kept for 24 h, at 28 °C. Final volume (mL) occupied by each sample was measured and WSC was expressed as mL of water/ g of dry weight.

Water swelling capacity (mL/g) = Swollen volume (mL)/ Dry weight of the sample (g)

Glucose adsorption capacity (GAC)

The dinitrosalicylic acid (DNS) colorimetric assay as described by Ou *et al*. (2001) was conducted with minor modifications. Each sample (0.2 g) was incubated with 20 mL of 25 mmol/L glucose solution at 37 ° C for 6 h in an incubator (YAMATO IC600, Yamato Scientific Company Limited, Japan). The supernatants were separated after centrifugation (CUR-1A, Hitachi Koki Co, Ltd., Japan) at 4000 ×g for 20 min. Then, 1 mL from each supernatant was mixed with 1 mL of DNS reagent and 2 mL of distilled water. The contents were kept for 5 min in a boiling water bath. A blank was run with 3 mL of distilled water and 1 mL of DNS solution. Then, the volume was adjusted to 20 mL with distilled water. The absorbance was measured in a spectrophotometer (1209, Shimadzu Co. Ltd., Japan) at 540 nm. A standard curve was developed by measuring absorbance for 100 mmol/L, 50 mmol/L, 25 mmol/ L, 12.5 mmol/L and 6.25 mmol/L glucose concentrations at 540 nm to determine the glucose concentration after 6 h. The GAC was calculated as follows.

Glucose adsorption capacity (mmol/g) = [A−B−C]×D/ E

GAC- Glucose adsorption capacity (mmol/g)

A- Glucose concentration of original solution (mmol/L)
B- Glucose concentration after 6 h (mmol/L)
C- Correction for color effect of sample (mmol/L)
D- Volume of the sample (L)
E- Dry weight of the sample (g)

Statistical analysis

The data were analyzed by one-way analysis of variance (ANOVA) using SPSS 16.0 software. Results were expressed as Mean±SD. Treatment means were compared using Tukey's multiple comparison test at a 95 % confidence interval.

RESULTS AND DISCUSSION

The composition of CBW and CQ

Table 1 and 2 show the composition of CBW and CQ. The dry matter, crude fiber, crude fat, and ash contents of CQ were significantly higher ($p<0.05$) than CBW. The crude protein and NFE contents were not significantly different ($p>0.05$) in the two materials. The NDF, ADF, and ADL contents of the CBW were significantly higher ($p<0.05$) than those of the CQ. The hemicellulose contents of the two materials were not significantly different ($p>0.05$). However, the cellulose content of the CQ was significantly higher ($p<0.05$) than that of CBW. Moreover, the IDF and TDF contents of CQ and CBW were not significantly different ($p>0.05$). However, the SDF content of the CQ was significantly higher ($p<0.05$) than that of CBW. The SDF content of the two materials especially in the CBW was very low. CQ is the outermost layer of the bark which is used for the steam distillation to produce cinnamon essential oil. CBW is the byproduct of the cinnamon oil distillation. The fat content has reduced from 2.69% in CQ to 1.57% in CBW as a result of oil extraction. The changes in the compositions of CBW and CQ may be due to the steam distillation. More importantly, high temperature in steam has resulted a loss of cellulose and increase of lignin in CBW. The bark of cinnamon contains approximately 4% of volatile oils which are extracted through steam distillation in commercial scale production of essential oils (Ranasinghe et al., 2003; Baker and Grant, 2013). Moreover, the protein content is not different ($p>0.05$) between CBW and CQ. As SDF content in CBW was very low, it was decided to extract the IDF only.

Table 1: Proximate composition of CBW and CQ

Component (%)	CBW	CQ
Dry matter	89.57±0.02^{a}	94.79±0.14^{b}
Crude fiber	43.29±0.30^{a}	47.57±1.21^{b}
Crude protein	5.10±0.26^{a}	5.28±0.20^{a}
Crude fat	1.57±0.13^{a}	2.69±0.57^{b}
Ash	4.02±0.25^{a}	5.24±0.47^{b}
NFE*	35.60± 0.40^{a}	35.05±1.67^{a}

Values are expressed as mean±standard deviation (n=3) on dry matter basis. Values with different superscripts within a row are significantly different at P <0.05. (NFE*- Nitrogen-free extract)

Table 2: Composition of fiber in CBW and CQ

Component (%)	CBW	CQ
NDF	91.45±0.37^{a}	81.28±0.69^{b}
ADF	84.18±0.95^{a}	76.76±1.18^{b}
ADL	62.87±0.95^{a}	43.23±1.83^{b}
Hemicellulose	7.27±1.11^{a}	4.52±1.86^{a}
Cellulose	21.31±0.16^{a}	33.53±0.87^{b}
SDF	0.84±0.14^{a}	2.54±0.05^{b}
IDF	78.86±0.99^{a}	78.57±0.66^{a}
TDF	79.70±0.86^{a}	81.11±0.42^{a}

Values are expressed as mean±standard deviation (n=3) on dry matter basis. Values with different superscripts within a row are significantly different at P <0.05.

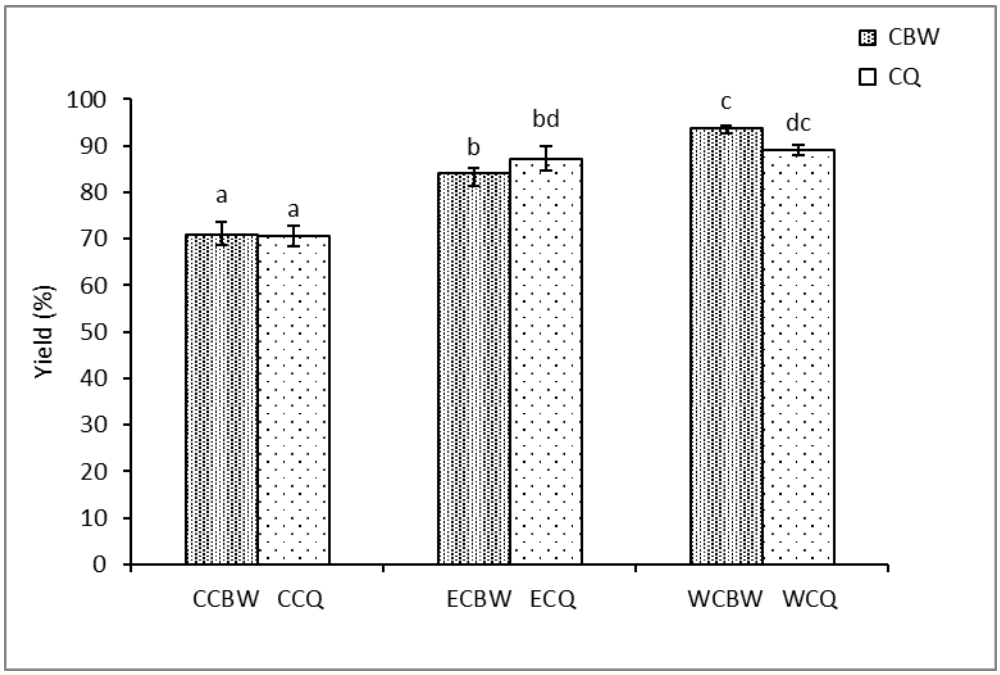

Figure 1: Yield of dietary fiber products obtained from cinnamon spent bark waste and cinnamon quillings[1].

Dietary fiber yield

The yields of DF from two material origins under the three extraction methods are depicted in the Figure 1. For both samples, chemical extraction resulted the significantly lowest ($p<0.05$) yield. Chemical treatments cause disruption of glycosidic linkages resulting losses of 10-20% cellulose, 30-40% hemicellulose and 100% SDF (Nyman and Svanberg, 2002; Ma and Mu, 2016). Therefore, the low yields in chemical extraction can be due to the loss of DF. In addition, chemical extraction creates effluent with large quantities of acids and alkali causing environmental problems (Ma and Mu, 2016). There is a complex structural network in plant cell walls due to cross-linking of polysaccharides and other components. The success of the extraction process depends on the complexity of structural network. Hot water extraction is a common extraction method followed by chemical methods. However, extractability of dietary fiber in aqueous methods is lower compared to chemical or enzymatic methods (Tejada-Ortigoza et al., 2016). In the present study also increased yield of DF produced by aqueous extraction of CBW can be due to low purity of DF resulted due to lack of extractability. Therefore, as Tejada-Ortigoza *et al*. (2016) also pointed out mechanical and enzymatic pretreatments can be used to increase the yields and efficiency of aqueous extraction.

Moreover, there were not significant differences ($p>0.05$) in the dietary fiber yields between the samples (CQ and CBW) subjected to the same extraction method. That must be because the IDF contents of the two materials were not significantly different ($p>0.05$). The yields of DF obtained from CQ by enzymatic (ECQ) and aqueous (WCQ) extraction were not significantly different ($p>0.05$). According to a study done by Benitez *et al*. (2019) both aqueous and enzymatic extraction produced

[1] The results are expressed as mean±sd (n=3). Different letters (a-d) among columns indicate significant ($p < 0.05$) differences according to ANOVA and Tukey's multiple comparison tests. CCBW, dietary fiber obtained from cinnamon spent bark waste by chemical extraction; ECBW, dietary fiber obtained from cinnamon spent bark waste by enzymatic extraction; WCBW, dietary fiber obtained from cinnamon spent bark waste by aqueous extraction; CCQ, dietary fiber obtained from cinnamon quillings by chemical extraction; ECQ, dietary fiber obtained from cinnamon quillings by enzymatic extraction; WCQ, dietary fiber obtained from cinnamon quillings by aqueous extraction

IDF with the same yield and polysaccharide and lignin composition from coffee parchment, thus making expensive enzymatic extraction unwanted. The enzymatic extraction is complex and expensive due to the use of amyloglucosidase, protease and amylase like enzymes to remove soluble sugars, starch and proteins. The enzymatic and chemical combination methods also have reported low dietary fiber yields as a result of polysaccharide losses during the processes of hydrolysis and chemical pretreatments (Ma and Mu, 2016).

Bulk density

The results of the bulk density are shown in the table 3. The lower bulk density is due to the higher volume of pores (Kurek et al., 2018). Bulk densities of original materials were not significantly different ($p>0.05$). All the fiber products had significantly lower ($p<0.05$) bulk densities compared to the original materials indicating fiber extraction has improved the structure of dietary fiber. DF products originated from CQ reported significantly lower ($p<0.05$) bulk density compared to the respective DF originated from CBW. From all DF products, the lowest BD was recorded by CCQ, followed by ECQ. Bulk density of CCBW, ECBW and WCQ were not significantly different ($p>0.05$). Moreover, bulk density of ECBW and WCBW were not significantly different. The bulk densities of the fiber products of the present study were lower than the bulk density of ordinary cellulose (0.50 g/mL). IDF of ginseng IDF reported a BD of 0.58 g/mL which is closer to cellulose (Hua et al., 2019).

Water holding capacity

WHC indicates the hydration properties of DF (Tejada-Ortigoza et al., 2016). It measures the quantity of water retained by a unit weight of DF under an external force such as centrifugal gravity or compression (López-Vargas et al., 2013; Tejada-Ortigoza et al., 2016). WHC is important when DF is included as a functional ingredient in processing food such as bakery products, custards, meat, fish and dairy products (de Moraes Crizel et al., 2013). DF with higher WHC can avoid syneresis and enhance the texture of the product (de Moraes Crizel et al., 2013; Chu et al., 2019). Moreover, greater WHC of IDF increases the fecal volume leading to reduced gastrointestinal transit time (Tejada-Ortigoza et al., 2016; Wen et al., 2017). WHC of original and extracted DF samples are shown in the figure 2. In both CBW and CQ, WHC of DF produced by enzymatic and aqueous methods were not significantly different ($p>0.05$) compared to the original samples. Therefore, for both CBW and CQ, DF extraction with enzymes or water has not improved WHC. According to Benitez *et al*. (2019), IDF produced from coffee parchment by aqueous extraction had a lower WHC compared to original flour. In the present study, chemically extracted DF (CCBW and CCQ) had significantly higher ($p<0.05$) WHC than the raw samples. Therefore, the chemical extraction with NDF solution has improved the WHC compared to the raw CBW and CQ. Findings of Ma and Mu (2016) indicate that materials with higher porosity are having increased WHC. Therefore, the higher WHC of chemically extracted fiber must be due to the physically entrapped water caused by structural modification from the chemicals used. According to Al-Sheraji *et al*. (2011), non-cellulosic components of DF contribute more to the WHC compared to the cellulose. Treatment of DF with low concentrated sulfuric acid increases WHC of IDF due to the removal of protein and starch effectively (Wen et al., 2017). According to Naumann *et al*. (2021), thermal and mechanical processing also cause changes in the structure resulting increased WHC. In contrast, processing can reduce the number of hydrophilic groups in polysaccharides thus; reduce the bonding sites which hold water within the DF matrix (Benitez et al., 2019). However, in the present study, especially the chemical treatments have improved the WHC of DF. Moreover, there were not significant differences ($p>0.05$) in the WHC between the DF products (ECBW, ECQ and WCBW, WCQ) produced using aqueous and enzymatic extraction methods. However, the WHC of CCQ was significantly higher ($p<0.05$) than the CCBW. This may be due to the higher cellulose and lower lignin contents in CQ than CBW. Nevertheless, WHC of CBW and CQ were not significantly different ($p>0.05$).

WHC consists of bound water, physically entrapped water and hydrodynamic water. Physically entrapped water contributes most to the WHC of DF (López-Vargas et al., 2013; Ma and Mu, 2016; Tejada-Ortigoza et al., 2016). Water uptake is affected by the chemical composition and structural characteristics of fiber. Surface tension of water facilitates its retention inside capillary structures of DF (Al-Sheraji et al., 2011). In addition, water may bond with some hydrophilic components in fiber through hydrogen bonds or dipole-dipole interactions (Al-Sheraji et al., 2011; Benitez et al., 2019; Naumann et al., 2021). Therefore, hydrophilic groups and mesh structure are the basis of WHC (Huang et al., 2021). The WHC of IDF of present study are much lower compared to the IDF of ginseng 17.66 g/g and higher compared to bamboo shoot shell IDF (2.83 g/g) (Hua et al., 2019).

Table 3: Bulk density of original materials and DF products

Treatment	CBW	CQ
Original samples	0.343±0.003^{a}	0.350±0.009^{a}
Chemical		
CCBW, CCQ	0.306±0.003^{b}	0.265±0.003^{d}
Enzymatic		
ECBW, ECQ	0.312±0.005^{bc}	0.288±0.003^{e}
Aqueous		
WCBW, WCQ	0.324±0.008^{c}	0.289±0.002^{be}

Results are expressed as mean± standard deviation (n=3). Values with different superscripts are significantly different at P <0.05.

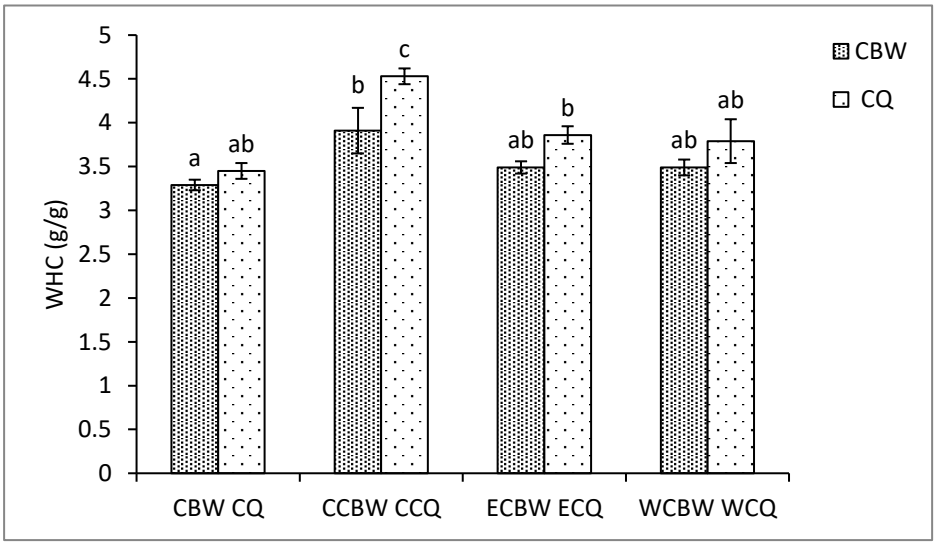

Figure 2: Water holding capacity of original materials and dietary fiber products[2].

Water swelling capacity

[2] The results are expressed as mean±sd (n=3). Different letters (a-d) among columns indicate significant ($p < 0.05$) differences according to ANOVA and Tukey's multiple comparison tests. CBW, Cinnamon spent bark waste; CQ, Cinnamon quillings; CCBW, dietary fiber obtained from cinnamon spent bark waste by chemical extraction; ECBW, dietary fiber obtained from cinnamon spent bark waste by enzymatic extraction; WCBW, dietary fiber obtained from cinnamon spent bark waste by aqueous extraction; CCQ, dietary fiber obtained from cinnamon quillings by chemical extraction; ECQ, dietary fiber obtained from cinnamon quillings by enzymatic extraction; WCQ, dietary fiber obtained from cinnamon quillings by aqueous extraction.

WSC is the volume of water occupied by a unit weight of DF immersed in excess amounts of water after equilibration (Ma and Mu, 2016) It indicates the ability of fiber matrix for volume expansion after water absorption (López-Vargas et al., 2013). The swelling of DF gives the feel of fullness after food consumption and reduces the food intake. WSC depends on the particle size, chemical composition, structural characteristics, presence of polar groups and the content of SDF, especially pectin (López-Vargas et al., 2013; Ma and Mu, 2016). However, WSC can be related to the amount of IDF as water can be trapped inside the capillary structure of fiber through surface tension (Mei et al., 2010; Tejada-Ortigoza et al., 2016). According to the results shown in the figure 3, only enzymatic extraction resulted DF with significantly higher ($p<0.05$) WSC compared to the original samples. However, WSC of chemically extracted fiber and enzymatically extracted fiber were not significantly different ($p>0.05$). Though the compositions of CBW and CQ are different, WSC of CBW and CQ were not significantly different ($p>0.05$). Moreover, WSC of fiber products produced from two original materials using the same extraction method were not significantly different.

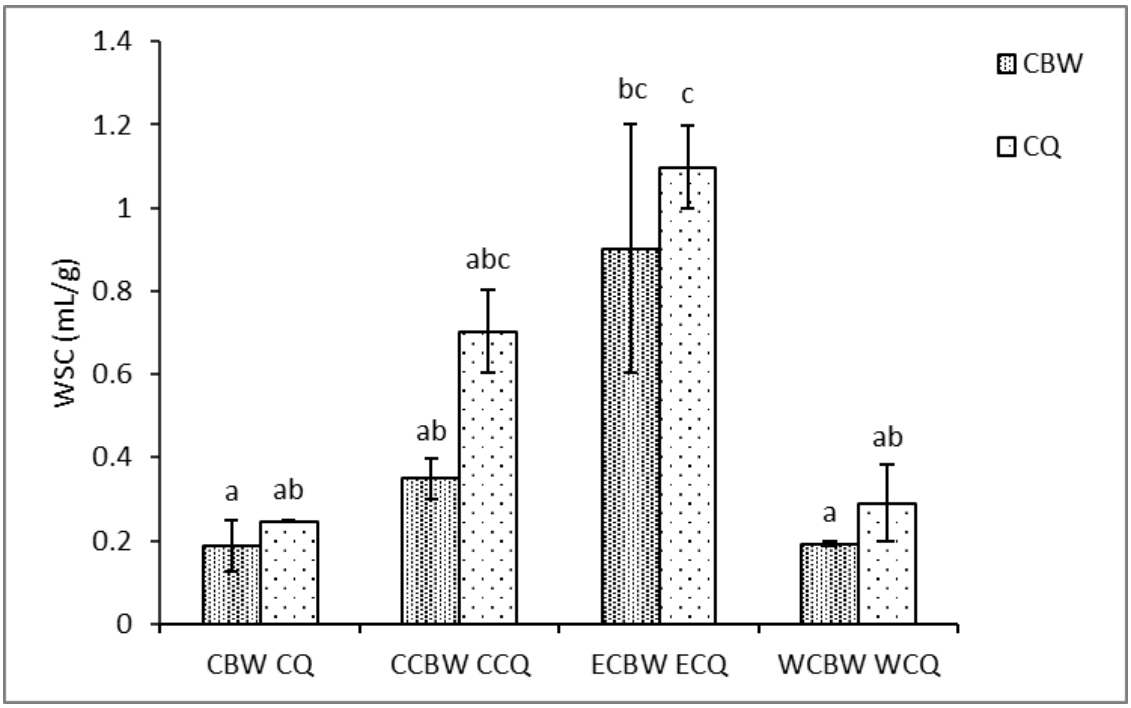

Figure 3: Water swelling capacity of original materials and dietary fiber products.[3]

According to Benitez *et al*. (2019), the major factors affecting swelling properties of DF are composition and organization of polysaccharides within the cell wall. Swelling capacity indicates higher hydration levels which occur inside the structure of DF leading to swelling. Mechanical, chemical, enzymatic or thermal treatments can change the swelling capacities of IDF (J. Chen et al., 2013). DF obtained from coffee parchment by aqueous extraction recorded low WSC (Benitez et al., 2019). In the present study also WSC of water

[3] The results are expressed as mean±sd (n=3). Different letters (a-d) among columns indicate significant ($p < 0.05$) differences according to ANOVA and Tukey's multiple comparison tests. CBW, Cinnamon spent bark waste; CQ, Cinnamon quillings; CCBW, dietary fiber obtained from cinnamon spent bark waste by chemical extraction; ECBW, dietary fiber obtained from cinnamon spent bark waste by enzymatic extraction; WCBW, dietary fiber obtained from cinnamon spent bark waste by aqueous extraction; CCQ, dietary fiber obtained from cinnamon quillings by chemical extraction; ECQ, dietary fiber obtained from cinnamon quillings by enzymatic extraction; WCQ, dietary fiber obtained from cinnamon quillings by aqueous extraction.

extracted DF were very low and similar compared to the original samples. In a previous research, sugar beet fibers treated with acidic and basic solutions have shown higher water swelling capacities. These increased swelling capacities may be due to the destruction of the coherence of cell walls in DF (J. Chen et al., 2013). Ma and Mu (2016) also pointed out that WSC depends on structural characteristics which can be altered through treatments or extraction conditions such as pH and temperature (Mei et al., 2010; Tejada-Ortigoza et al., 2016). SDF and porous structure of fiber contribute more to the swelling of fiber (Chu et al., 2019). Fiber products of the present study did not contain SDF. Thus, higher swelling capacities of chemically and enzymatically extracted fiber must be related to the modified structure of DF. Polysaccharides have water binding sites to bind with surrounding water through hydrogen bonds. DF, especially IDF has the ability to form a hydrophilic matrix to entrap water. Filling the interstices of the polysaccharides results considerable swelling of fiber (Benitez et al., 2019). Thus, chemical and enzymatic treatments must have increased these water binding sites and modified the structure of DF.

According to previous research, WSC of vegetables and fruits varied from 4-20 mL/g (Benitez et al., 2019). WSC values of the present study were very low compared to other IDF products. For examples, according to Mei *et al*. (2010), coconut fiber reported a higher WSC (20 mL/g) while oat bran had relatively a lower WSC (5.3 mL/g). Moreover, WSC values of the DF of the current study are lower compared to that of de-oiled cumin (3.49- 7.98 mL/g) which is a byproduct in cumin oil extraction (Ma and Mu, 2016).

Oil holding capacity

OHC indicates the ability of DF to adsorb oil into its structure under centrifugal force (Tejada-Ortigoza et al., 2016). DF with higher OHC can reduce fat loss during food processing (Chen et al., 2019). Furthermore, it is associated with reduction of cholesterol levels in the blood by adsorbing fat and bile acids in the intestinal lumen (Xue et al., 2019). OHC depends on the chemical composition, overall charge density, surface properties, and hydrophobic nature of dietary fiber (Tejada-Ortigoza et al., 2016; Huang et al., 2021). According to the results (Figure 4), no significant difference ($p>0.05$) was recorded between OHC of original materials. Extracted DF from both CBW and CQ had significantly higher ($p<0.05$) OHC compared to the original materials. Therefore, DF extraction by chemical, enzymatic and aqueous methods has improved the OHC. There was not any significant difference ($p>0.05$) among the OHC of CCQ, ECQ and WCQ indicating the method of extraction has not affected the OHC of DF products obtained from CQ. In contrast, chemical treatment has increased the OHC of DF of CBW compared to the DF obtained from aqueous and enzymatic methods. However, OHC of CCBW was not significantly different ($p>0.05$) from that of CCQ, ECQ and WCQ. Moreover, DF products obtained from CQ had significantly higher ($p<0.05$) OHC than DF products of CBW.

The lignin content of CBW was significantly higher ($p<0.05$) than that of CQ. Navarro-González *et al*. (2011)) reported that lignin content in fiber is positively correlated with OHC. However in the present study, DF products of CBW did not record higher OHC than DF products of CQ. Khan *et al*. (2018) observed that DF extracted from walnut flour by treating with alcalase enzyme had more porous structure due to the removal of non-cellular low molecular weight substances. In the present study, IDF products which reported lower bulk densities reported higher OHC. According to Chen *et al*. (2019), the adsorption capacity of porous fiber is relatively strong due to increased surface area. Therefore, higher OHC of chemically and enzymatically extracted fiber in the present study can be related to their modified structure. Similar results were observed by Xue *et al*. (2019) where extrusion treatment increased the OHC of DF (88% IDF) from *Lentinula edodes* mushroom compared to untreated fiber. Moreover, OHC of IDF from soybean significantly increased after the treatment with cellulase (Chen et al., 2019). In contrast, OHC of lupin kernel fiber had an initial OHC of 2.28 mL/g, and significantly reduced to 1.09–1.87 mL/g after extrusion processing. According to the authors, this reduction of OHC may be due to the changes in

the structure of DF such as reduction of surface area, pore volume and lipophilic sites resulted by extrusion processing (Naumann et al., 2021). OHC of DF of the present study were higher than that of DF extracted from citrus fruits (1.81 g/g), grapefruits (1.20–1.52 g/g) and apples (0.60–1.45 g/g). Moreover, the OHC of fiber products of the present study were slightly similar to that of orange fiber (3.50-3.63) (Ma and Mu, 2016).

Glucose adsorption capacity

Glucose adsorption by the fibrous network of DF delays the adsorption of glucose and thereby reduces the sugar level in the blood (Chu et al., 2019; Xue et al., 2019). Ability of DF to adsorb glucose varies with the source of fiber, particle size, surface area, viscosity and porosity (Xue et al., 2019). GAC of different fiber products and original materials are shown in the figure 5. According to the results, GAC of CCBW and CCQ were significantly higher ($p<0.05$) than original samples and other fiber products. Increase in porosity can increase the entrapment of glucose molecules within the fibrous network (B. Chen et al., 2019). As CCQ had the lowest bulk density, its higher GAC may be attributed to the increased porosity. DF obtained from enzymatic methods also showed significantly higher ($p<0.05$) GAC compared to original materials and water-extracted DF. According to B. Chen *et al*. (2019), cellulase treatment increased the number of cavities on the surface of soybean IDF. Moreover, GAC of ECQ was significantly higher ($p<0.05$) than ECBW. No significant differences ($p>0.05$) were observed among original materials and DF obtained by aqueous extraction. Therefore, aqueous extraction has not improved the glucose adsorption properties of DF. Even though, WCQ reported a relatively low bulk density, its GAC was not significantly different ($p>0.05$) to original samples.

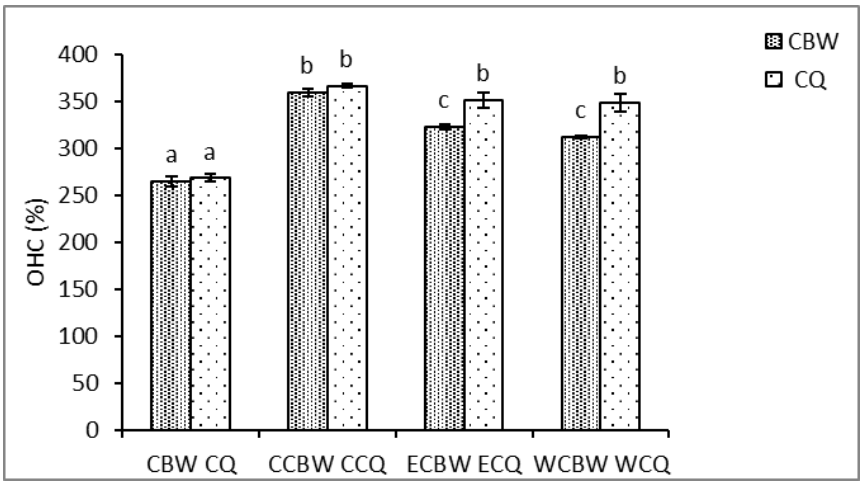

Figure 4: Oil holding capacity of original materials and dietary fiber products[4].

[4] The results are expressed as mean±sd (n=3). Different letters (a-d) among columns indicate significant ($p < 0.05$) differences according to ANOVA and Tukey's multiple comparison tests. CBW, Cinnamon spent bark waste; CQ, Cinnamon quillings; CCBW, dietary fiber obtained from cinnamon spent bark waste by chemical extraction; ECBW, dietary fiber obtained from cinnamon spent bark waste by enzymatic extraction; WCBW, dietary fiber obtained from cinnamon spent bark waste by aqueous extraction; CCQ, dietary fiber obtained from cinnamon quillings by chemical extraction; ECQ, dietary fiber obtained from cinnamon quillings by enzymatic extraction; WCQ, dietary fiber obtained from cinnamon quillings by aqueous extraction.

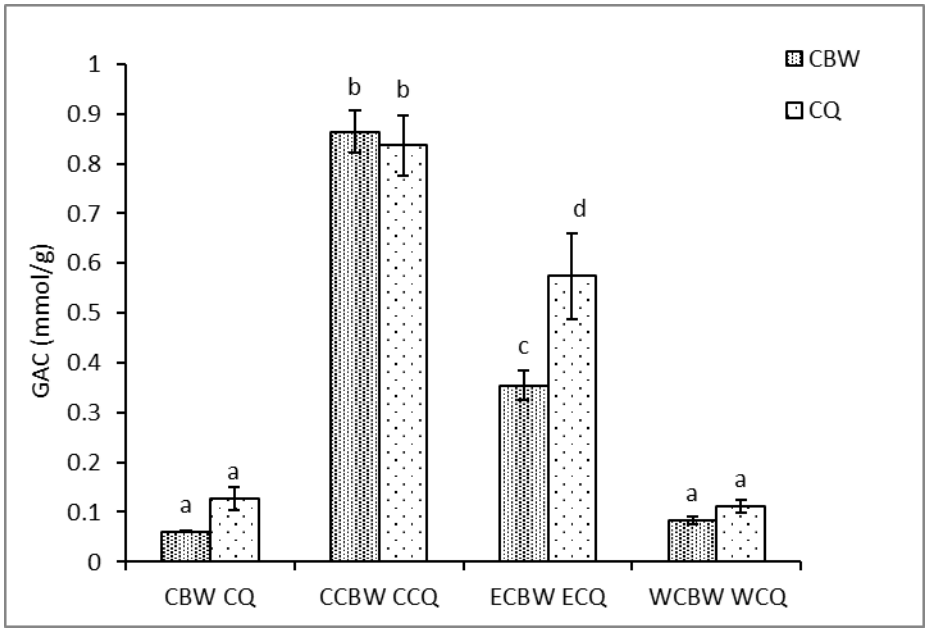

Figure 5: Glucose adsorption capacity of original materials and dietary fiber products[5].

According to Mei *et al*. (2010), GAC values of IDF from orange and cellulose were 11.3 mmol/g and 8.75 mmol/g respectively. Therefore, the GAC values of the DF of present study were very low compared to other DF products. SDF with higher viscosity can trap more glucose molecules than IDF and thereby delay glucose diffusion (Ma and Mu, 2016). Therefore, low GAC values of DF in the present study may be due to absence of SDF. GAC of IDF obtained from wheat bran as reported by Ou *et al.* (2001) was also comparatively low (0.05- 0.56 mmol/g). However, IDF obtained from ginseng residue had a considerable GAC (Hua et al., 2019).

CONCLUSION

In conclusion, this study investigated the potential of CBW, a byproduct of cinnamon oil extraction, as a source of IDF. Even though, the water extraction yielded the highest IDF from CBW, while chemical extraction resulted in the lowest, fibers obtained through chemical and enzymatic methods showed better functional properties compared to water-extracted fibers and the original samples. Especially, chemically extracted fiber demonstrated the highest OHC and significant GAC. However, except OHC, other functional properties (WHC, WSC, and GAC) did not meet the standards expected from IDF with functional values. Based on the analyzed functional properties, use of IDF from CBW in functional food/ feed can be limited. Therefore, it can be suggested to investigate other potential functional properties such as antioxidant, antimicrobial and prebiotic activities to widen the applications of IDF from CBW in food/ feed industry.

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[5] The results are expressed as mean±sd (n=3). Different letters (a-d) among columns indicate significant ($p < 0.05$) differences according to ANOVA and Tukey's multiple comparison tests. CBW, Cinnamon spent bark waste; CQ, Cinnamon quillings; CCBW, dietary fiber obtained from cinnamon spent bark waste by chemical extraction; ECBW, dietary fiber obtained from cinnamon spent bark waste by enzymatic extraction; WCBW, dietary fiber obtained from cinnamon spent bark waste by aqueous extraction; CCQ, dietary fiber obtained from cinnamon quillings by chemical extraction; ECQ, dietary fiber obtained from cinnamon quillings by enzymatic extraction; WCQ, dietary fiber obtained from cinnamon quillings by aqueous extraction.

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