EXTRACTION AND PROPERTIES OF CELLULOSE FROM BANANA PEELS

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Abstract

This research illustrates the extraction of cellulose from banana peel due to the removal of fat, protein, and pigments from banana peel cellulose (BPC). The optimum extraction and bleaching conditions included using 90% ethanol for 16 h for fat removal, followed by sodium hydroxide pH 11.6 for 24 h for elimination of protein, and soaking in 15% hydrogen peroxide for 3 h for bleaching. The obtained BPC was washed and dried at 60°C for 10 h. The chemical, physical, and microbiological properties and the cellulose structure as well as the functional properties of the BPC were studied. The BPC contained some impurities and had a lower L* value (84.66) compared with commercial cellulose (CC, 98.61). It also had higher moisture, fat, protein, and ash content as well as water activity but was lower in fiber and cellulose contents than those of the CC. The BPC microstructure was glacial and of various sizes. The bulk, packed, and hydrated densities, and the water retention capacity of the BPC were 0.646 g/ml, 0.923 g/ml, 2.5 g/ml, and 2.91 g water/g dried basis, respectively. The emulsifying activities and oil retention capacity were 40.70 and 0.08 (g oil/g dried basis), respectively. The nuclear magnetic resonance spectra of the BPC indicated that it contained some impurities.

Keywords: Banana peels, cellulose, properties of cellulose, extraction of cellulose

Introduction

Banana is one of the most extensively consumed fruits in the world and represents 40% of world trade in fruits. Thailand is one of the largest producing countries of banana, especially in Phitsanulok province with a planting area of 64000 ha producing 43750 ton/ha and the OTOP (One Tambon, (subdistrict) One Product) products from banana were 60-70 ton/day. The OTOP factories produce a lot of banana peels, which can cause an environmental problem such as a bad smell and become a source of human disease. One way of reducing the problem is to convert the banana peels into a more valuable product, cellulose, which can be more extensively used in the food industry.

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Cellulose, the major structure component of plants, is a glucose polymer bounded in the β-1, 4 linkage configuration. The β-1, 4 linkage allows the cellulose polymer to crystallize in a linear configuration, with a high degree of intermolecular hydrogen bonding, which gives it substantial shear and tensile strength. Because of its chemical makeup, cellulose can be purified for use as a food ingredient. Cellulose is probably the least soluble of all fiber components, being insoluble not only in cold or hot water, but also in hot dilute acids and alkalis as well. Cellulose is not biodegradable nor does it provide energy; therefore, the remaining waste is for excretion. It is used to increase the fecal waste in the digestive system easily and reduce the risk of colon cancer (Prosky and DeVries, 1992). Cellulose can be extracted from various raw materials such as soybean hull, pea hull, corn bran, dried beet pulp, and oat hull (Vail, 1991). The objectives of this study were to extract cellulose from banana peels and investigate its functional properties for application in food products.

Materials and Methods

Materials

Bananas (*Musa sapientum* Linn. cv. Mali-Ong) were obtained from the market in Phitsanulok, Thailand. The various chemicals used for the extraction of cellulose were ethanol (AR grade, from Merck KGaA, Darmstadt, Germany), sodium hydroxide (AR grade, from Merck KGaA, Darmstadt, Germany), hydrogen peroxide (AR grade, from Fisher Scientific UK Ltd., Loughborough, UK), phosphoric acid (AR grade, from Ajax Finechem Pty Ltd., Taren Point, NSW, Australia), and commercial cellulose (CC; cellulose powder or cotton linters, medium fibers, produced by Sigma-Aldrich Co., St. Louis, MO, USA).

Methods

Preparation of Banana Peel Powder

Fresh banana peels (*Musa sapientum* Linn. cv. Mali-Ong) of maturity stage 7 (yellow peel and little brown spots (Silayoi, 2002)), were purchased from the market in Phitsanulok province and immediately cut into pieces 0.3×2.5 cm. in size and dried at 55°C for 10 h or until reaching a moisture content of 7.5% (dry basis) using a hot air convection oven (Model KPO-700). After cooling to room temperature, the peel was weighed, ground, and passed through a 35 mesh sieve before sampling for its chemical composition analysis (AOAC, 2000) and it was then kept in a polyethylene plastic bag and placed in a refrigerator at 4°C until analysis.

Extraction of Cellulose

Extraction of Fat

The extraction of fat from banana peel powder was adapted from Vail (1991). Banana peel powder was soaked in ethanol solution concentrations of 90, 95, and 99% for 8, 16, and 24 h. Twenty grams of banana peel powder were mixed with 200 ml of ethanol 10% (w/v) in a water bath at 50°C and placed in a shaker with a shaking speed of 150 rpm (shaker Model: NB101-MH 25, S/N NBI 10N101M112 from Scientific Promotion Co., Ltd., Bangkok, Thailand). Then it was washed 3 times with distilled water and filtered with Whatman paper No. 4 and the defatted banana peel powder was dried in a hot air oven (Model KPO-700, from Kittipoom Equipment Ltd.) at 80±2°C for 7 h at a velocity 304.8 mm/h. The sample soaked in distilled water served as a control.

Extraction of Protein

The extraction of protein was adapted from Vail (1991) and Phongnori (2004). The defatted banana peel powder was soaked in sodium hydroxide (1:10 w/v) at 3 pH levels of 11.6, 11.8, and 12.0 for 8, 16, and 24 h and that soaked in distilled water served as a control. The experiment was conducted in a water bath at 50°C with a shaking speed of 150 rpm. The samples were washed 3 times with distilled water, filtered with Whatman paper No. 4, and dried in the hot air oven at 80±2°C for 7 h.

Bleaching of the Cellulose

The method of bleaching of cellulose powder was adapted from Gould (1987), Vail

(1991), Prakhongpan *et al*. (2002), and Phongnori (2004). The defatted and protein-removed banana peel powder was soaked in hydrogen peroxide solutions of 10, 15, 20, and 30% for 1.5, 3.0, 4.5, 6.0, and 7.5 h. The bleached samples were washed 3 times with distilled water, filtered with Whatman paper No. 4, and dried in the hot air oven at 60±2°C for 10 h.

Properties of the BPC as Compared with Commercial Cellulose (CC)

The obtained BPC and CC were chemically analyzed for moisture, fat, protein, carbohydrate, ash, and fiber contents (AOAC, 2000), and the cellulose content (Committee on Codex Specifications, 1981). The physical properties were analyzed for L*, a*, and b* values (Hunter Lab Model DP–9000, Hunter Associates Laboratory Inc., Reston, VA, USA), pH (AOAC, 2000), water activity (water activity analyzer Model MB – MIK 3000, Novasina AG, Lachen, Switzerland), water retention capacity and oil retention capacity (Ang, 1991), and Pb and Sulfite (atomic absorption spectrosphotometer, Avanta PM, GBC Scientific Equipment Pty Ltd., Braeside, VIC, Australia).

The microbial properties of the BPC and CC were analyzed for total viable count, yeasts and molds, *Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli,* and Salmonella, and Shigella (Committee on Codex Specifications, 1981).

Microstructural Characteristics of the BPC as Compared to the CC

The microstructural characteristics of the obtained BPC and CC were studied by using a scanning electron microscope (SEM, model JSM- 5410LV, JEOL Ltd., Tokyo, Japan).

Functional Properties of the Cellulose as Compared with the CC

The obtained BPC and CC were analyzed for bulk density, packed density, hydrated density, emulsifying activity, and viscosity (Prakhongpan *et al*., 2002), setting volume (Luangpituksa, 1992), and water and oil retention capacities (Committee on Codex Specifications, 1981).

Bulk Density

A pre-weighed graduate cylinder was filled with 50 g of sample and shaken slightly. The volume of the sample was recorded, the content of the cylinder was weighed, and the bulk density was expressed as weight per volume (Prakhongpan *et al*., 2002). The bulk density was calculated using the following equation:

$$\text{Bulk density (g/ml)} = \frac{\text{weight of the sample (g)}}{\text{volume of the sample (ml)}}$$

Packed Density

A calibrated 10-ml graduated syringe was filled with a known weight of sample. Pressure was applied manually until additional pressure would not further reduce the volume. The packed density was calculated as the weight of the sample per least volume of the sample (Prakhongpan *et al.,* 2002). The packed density was calculated using the following equation:

$$\text{Packed density (g/ml)} = \frac{\text{weight of the sample (g)}}{\text{least volume of the sample (ml)}}$$

Hydrated Density

A calibrated 10 ml graduate cylinder was filled with a known amount of distilled deionized water, and a known weight of sample was added carefully to avoid adhesion to the cylinder's walls. The difference between the volume of the water before and after adding the sample was recorded as ml of water displaced. Results were expressed as grams of the sample per ml of water displaced (Prakhongpan *et al.,* 2002). The hydrated density was calculated using the following equation:

$$\text{Hydrated density (g/ml)} = \frac{\text{grams of the sample (g)}}{\text{ml of water displaced}}$$

Water Retention Capacity (WRC) and Oil Retention Capacity (ORC)

WRC and ORC were analyzed by using a glass rod; for the WRC, 2 g of sample was mixed with 30 ml of distilled water in a 50 ml

centrifuge tube. The slurry was allowed to stand for 10 min, and then centrifuged at 2000 × g for 15 min. After centrifugation, the supernatant was drained and the wet sample precipitate was weighed. The result was expressed as gram of water per gram of the sample. For the ORC, the procedure was similar to the one described for the WRC except that palm oil was used instead of water (Committee on Codex Specifications, 1981). The WRC and ORC were calculated using the following equation:

$$\text{Water retention capacity (g water/g dried sample)} = \frac{\text{gram of water}}{\text{gram of the sample}}$$

$$\text{Oil retention capacity (g oil/g dried sample)} = \frac{\text{gram of oil}}{\text{gram of the sample}}$$

Emulsifying Activity (EA)

Seven grams of sample was suspended in 100 ml distilled water and then 100 ml soybean oil was added. The mixture was emulsified using a homomixer (IKA Ultra Turrax-T25, Ika Japan KK, Osaka, Japan) with the designation of the dispersing tool (S25N 25F) at 1000 rpm for 1 min. The emulsion obtained was divided evenly into 4 50 ml centrifuge tubes and centrifuged at 1300 × g for 5 min (Prakhongpan *et al*., 2002). The EA was calculated using the following equation:

$$\text{EA} = \frac{\text{height of emulsified layer (cm)} \times 100}{\text{height of whole layer (cm)}}$$

The amount of the sample was reduced to 1.75 g when there was no excess water and oil retained before centrifugation.

Settling Volume

The settling volume (SV) of the dietary fiber and cellulose samples was measured. This experiment was performed by mixing 1 g of sample with 70 ml distilled water in a 100 ml screw-cap bottle. These bottles were subjected to ultrasonic treatment for 30 min in order to allow water to saturate the samples and also to remove some of the excess gas in the mixture. The mixtures were then degassed by vacuum suction for 30 min and placed in a cold storage room for 24 h to facilitate the penetration of water into the interstices of the samples. The individual mixture in each bottle was quantitatively transferred to a 100 ml volumetric cylinder. The content of each cylinder was adjusted to 100 ml by adding distilled water. The SV is the volume, in ml, formed by the sample residue layer, read by the naked eye after 24 h at room temperature (Prakhongpan *et al*., 2002).

Purity of BPC

The BPC and CC were analyzed for purity by using nuclear magnetic resonance spectroscopy (NMR) (Avance DPX 300 Biospin, Bruker Corp., Billerica, MA, USA).

Sample Preparation and Testing Conditions

All samples were characterized at room temperature (20±1°C) with solid state cross-polarization magic angle spinning carbon-13 NMR (CP/MAS ^{13}C NMR). CP/MAS ^{13}C NMR spectra were recorded at a frequency of 75 MHz. The spectral parameters used were as follows: the number of scans (NS) was 4000, a relaxation delay of 4 s., a spin rate of 5 kHz, and a spectral size 2 K with a 4 K time domain size. Solid state CP/MAS ^{13}C NMR was used to study the BPC and CC ultra-structure.

Statistical Analysis

The experimental design for extraction of the BPC was a completely randomized design. The data were statistically analyzed using ANOVA, and differences in means were analyzed using Duncan's New Multiple Range Test ($p \leq 0.05$).

Results and Discussion

Chemical Composition of Dried Banana Peel Powder

The chemical composition of dried banana peel powder of maturity stage 7 banana is shown in Table 1. It can be seen that the banana peels contained mainly carbohydrates (56.35%), followed by fiber

(15.30%), ash (12.62%), moisture content (7.65%), crude fat (4.34%), and protein (3.74%).

Extraction of Fat

The mechanism of fat extraction from the banana peels was due to the polarity. Fat contains both hydrophilic and hydrophobic polar. The solute is dissolved in a solvent as both substances must have the same properties; as a rule "like dissolves like" so that the polar solute will be dissolved in the polar solvent. Since the attraction between polar molecules is a force dipole-dipole and it is insoluble in non-polar solvents, fat will be dissolved in alcohol (slightly polar) (Rattanapanon, 2002; Intranupakorn, 2007)

The control (soaked in distilled water) had a significantly higher crude fat content than those of the other samples (Table 2). Ethanol was the solvent used to extract fat from the samples. As the extraction time increased, the total fat content of the samples significantly decreased ($p \leq 0.05$). It can be seen that the extraction time affected the crude fat but the concentration of ethanol (90, 95, and 99%) had no effect on the crude fat content. The lowest concentration of crude fat was selected. Table 2 shows the lowest crude fat at conditions of 90 % ethanol 16 h,

Table 1. Chemical composition of dried banana peel of maturity stage 7 banana

Chemical composition	Dry basis (%)
Moisture	7.65 ± 0.05
Crude fat	4.34 ± 0.74
Protein	3.74 ± 0.42
Carbohydrate	56.35 ± 0.37
Ash	12.62 ± 0.09
Fiber	15.30 ± 0.85

Results are mean ± SD of triplicate analysis

Table 2. Crude fat content of the BPC after ethanol extraction with various conditions

	Sample	Crude fat content (%)
Control		4.34 ± 0.74[a]
8 h	90%	0.89 ± 0.07[b]
	95%	0.72 ± 0.07[bc]
	99%	0.35 ± 0.19[cd]
16 h	90%	0.48 ± 0.02[bcd]
	95%	0.37 ± 0.04[cd]
	99%	0.23 ± 0.02[d]
24 h	90%	0.28 ± 0.02[cd]
	95%	0.18 ± 0.02[d]
	99%	0.21 ± 0.02[d]

[1]*Means with different superscripts in the same column are significantly different ($p \leq 0.05$) by Duncan's multiple range test. Means ± SD of triplicate analysis.*

90 % ethanol 24 h, 95% ethanol 16 h, 95% ethanol 24 h, 99% ethanol 8 h, 99% ethanol 16 h, and 99% ethanol 24 h which were not significantly different ($p > 0.05$). However, from the economic point of view, the lower chemical concentration for extraction and a slightly longer extraction time are likely to have a negligible effect, so the condition using 90% ethanol and 16 h extraction time was selected. This condition was different from that reported by Phongnori (2004) in that the condition for cellulose extraction from corn cob was by using 95% ethanol for 8 h extraction time.

It is shown from Table 2 that all the samples still contained some fats, hence their purities were lowered.

Extraction of Protein

It was found that the protein content of defatted banana peel powder significantly decreased ($p \leq 0.05$) with the time of extraction (Table 3). With regard to the same extraction time, there was no significant difference ($p > 0.05$) in protein content between the samples. This indicated that both the extraction time and pH had more effect on removing protein from the sample; 16 h at pH 11.8, 24 h at pH 11.6, 24 h at pH 11.8, and 24 h at pH 12 produced the lowest protein content. Therefore, to save the chemical cost, the extraction condition of 24 h at pH 11.6 was selected for further experiment. This condition was different from Prakhonpan *et al*. (2002) who reported the appropriate pH and time for cellulose extraction from pineapple core was pH 12 and 24 h. It was also concurrent with the extraction of cellulose from soybean by Vail (1991). However, Phongnori (2004) extracted cellulose from corn cob by using 15% sodium hydroxide for 30 min whereas Gould (1987) reported that cellulose from peanut shell was extracted by using sodium hydroxide with pH 11.2-11.8 for 24 h. This was due to the solubility of the protein which increased with increasing the pH, reaching the maximum at pH 12, and decreasing thereafter to pH > 12 (Praksash, 1996; Intarasil and Sringam, 2006).

Bleaching of Cellulose

The defatted and protein-removed banana peel powder was bleached by hydrogen peroxide solutions at concentrations of 10, 15, and 20% for 1.5, 3.0, 4.5, 6.0, and 7.5 h. The results are shown in Table 4. The mechanism of pigment bleaching from banana peels is due to the oxidizing property. Hydrogen peroxide (H_2O_2) is a strong oxidizer and commonly used as an agent that oxidizes a range of organic compounds by dissociation into perhydroxyl anion under alkaline conditions. In an alkaline aqueous solution, H_2O_2 first dissociates to yield perhydroxyl anion; the bleach activator reacts with the formed perhydroxyl anion to generate peracid, which is a more kinetically potent bleaching specie than H_2O_2 and thus can be used for bleaching under mild conditions such as low temperature and reduced time (Abdel-Halim and Al-Deyab, 2013).

The L* value significantly increased ($p \leq 0.05$) with the increasing hydrogen peroxide concentration and extraction time at the condition of 10% hydrogen peroxide. Samples bleached with 15% hydrogen peroxide for 3.0, 4.5, 6.0, and 7.5 h and 20% hydrogen peroxide for 1.5, 3.0, 44.5, 6.0, and 7.5 h had significantly higher ($p \leq 0.05$) L* values than those of other samples. The a* (redness) and b* (yellowness) values of the BPC and CC were not significantly different ($p > 0.05$). To save the chemical cost and time, the use of 15% hydrogen peroxide for 3 h bleaching was selected for further experiment. When comparing this finding with cellulose from other raw materials, it was found that cellulose from rice straw was bleached by using 50% hydrogen peroxide for 3 h (Chareonsinsab *et al.,* 2005), 50% hydrogen peroxide for 30 min for soybean residues (Ranhotra and Gelroth, 1988), and 35% hydrogen peroxide for 3 h for pineapple core (Prakhongpan *et al.,* 2002). The concentration of the solution and time of bleaching differed entirely depending on the natural pigments presented in the raw materials and also the level of fat and protein residual in the samples.

Table 3. Protein content of the BPC after sodium hydroxide extraction with various conditions

	Sample	Protein content (%)
Control		3.74 ± 0.42^{ab}
8 h	pH 11.6	3.83 ± 0.45^{a}
	pH 11.8	4.15 ± 0.12^{a}
	pH 12.0	3.57 ± 0.41^{b}
16 h	pH 11.6	3.85 ± 1.00^{a}
	pH 11.8	3.27 ± 0.04^{abc}
	pH 12.0	3.77 ± 0.85^{ab}
24 h	pH 11.6	2.75 ± 0.48^{c}
	pH 11.8	2.48 ± 0.03^{c}
	pH 12.0	2.48 ± 0.02^{c}

[1]Means with different superscripts in the same columns are significantly different ($p > 0.05$) by Duncan's multiple range test. Means ± SD of triplicate analysis.

Table 4. Color value of the BPC after bleaching with various hydrogen peroxide conditions

Condition		Color values		
		L^{*}	a^{*ns}	b^{*ns}
10%	1.5 h	80.08 ± 0.12^{bc}	-1.75 ± 1.11	15.17 ± 0.08
	3.0 h	83.44 ± 0.12^{b}	-1.85 ± 1.06	15.97 ± 1.30
	4.5 h	83.53 ± 010^{b}	-1.89 ± 1.04	15.87 ± 1.15
	6.0 h	83.51 ± 0.17^{b}	-1.87 ± 1.07	15.90 ± 1.23
	7.5 h	74.21 ± 0.15^{c}	-1.96 ± 1.06	15.94 ± 1.18
15%	1.5 h	83.68 ± 0.10^{b}	-1.95 ± 1.09	15.25 ± 0.03
	3.0 h	84.66 ± 0.11^{a}	-1.91 ± 1.13	16.10 ± 1.18
	4.5 h	84.37 ± 0.24^{a}	-1.84 ± 1.06	15.87 ± 1.18
	6.0 h	84.72 ± 0.15^{a}	-1.90 ± 1.11	15.94 ± 1.16
	7.5 h	84.65 ± 0.07^{a}	-1.95 ± 1.10	16.00 ± 1.28
20%	1.5 h	84.21 ± 0.11^{a}	-1.87 ± 1.05	15.34 ± 0.08
	3.0 h	84.77 ± 0.10^{a}	-1.91 ± 1.10	16.14 ± 1.05
	4.5 h	84.75 ± 0.09^{a}	-1.89 ± 1.06	16.18 ± 0.88
	6.0 h	84.73 ± 0.11^{a}	-1.89 ± 1.04	16.54 ± 0.88

[1] Means with different superscripts in the same columns are significantly different ($p \leq 0.05$) by Duncan's multiple range test.
[ns] Not differ significantly ($p > 0.05$)
Means ± SD of triplicate analysis.

Chemical, Physical, and Microbial Properties of BPC

The BPC had moisture, total fat, protein, and ash contents, and water activity significantly higher ($p \leq 0.05$) than those of the CC but were lower in fiber and cellulose contents ($p \leq 0.05$). The L*, a* and b* values of the BPC and CC were significantly different ($p \leq 0.05$). The CC had higher L* (lightness) and a* values (redness) than those of the BPC. On the other hand, the BPC had a higher b* (yellowness) value than that of the CC. The BPC and the CC were also analyzed for total viable count, yeasts and molds, *Staphylococcus aureus, Pseudomonas aeruginosa, Escherichia coli*, and Salmonella and Shigella and all microorganisms found in the BPC and CC conformed to the Food Chemical Codex (FCC) (Table 5). The difference in the chemical, physical, and microbial properties between the BPC and CC might be due to differences in the raw materials as well as the extraction conditions.

Microstructural Characteristics of BPC

The microstructural characteristics of the obtained BPC compared with the CC by using SEM are shown in Figure 1. It was found that the microstructure of the BPC was glacial and porous with various sizes. It might be due to the impurities of the BPC which affected the microstructural characteristics when it was likely to be more global in shape rather than fibrous. In contrast, the microstructure of the CC was fibrous with a smooth surface and it had a fiber length of about 200-300 μm.

Functional Properties of the BPC

The obtained BPC and CC were analyzed for the functional properties of standard cellulose powder according to the FCC (Committee on Codex Specifications, 1981) and the results are shown in Table 6.

The CC had a cellulose content of 98.89% which was in the range of the FCC (Committee on Codex Specifications, 1981) while the BPC had a lower content than both the FCC and CC. The pH and loss on drying found in the BPC and the CC conformed to the requirement of powdered cellulose according to the FCC. The ash content of the BPC was higher than that of the CC and Pb and S were undetectable for both samples. The total fat and protein contents of the BPC and CC were 2.57 and 0.66 and 1.65 and 0.26%, respectively, and the total dietary fiber of the BPC (90.43%) was also lower than those of the CC and FCC. This indicated that the selected extraction process of the BPC was still to be improved. The cellulose extracted from banana peels contained a high caloric content which was consistent with the results of chemical analysis, which showed the remaining protein, fat, and carbohydrate contents in the BPC. The water activity and all microorganisms of the BPC and CC conformed to the requirement of powdered cellulose.

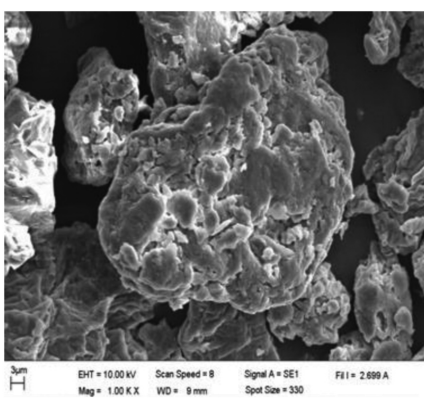
The bulk, packed, and hydrated densities of the BPC and CC are shown in Table 7. The values of the BPC were higher than those of the CC due to the particle size of the CC which was smaller. These results were similar to those reported by Prakhonpan *et al*. (2002).

The WRC and ORC of the BPC and CC were determined and are shown in Table 7. The BPC had a higher WRC (2.91 g water/g dried sample) than that of the CC (1.93 g water/g dried sample). Normally, fiber has an ability to absorb water due to the large number of hydroxyl groups forming a hydrogen bond with water. Measuring the water retention capacity in the fiber's structure found that the fiber is both water soluble and water insoluble and can absorb large quantities of water (Spiller, 2001). In addition, Cadden (1987) found that reducing the particle size of cellulose from rice bran resulted in lowered water adsorption. These results were consistent with the BPC which had a higher WRC than that of the CC. The small particle size had lower bulk, packed, and hydrated density properties than the large particle size due to the reduced size of the powder particles damaging the fibrous network of the pores which can retain water in the structure resulting in lower water

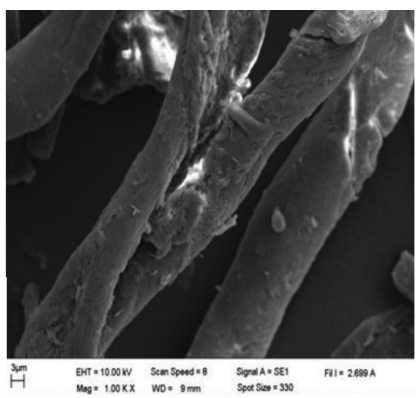
Table 5. Chemical, physical, and microbial properties of the BPC compared with the CC

Properties	BPC	CC
Chemical		
Moisture (%)	5.16 ± 0.13^{a}	2.25 ± 0.02^{b}
Total fat (%)	2.57 ± 0.10^{a}	0.66 ± 0.06^{b}
Protein (%)	1.65 ± 0.01^{a}	0.26 ± 0.06^{b}
Carbohydrate (%)	53.01 ± 0.64^{a}	24.33 ± 2.87^{b}
Ash (%)	4.04 ± 0.14^{a}	0.03 ± 0.01^{b}
Fiber (%)	33.57 ± 0.65^{b}	72.36 ± 2.87^{a}
Water activity	0.45 ± 1.27^{a}	0.11 ± 0.01^{b}
Cellulose (%)	75.90 ± 1.39^{b}	98.89 ± 0.1^{7a}
Physical		
L*	84.66 ± 0.11^{b}	98.61 ± 0.45^{a}
a*	-1.91 ± 1.13^{b}	0.11 ± 1.18^{a}
b*	16.10 ± 1.18^{a}	3.89 ± 0.23^{b}
Microbial		
Total viable count (cfu/g)	1.22×10^{2}	1.21×10^{2}
Yeasts and molds (cfu/g)	$< 10^{2}$	$< 10^{2}$
Staphylococcus aureus (cfu /g)	Negative	Negative
Pseudomonas aeruginosa (cfu /g)	Negative	Negative
Escherichia coli (MPN/g)	Negative	Negative
Salmonella and Shigella (MPN/g)	Negative	Negative

[1]Means with different superscripts in the same rows are significantly different ($p \leq 0.05$) by T-test.
Means $\pm$ SD of triplicate analysis.



Scanning electron micrograph of the BPC, size 100 mesh; Bar = 3 microns
(a)



Scanning electron micrograph of the CC, size 100 mesh; Bar = 3 microns
(b)

Figure 1. The microstructural characteristics of the BPC (a) compared with the CC (b) with SEM technique

absorption (Ang, 1991; Lario *et al*., 2004; Sansawat, 2008). Ang (1991) also found that the WRC was observed to increase with an increasing fiber length.

The characteristics of fiber in imbibing and swelling in water are important not only in food applications, but also in the human gastrointestinal function and the results of

Table 6. Chemical and microbial properties of the FCC*, BPC, and CC

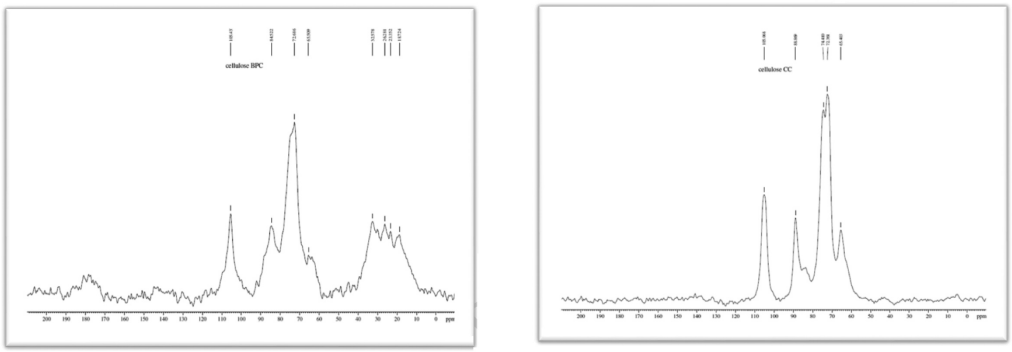
Property	FCC*	BPC	CC
Assay (% cellulose)	97-102	75.90 ± 1.39	98.89 ± 0.17
pH	5.0-7.5	6.05 ± 0.05	4.92 ± 0.77
Loss on drying (%)	≤ 0.3	4.04	0.03
Heavy metals (ppm as Pb)	≤ 10	Undetected	Undetected
Fat (%)	0	2.57	0.66
Protein (%)	0	1.65	0.26
Total dietary fiber (% dry basis)	> 99.00	90.43	99.00
Caloric content (kcal/100g)	0	240	32.40
Sulfite (ppm)	≤ 10	Undetected	Undetected
Water activity (25°C)	0.1-0.3	0.30	0.30
Total viable count (cfu/g)	$\leq 1 \times 10^3$	1×10^2	1×10^2
Yeast and molds (cfu/g)	$\leq 1 \times 10^2$	0.47	0.11
S*taphylococcus aureus* (cfu/g)	Negative	Negative	Negative
Pseudomonas aeruginosa (cfu/g)	Negative	Negative	Negative
Escherichia coli (MPN/25g)	Negative	Negative	Negative
Salmonella and Shigella (MPN/25g)	Negative	Negative	Negative

**FCC: the requirement of powdered cellulose according to Food Chemical Codex (Committee on Codex Specifications, 1981)*

Table 7. Functional properties of the BPC compared with the CC

Functional property	**BPC**	**CC**
Bulk density (g/ml)	0.646 ± 0.27[a]	0.192 ± 0.01[b]
Packed density (g/ml)	0.923 ± 0.07[a]	0.265 ± 0.07[b]
Hydrated density (g/ml)	2.50 ± 0.48[a]	1.67 ± 0.36[b]
Emulsifying activity	40.70 ± 0.11[b]	56.05 ± 0.06[a]
WRC (g water/g dried sample)	2.91 ± 0.15[a]	1.93 ± 0.82[b]
ORC (g oil/g dried sample)	0.08 ± .010[b]	3.17 ± 0.15[a]
Setting volume[ns] (ml/g)[3]	15.0 ± 0.18	14.0 ± 0.16

[1]Means with different superscripts in the same rows are significantly different ($p \leq 0.05$) by T-test.
Means ± SD of triplicate analysis.
[ns] Not differ significantly ($p > 0.05$)



(a) **(b)**

Figure 2. Cross polarization/magic angle spinning 13C NMR spectra of the BPC (a) and CC (b)

the analyzed WRC and ORC indicate the characteristics of the fiber. The ability of the WRC and ORC of cellulose could be different depending on the nature of the raw materials (Chen *et al*., 1988; Ang, 1991). When comparing the WRC property of cellulose from different raw materials, it was found that mango and pineapple core cellulose and orange residue dietary fiber had WRC of 11.4, 9.92, and 13.36 (g water/g dried sample), respectively. The cellulose with high WRC is suitable for products that need to increase in volume and to improve in texture such as bakery products (Chen *et al*., 1988; Ang, 1991). The CC had a higher ORC (3.17 g oil/g dried sample) than that of the BPC (0.08 g oil/g dried sample) which was different from those reported by Prakhonpan *et al*. (2002) and Sansawat (2008). They found that the large particle size had a higher ORC than the small one. When comparing the ORC property of cellulose from different raw materials, it was found that orange residue dietary fiber and pineapple core cellulose had an ORC of 2.01 and 2.15 g oil/g dried sample, respectively. The cellulose with a high ORC is also suitable for products that need to improve in texture.

The CC showed a higher emulsifying activity (EA) than that of the BPC due to its greater ORC (3.17 g oil/g dried sample) than that of the BPC (0.08 g oil/g dried sample). When comparing the EA of the BPC with pineapple core cellulose, the BPC had a lower EA than that of pineapple core cellulose (4.27 %) (Prakhongpan *et al*., 2002). The setting volumes of the BPC and CC were 15.00 and 14.00 m/g^3, respectively, which were similar to the cellulose from pineapple core (14.00-16.25 m/g^3) (Prakhongpan *et al*., 2002).

Purity of BPC

Figure 2 represented the CP/MAS ^{13}C NMR spectra of the BPC (a) and CC (b). The peak of Figure 2(b) is the spectra of pure CC from cotton. It was found that the peaks at δ 61.9 ppm and δ 64.8 ppm were assigned to the C-6 (δ 61.9 ppm for amorphous cellulose and δ 64.8 ppm for crystalline cellulose). The cluster of resonances around the peaks at δ 72.2 ppm and δ 75.8 ppm were assigned to C-2, C-3, and C-5. The peaks at δ 84.4 ppm and δ 89.0 ppm were attributed to C-4 and the absorption peak at δ 105.0 ppm was assigned to C-1 of glucose in cellulose (Hiroyuki *et al*., 2002). The peak of Figure 2a was the spectra of the BPC and it was found that the peaks at δ 61.9 ppm, δ 64.8 ppm, δ 72.2 ppm, δ 75.8 ppm, δ 84.4 ppm, δ 89.0 ppm, and δ 105.0 ppm were similar to the peak of cellulose from cotton (b) but the peaks of the BPC at δ 32.577 ppm, δ 26.281 ppm, and δ 18.724 ppm were identified as impurities. The results

indicated that there were still some impurities which may be fat, carbohydrate, and protein (Table 5) which could not be fully extracted from the BPC.

Conclusions

The optimal extraction and bleaching conditions of the BPC included using 90% ethanol for 16 h for removing fat, a sodium hydroxide pH of 11.6 for 24 h for the extraction of protein, and 15% hydrogen peroxide for 3 h for bleaching. By using these conditions, however, there were some amounts of fat (2.57%), protein (1.65%), and carbohydrate (53.01%) still remaining in the BPC. The BPC was light yellow while the CC was creamy white. The microstructure study showed that the BPC was glacial, variously sized, and more porous, while the CC was fibrous and had a smooth surface.

The bulk, packed, and hydrated densities, WRC, ORC, EA, and setting volume of the BPC were 0.646 g/ml, 0.923 g/ml, 2.50 g/ml, 2.91 g water/g dried sample, 0.08 g oil/g dried sample, 40.70%, and 15.0 ml/g^3, respectively.

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