

Grinding characteristics and hydration properties of coconut residue: A source of dietary fiber

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Abstract

After the extraction of coconut milk from the disintegrated coconut grating, the spent grating (residue) can be utilized as dietary fiber. The fiber was ground in a disc mill and grinding characteristics were evaluated by calculating work index (0.206 kW h/kg) as well as Bond's (0.065 kW h/kg), Kick's (0.047 kW h/kg) and Rittinger's (0.022 kW h/kg) constants. The reduction in the particle size from 1127 to 550 μm resulted in increased hydration properties (water holding, water retention, swelling capacity), which may be due to increase in theoretical surface area and total pore volume as well as structural modification. Beyond 550 μm , the hydration properties were found to decrease with decrease in particle size during grinding. The fat absorption capacity was found to increase with decrease in particle size. The study of microstructures revealed that the grinding operation resulted in rupture of honey comb physical structure fiber matrix and resulting in flat ribbon type structure, thereby providing increased surface area for water and fat absorption.

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1. Introduction

Dietary fiber mainly consists of plant cell wall complex carbohydrates such as cellulose, hemicellulose, pectin and lignin as well as intracellular polysaccharides such as gums and mucilage, which are not hydrolysed by human digestive enzymes (Spiller, 2000). Dietary fiber has been shown to play an important role in the prevention of the risk of carcinogenesis and atherosclerosis. It also controls the release of glucose with time, thus

help in the proper control and management of diabetes mellitus and obesity (Trinidad et al., 2001). Adequate amount of dietary fiber in food is good for proper bowel moments. Addition of fruits and vegetables to the regular diet of infarcted survivors resulted in a decreased mortality and subsequent infarctions. Therefore, dietary fiber plays a major role in determining the health and disease conditions of different population groups (Ramulu & Rao, 2003). Consumption of cereal-based dietary fiber has been promoted for its prophylactic value in regulating colonic function. Fibers are added to cooked meat products to increase the cooking yield owing to their water and fat retention properties. In fried food products, addition of fiber reduces lipid retention and increases moisture content. Some fiber rich

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ingredients are used for their textural and stabilizing effects (water and fat retention). Insoluble fibers in biscuits, confectionery, drinks, sauces, desserts and yogurt act as bulking agent and reduce the calorie content (Larrauri, 1999).

The clear definition and standards for the measurement of hydration properties is a major considerations (Robertson et al., 2000). Hydration properties of dietary fiber are important determinant of stool bulking effect, which may be due to the manner in which the water is held, rather than the absolute amount held. Strongly bound water has been found to have no effect on stool weight, where as loosely associated water readily increases stool weight (Robertson & Eastwood, 1981). The maximum amount of water that the fiber may hold is dependent on the fiber source, method of measurement and preparation as well as its physico-chemical and structural characteristics. The hydration properties of dietary fiber determine their optimal usage levels in food because a desirable texture must be retained. Usually, the hydration properties are described by three different measurable parameters such as water holding, water retention and swelling capacity.

Cadden (1987) and Auffret, Ralet, Guillon, Barry, and Thibault (1994) reported that the hydration properties of the dietary fiber could be enhanced due to grinding, because of increased ability to entrap water within the fiber matrix. The enhancement of hydration properties of ground fiber results in the stool bulking properties of fiber, which is a desirable feature. The solubility of the fiber depends on the nature of the glucidic components of the dietary fibers and on the structural characteristics of the dietary fibers (Thebaudin, Lefebvre, Harrington, & Bourgeois, 1997).

During the wet processing of coconut, fresh coconuts, after shelling and paring, are disintegrated and expressed in a screw press to extract coconut milk, which is either used for the preparation of virgin coconut oil or can be converted to spray dried coconut milk powder. The defatted coconut residue, after milk extraction and drying, can be utilized as dietary fiber (Raghavendra, Rastogi, Raghavarao, & Tharanathan, 2004; Trinidad et al., 2001). Physico-chemical and nutritional properties of coconut fiber were thoroughly studied by Trinidad et al. (2001). The method of preparation of coconut dietary fiber and the effect of particle size on hydration properties were recently reported by Raghavendra et al. (2004).

The objective of the present work was to study the grinding characteristics of coconut fiber and the effect of reducing the particle size, due to grinding on its hydration properties (water holding, water retention and swelling capacity) and fat absorption capacity. The physico-chemical properties of coconut fiber were evaluated and compared with other dietary fibers.

2. Materials and methods

2.1. Preparation of sample

The coconut endosperm, after removal of its shell and paring, was passed through a Krauss-Maffei (rotary wedge type) cutter having a sieve plate (3-mm hole) through which shredded coconut meal was forced out (Banzon, Gonzalez, Leon, & Sanchez, 1990). The resulting coconut gratings were expressed in a screw press to extract coconut milk. The residual coconut fiber, after extraction of milk, was dried and then was subjected to hexane treatment for 9 h for fat removal in a percolator type solvent extractor using 1:5 solid to solvent ratio. Finally, the sample was kept in a hot air oven at 55 °C for 3 h to remove hexane (Raghavendra et al., 2004).

2.2. Physico-chemical properties of coconut residue

Moisture, ash and protein contents of coconut dietary fiber were determined as per Ranganna (2003).

2.3. Grinding characteristics of coconut residue

Coconut residue was ground with a disc mill and the sample was separated into different particle size fractions using a set of screens. The set of standard screens (200–2000 µm) was arranged serially in a stack with smallest mesh screen at bottom and the largest at the top. The sample was placed on the top screen and the stack was shaken mechanically for 20 min. The particles retained on each screen were removed and weighed, and the mass of the individual screen increments were converted to mass fractions of the total sample and their volume surface mean diameter was calculated for feed as well as ground sample as shown in Table 1.

2.4. Determination of hydration properties

The hydration properties of the coconut residue were determined as per the following procedure reported by Robertson et al. (2000) and Raghavendra et al. (2004). The water holding capacity is defined by the quantity of water that is bound to the fibers without the application of any external force, except for gravity and atmospheric pressure. It is calculated as the ratio of quantity of water held up to the initial dry weight of the residue. Water retention capacity was defined as the quantity of water that remains bound to the hydrated fiber following the application of an external force such as pressure or centrifugation. It is the ratio of the water retained to the initial dry weight of the residue. Swelling property is measure of the ratio of volume occupied when the sample is immersed in an excess of water and after equilibration to the actual weight.

Table 1
Particle size distribution

S. no.	D_{pi} (mm)	D'_{pi} (mm)	Before grinding (feed)			After grinding (product)		
			SR _f (g)	X_{if}	X_{if}/D'_{pi} (mm)	SR (g)	X_{ip}	X_{ip}/D'_{pi} (mm)
1	2.057	–	0	0.000	–	–	–	–
2	1.405	1.731	0.859	0.086	0.0499	0.000	0.000	–
3	0.850	1.128	5.345	0.537	0.4765	0.351	0.036	0.0315
4	0.710	0.780	0.519	0.052	0.0669	0.522	0.053	0.0678
5	0.600	0.655	1.631	0.164	0.2503	1.125	0.114	0.1739
6	0.500	0.550	0.186	0.019	0.0340	0.551	0.056	0.1014
7	0.425	0.463	0.969	0.097	0.2106	3.425	0.347	0.7498
8	0.355	0.390	0.102	0.010	0.0263	0.495	0.050	0.1285
PAN	–	0.178	0.338	0.034	0.1914	3.410	0.345	1.9435
Total			9.949		1.3058	9.880		3.1965
			$L_1 = 0.766$ mm			$L_2 = 0.313$ mm		

D_{pi} and D'_{pi} are the screen opening and average particle diameter increment, respectively; SR and X_i are the amount of sample retained and mass fraction on corresponding sieve, respectively; L_1 and L_2 are the volume surface mean diameter and are defined as $\frac{1}{L_1} = \sum_{i=1}^n \frac{X_{if}}{D'_{pi}}$ and $\frac{1}{L_2} = \sum_{i=1}^n \frac{X_{ip}}{D'_{pi}}$, respectively.

2.5. Determination of fat absorption capacity

Fat absorption capacity is the measure of retention of fat in the food that is normally affected during cooking (Caprez, Arrigoni, Amado, & Neukom, 1986). A mass of 0.5 g of dry sample received 10 ml of refined oil in a centrifuge tube and allowed to equilibrate over night. It was then centrifuged at 10,000 rpm for 30 min, the supernatant was decanted and the weight of the residue was recorded. Fat absorption capacity is calculated as the ratio of quantity of fat held up to the initial dry weight of the residue.

2.6. Examination of microstructure

Control, solvent extracted and ground samples were mounted on aluminum stubs with conductive adhesive followed by coating with gold employing a sputter coater. The control and defatted samples were viewed at 112×, whereas the ground sample was observed at 250× magnification to study the effect of grinding on the structure modification. All examinations were carried out at 15 kV using scanning electron microscope (model 435 VP, Leo Electron Microscopy Ltd., Cambridge, UK).

3. Results and discussion

3.1. Physicochemical properties

Physicochemical properties of defatted coconut residue have been represented in Table 2. It contains 84.5% carbohydrates (total sugar) and 63.24% dietary fiber (soluble fiber 4.53% and insoluble fiber 58.71%) which are found to be quite high as compared to other commercially available dietary fibers from different sources (Raghavendra et al., 2004).

Table 2

Physicochemical properties of coconut fiber

S. no.	Parameters	Percentage
1	Moisture content	9.50
2	Fat content (defatted)	1.15
3	Protein content	0.11
4	Total sugars as carbohydrates	84.50
5	Ash content	1.80
6	Solubility	2.20
7	Dietary fiber content	63.24

3.2. Grinding studies

The particle size distribution of the initial as well as ground product is shown in Table 1. Grinding of the defatted coconut residue resulted in reduction in the volume surface mean diameter by approximately 2.5× (0.766–0.313 μm). Bond's (Work index), Kick's and Rittinger's constants were calculated as per the following equations (McCabe, Smith, & Harriott, 1993).

Work index is defined as the energy required for grinding of the material of large particle size to a size so that it can pass through 100 μm sieve, which is expressed as the following equation.

$$\text{Bond's law } E = K_B \left[\frac{1}{\sqrt{L_2}} - \frac{1}{\sqrt{L_1}} \right] \quad (1)$$

$$\text{Work index } W_i = \frac{K_B}{0.3162} \quad (2)$$

$$\text{Kick's law } E = K_K \ln \left[\frac{L_1}{L_2} \right] \quad (3)$$

$$\text{Rittinger's law } E = K_R \left[\frac{1}{L_2} - \frac{1}{L_1} \right] \quad (4)$$

where L_1 and L_2 are the volume surface mean diameter of the feed and the ground sample, respectively. K_B , K_K

and K_R are the Bond's, Kick's and Rittenger's constants, respectively. E is the energy required for grinding and W_i is work index.

The work index and energy consumed were found to be 0.206 kW h/kg and 0.042 kW h/kg, respectively. The values of work index as well as Bond's, Kick's and Rittenger's constants were 0.065 kW h/kg, 0.047 kW h/kg and 0.022 kW h/kg, respectively. It may be noted that these values are similar to that reported in the literature for other food materials (Walde, Balaswamy, Shivaswamy, Chakkaravarthi, & Rao, 1997). These constants indicate the energy requirement for grinding.

3.3. Effect of particle size on hydration properties

The reduction in particle size has a significant effect on the physical structure of the fibers, which is related to the hydration properties such as water holding capacity, water retention capacity and swelling capacity. These hydration properties were studied for different particle sizes of coconut fiber. The decrease in particle size up from 1127 to 550 μm resulted in an increase in hydration properties. Beyond this particle size, the hydration properties were found to decrease with particle size as shown in Fig. 1. The increase in hydration properties may be due to shearing of the cell wall and collapse of matrix structure upon grinding due to in-

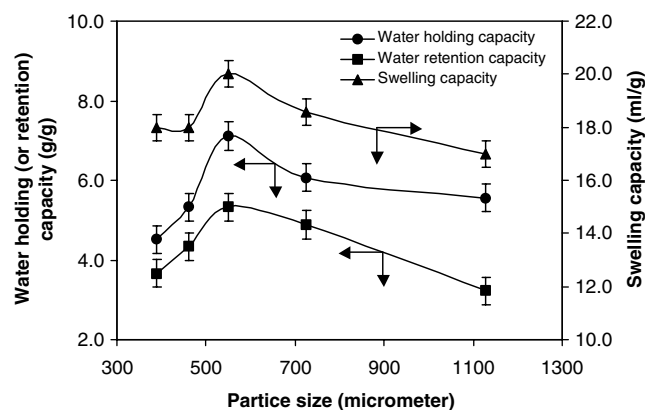


Fig. 1. Effect of particle size on water holding, water retention and swelling capacity. Arrows point to respective axes.

crease in the theoretical surface area and total pore volume (Cadden, 1987), whereas the decrease in hydration properties beyond 550 μm may be due to damaging the fiber matrix and the collapse of the pores during grinding (Auffret et al., 1994). Smaller particles will have higher packing density, although particle composition and structure will contribute to the overall distribution of water (Robertson et al., 2000).

The swelling capacity is dependent on the characteristics of individual components and the physical structure (porosity, crystallinity) of the fiber matrix. It was found to increase from 17.0 to 20.0 ml/g as the particle size was decrease from 1127 to 550 μm . Further reduction in size up to 390 μm resulted in a decreasing swelling capacity to 18.0 ml/g. The swelling capacity was found to be of the same order for sugar beet and citrus fiber (Auffret et al., 1994).

The water holding and retention capacities were increased from 5.56 to 7.11 g/g and 3.22 to 5.33 g/g, respectively as the particle size was decreased from 1127 to 550 μm . The increase in particle size beyond 550 μm resulted in a decrease in water holding and retention capacities up to 4.42 and 3.67 g/g, respectively. The increase in water holding and retention capacity could be attributed to a better water accessibility of the surface capillaries and increase in the surface area due to grinding. The water holding capacity for coconut residue was found to be comparable with sugar beet fiber and citrus fiber, whereas water retention capacity

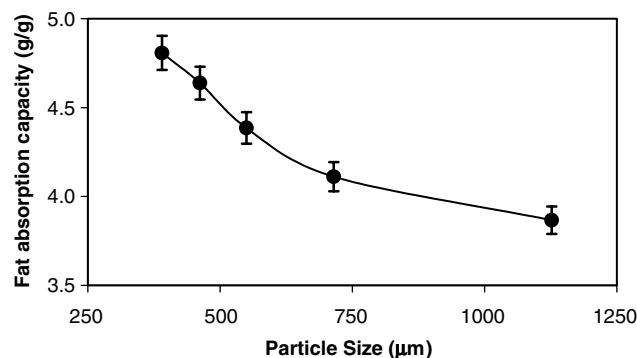


Fig. 2. Effect of particle size on fat absorption capacity.

Table 3
Comparison of coconut fiber with other dietary fiber

Fibers	Hydration properties				References
	WHC (g/g)	WRC (g/g)	SC (ml/g)	FAC (g/g)	
Apple	4.50	3.50	9.00	1.30	Thebaudin et al. (1997)
Pea	3.50	2.70	5.50	1.00	Thebaudin et al. (1997)
Wheat	3.10	2.50	7.50	1.30	Thebaudin et al. (1997)
Carrot	3.80	3.10	7.50	1.20	Thebaudin et al. (1997)
Sugar beet	10.10	5.00	10.50	5.10	Thebaudin et al. (1997)
Coconut fiber	7.11	5.33	20.00	4.80	From our work

WHC, WRC, SC and FAC are the water holding capacity, water retention capacity, swelling capacity and fat absorption capacity, respectively.

was of similar magnitude to that of the pea hull and wheat (Auffret et al., 1994).

Hydration properties of coconut residue were compared with other commercially available dietary fibers (Table 3). The water retention capacity of coconut residue (5.33 g/g) was higher as compared to the other samples such as sugar beet, apple pea, wheat and carrot. Similarly water holding capacity (7.11 g/g) and swelling capacity (20 ml/g) of coconut residue was higher than that of the fibers listed above. The fat absorption capacity for coconut fiber was found to be 4.80 g/g, which

was slightly lower than that reported for sugar beet (5.10 g/g). This shows that coconut fiber has a great swelling capacity as compared to other commercially available fibers, which is most desirable for the physical functioning of the dietary fiber (Thebaudin et al., 1997).

3.4. Effect of particle size on fat absorption capacity

Insoluble fiber when added to any formulation can absorb oil present and the extent of absorption is measured as fat absorption capacity. The higher the fat absorption capacity of the fiber, the higher will be flavour retention and product yield increased for cooked meat products losing fat normally during cooking (Thebaudin et al., 1997). Any treatment (or cooking) of the fiber may adversely affect the fat absorption capacity. Grinding of coconut fiber resulted in an increase in the physical structure and surface area, responsible for an increased fat absorption capacity as particle size decreased from 1127 to 390 μm (Fig. 2).

3.5. Effect of processing on microstructures of coconut fibers

The microstructures of ground sample were compared with defatted (solvent extracted) and control (fresh and dried coconut) sample (Fig. 3). The removal of fat from solvent extraction resulted in a more transparent cell structure as shown in Fig. 3b. The grinding operation resulted in the rupture of the honey comb physical structure fiber matrix (as shown in Fig. 3c) and in a flat ribbon type structure, thereby providing increased surface area for water and fat absorption (Figs. 1 and 2, respectively). Grinding leads not only particle size reduction, but to a deep structural modification of the fiber (Fig. 3).

4. Conclusion

The grinding operation resulted in the rupture of the honey comb physical structure fiber matrix and resulted in a flat ribbon type structure, as shown by its microstructure, thereby providing an increase in surface area for water and fat absorption. The grinding characteristics were evaluated by calculating work index as well as Bond's, Kick's and Rittinger's constants. The hydration properties (water holding, water retention, swelling capacity) of the coconut residue depended on particle size. The reduction in the particle size up to a certain extent (550 μm) resulted in higher hydration properties, beyond which these properties decreased. Fat absorption capacity was found to increase with smaller particle size. The variations in the hydration and fat absorption capacity may be due to an increase in the theoretical surface area and total pore volume as well as structural modification.

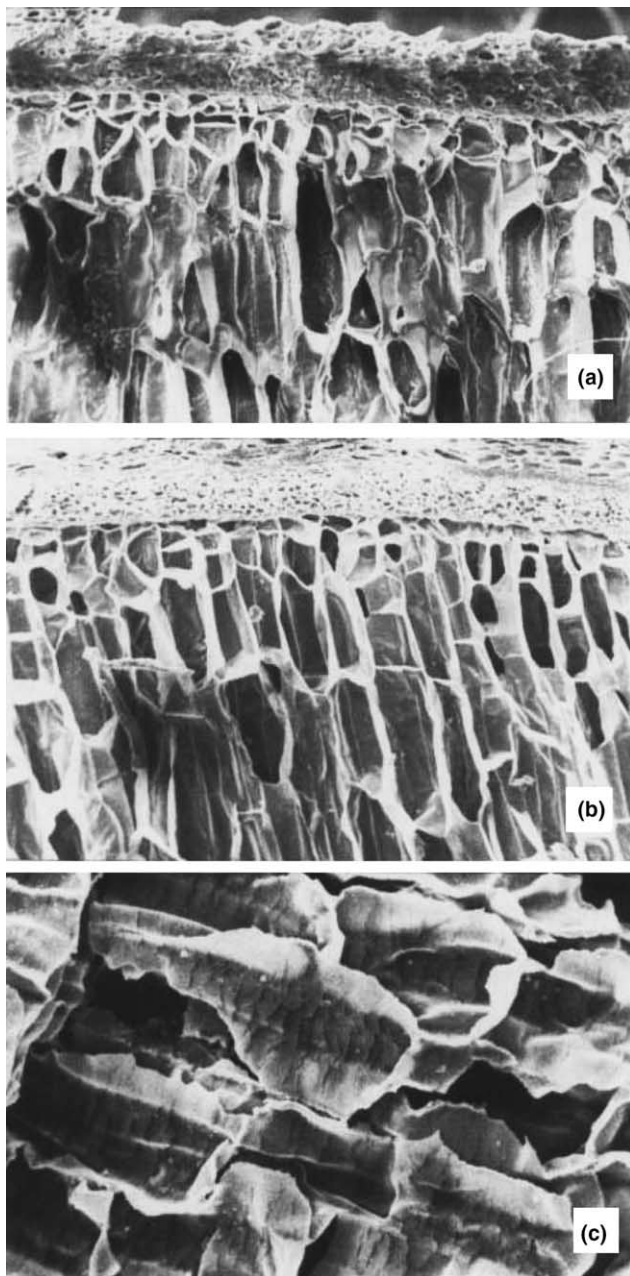


Fig. 3. Microstructures of (a) control; (b) defatted and (c) ground coconut fiber samples. The magnification for control and defatted samples was 112 $\times$ and for ground sample 250 $\times$.

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