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FUNCTIONAL PROPERTIES OF CELLULOSE POWDER PREPARED FROM RICE STRAW

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ABSTRACT

Multi-hydrogen peroxide process can improve all physical properties of rice straw. Rice straw quantity of 0.2% (w/v) provided maximum values of cellulose content, brightness, water holding capacity, and oil-binding capacity of prepared cellulose. The smallest particle of prepared cellulose (less then 0.075 mm) had less water holding capacity, oil binding capacity, redness (a*) and yellowness (b*) than the biggest particle size (0.3- 0.5 mm) while the smallest particle had more lightness (L*) than the biggest particle. An additional 5% of the smallest prepared cellulose particle gave the highest doughnut quality. Finally, the smallest particle size of cellulose powder was added to a doughnut ranging from 5-15% of flour weight combination with the increasing of water content from 50 to 60% of flour weight. Consumers scored the doughnut made by 10% of the smallest particle addition favorable when water was added at 60% of flour weight.

Keywords: Dietary fiber, cellulose powder, particle sizes, rice straw, functional properties

INTRODUCTION

Dietary fiber is a food component necessary for health but resistant to hydrolysis by human digestive enzymes. It occurs as either a water soluble or insoluble form. Cellulose, a linear polymer of anhydroglucose units linked at C-1 and C-4 by β-glycosidic bonds, is an insoluble dietary fiber and one of the most common functional ingredients in bakery products. It has been used as a fat replacer, fat reducing agent during frying, volume enhancer, binder, bulking agent and stabilizer (Ang and Miller, 1991; Prakongpan et al., 2002). Cellulose comprises 20 to 50% dry matter of many fibrous foods, such as vegetables and cereals (Spiller and Amen, 1976) and is found usually in combination with lignin

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and hemicellulose (Kadla and Gillbert, 2000). The sources of cellulose are also important because various arrays of plant can affect cellulose properties. In Thailand, rice straw is an extremely abundant waste product from rice production estimated at 117 million tons per annum (Sundhagul and Attasampunna, 2002). Normally, straw is used as a fertilizer and cattle feed. According to Sangnark and Noomhorm (2004) and El-Masry (1983), straw consists of approximately 43% cellulose, 26% hemicellulose, 16% lignin, 12% ash, and 2% waxes. Sangnark and Noomhorm (2004) enhanced the functional properties of dietary fiber from straw by treating with alkaline hydrogen peroxide (AHP) at room temperature. With AHP-treatment, 9 and 29% of lignin and hemicellulose of prepared dietary fiber were removed and cellulose content increased to 49%. However, the quality of bread, especially in term of color, was significantly reduced with prepared dietary fiber addition. Vail (1991) produced a highly purified dietary fiber component as cellulose from soy bean hull by using a multi-stage AHP-treatment combined with heating to produce powdered cellulose. The product from this process was pure white in color with cellulose content of more than 75% and improved water holding and oil binding capacity. Many factors affect cellulose production and utilization, such as conditions of AHP-treatment, surface structure, and particle size of cellulose (Prakongpan et al., 2002; Theander, 1977).

This investigation had three objectives: (1) to study the effect of rice straw quantity on the physical and chemical properties of the products following multi-stage AHP-treatment, (2) to examine the effect of cellulose particle sizes prepared from rice straw on their physical and doughnut properties, and (3) to test the effect of prepared cellulose and water content on doughnut properties.

MATERIALS AND METHODS

Material

Rice straw was obtained from a Suphan variety of rice. The straw was cleaned by soaking in water for 1 h then the water was drained, and the wet straw sun-dried (35 ± 5 °C) for 4 h. Straw was then cut into 5 cm strips, packed in polyethylene (PE) bags and kept at room temperature (30 ± 5 °C) for further use.

Multi-stage of AHP treatment

Cellulose was extracted from rice straw by alkaline extraction (Vail, 1991). The amount of straw varied from 200 to 800 g. Each sample of rice straw was mixed in 100 L alkaline solution, of pH 12 adjusted by 25% (w/v) sodium hydroxide, in a double boiler kettle at room temperature (30 ± 5°C) for 6 h. Then, the slurry was heated to 95 °C and maintained at this temperature for 3 h. The material was collected by filtration, and washed with water. After washing, the material was treated with 100 L of 1% (w/v) hydrogen peroxide at pH 6.8-7.5, by adding 85% (w/v) phosphoric acid, at 95°C for 3 h. Finally, the treated material was collected by filtration, washed with water, and dried in a forced air-oven at 60 °C for 6 h. The treated material was then ground in a centrifugal mill (model ZM1000, Retch, Germany) at 10,000 rpm fitted with 0.5 mm screen.

Yield of extraction was calculated as:
(weight of prepared cellulose *100)/weight of rice straw

Chemical properties of cellulose powder

Cellulose content of untreated rice straw and cellulose from rice straw were determined as following the Food Chemical Codex assay method (CODEX, 1996).

Physical properties of prepared cellulose

Color of each treatment was determined using a Color-Guide Meter (Model 45/0, BYK-Gardner, Germany). Color specification values of L*, a*, and b* were measured where L* = 100 (white), L* = 0 (black); +a = red, -a = green; and +b = yellow, -b = blue.

Water holding capacity (WHC) of the prepared cellulose was determined using the method of Gould et al. (1989a) with some modifications. A dried sample (3 g) was mixed with an excess of distilled water and allowed to hydrate for 2 h. Excess water was then removed by draining sample on a fine-meshed wire screen. A portion of the wet sample on the screen was carefully removed, weighed and dried to constant weight (± 0.05 g) in a forced-air oven (110°C). WHC was defined as follows:

WHC = (wet weight - dry weight)/dry weight

Oil binding capacity (OBC) was determined by the method of Ang (1991). A dried sample (2 g) was mixed with soybean oil in a centrifugal tube and left for 1 h at room temperature (30°C). The mixture was then centrifuged at 2,000 rpm for 15 min, the supernatant decanted and the pallet recovered by filtration through a nylon mesh. OBC was expressed as follows:

OBC = (pallet weight - dry weight)/dry weight

Packed density was determined by packing cellulose powder in a syringe (Prakongpan et al., 2002). A calibrated 10-mL graduate 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 weight of sample per least volume of sample.

Sample preparation in various particle sizes

The cellulose powder sample, prepared from the selected multi-stage AHP-treatment was separated by particle size using a sieving machine. A ground sample of prepared cellulose weighing approximately 30 g was separated according to particle size using a sieve shaker (Model VE 100, Retch, Germany). Mesh sizes of sieves were 0.3, 0.15, 0.106, and 0.075 mm. Each sample was placed in the top sieve with the largest mesh and shaken for 5 min at an amplitude setting of 2 mm, disassembled and stirred lightly, then shaken for an additional 5 min.

Scanning Electron Microscopy

The effect of multi-stage AHP treatment on physical structure of rice straw was investigated by scanning electron micrograph. Dried ground native straw and prepared cellulose were sieved through a 0.075 mm screen, then mounted on a pin stub, coated with gold-palladium, and examined by a 1450VP scanning electron microscope (Leo Co. Ltd., Germany) with an accelerating voltage of 10 kV.

Doughnut performance

A yeast-raised doughnut test was carried out in which 5% prepared cellulose was added in each of several particle sizes to the doughnut formulation. Then, the selected particle size of prepared cellulose and water in doughnut formula were added in various amounts of flour to produce yeast raised doughnuts. Prepared cellulose was added at three concentrations: 5, 10, and 15% of flour weight. Water was also added at 3 levels: 50, 55, and 60% of flour weight. The commercially prepared mixed dough method of Pyler (1973) was used with a slight modification. The ingredients for a single doughnut (40 g) contained 12.5 g wheat flour, 7.5 g cake flour, 10 g water, 3.7 g shortening, 2.7 g liquid whole egg, 1.3 g nonfat dry milk, 1.3 g sucrose, 0.4 g active dry yeast, 0.3 g salt, and 0.3 g baking powder.

All dry ingredients were mixed in a Kitchen Aid mixer (Model K5SS, Hobart, USA) at speed 10 for 2 min. Egg, water, and shortening were then added and the mixture was continuously mixed for about 5 min. Dough fermentation was then conducted at 40°C for 45 min, the dough was cut into 40 g pieces and manually molded into a doughnut shape followed by additional fermentation for 45 min, fried for 1 min on each side in a frying kettle (Model 2160, Fritel, Belgium) containing soybean oil already preheated to 190 °C. After frying, the doughnut was allowed to cool to room temperature on fat absorbent paper for 1 h and then packed in a vapor proof polyethylene bag. The packed product was kept at room temperature about 2 h for subsequent determination of doughnut properties and sensory evaluation.

Determination of doughnut properties

Doughnut color

Each doughnut was cut into two equal halves. Color measurement was determined as both the interior and surface of each doughnut. Color was based on an average of three samples for each treatment.

Doughnut texture

Doughnut firmness and springiness were determined by following the method of Stable Micro System Ltd (1995) using a Texture Analyzer (TA-XT2, Stable Micro Systems Ltd., England). After cooling for 3 h, each doughnut was cut into four pieces. The force to compress to 25% of the height was measured by using a 3.5 cm diameter cylindrical probe with pre-test speed of 1 mm/s, test speed of 1 mm/s, held for 60 s, and then removed at post-test speed of 1 mm/s, respectively. Four measurements, as an average of a replication, were made on each piece from each doughnut. Each time a measurement was taken, the maximum peak force value was recorded as firmness and the average was calculated in force units. The elastic recovery or springiness values were determined as a ratio of constant force during time holding to peak force before time holding.

Sensory evaluation

The yeast-raised doughnuts were evaluated for acceptability of color, flavor, texture, and overall preference by the Hedonic 9-point scale where 9 are extremely liked and 1 is extremely disliked. The 40 panelists were members of a group of Food Science students, ranging in age from 20 to 25 years.

Immediately before sensory testing, a doughnut was divided into 4 pieces. Each piece was immediately placed in a plastic box. Each box was given a three-digit code number before testing.

Statistical analysis

A completely randomized design was used to evaluate the chemical and physical properties of prepared cellulose and a completely randomized block design was used to evaluate the effect of particle sizes of prepared cellulose on consumer acceptability of doughnut. A factorial experimental design (3*3=9) was then used to evaluate the doughnut texture at various amounts of prepared cellulose and water content. Cellulose and water were each added for one of three times. However, the doughnuts of the 9 treatment combinations of this study were too large to evaluate the doughnut properties in terms of sensory evaluation. Therefore, sensory evaluation was conducted on only 6 doughnut treatment combinations: 5, 10, and 15% of prepared cellulose, and 55 and 60% of water content, as well as a control sample, then the balanced complete block design was selected to analyze this sensory evaluation data. The experimental data were analyzed statistically by analysis of variance, for statistical significance ($p \leq 0.05$) using Duncan's Multiple Range Test (Statgraphics, Version 7, Manngistics, Inc., MD, USA) and inferences were reported at the appropriate place.

RESULTS AND DISCUSSION

Effect of rice straw quantity treated by the multi-stage AHP-treatment on chemical and physical properties of prepared cellulose

Chemical property determination

The result of the chemical analysis indicated that rice straw contained about 46% cellulose (dry weight, Table 1), similar to those by Sangnark and Noomhorm (2004), and EL-Masry (1983). These results indicate that rice straw can be used as a source of dietary fiber as a food supplement. The addition of unaltered rice fiber into food products reduced food quality, by increasing the gritty texture and dark color of bakery products. Therefore, raw fiber must be altered by chemical or physical treatment to enhance consumer acceptability. A single stage AHP- treatment is one such method to improve the chemical and physical properties of dietary fiber (Sangnark and Noomhorm, 2003a and 2004; Gould et al., 1989b). Nevertheless, product color from a single stage of AHP-treatment remained a major problem for food application. Vail (1991) explained that the multi-stage AHP-treatment was much more suitable than the single stage to produce cellulose as a source of dietary fiber. Moreover, the heating process during treatment could significantly improve bleaching and promote the breakdown of non-cellulose material.

By using the multi-stage AHP treatment, cellulose content of prepared cellulose powder increased from 72 to 90% when the amount of straw was reduced from 800 to 200 g. This compares favorably with a single stage AHP-treatment, where cellulose content of 200 g rice straw was only 49% dry weight. As well, with a single stage treatment a significant amount of undesirable components such as lignin were retained (Sangnark and Noomhorm, 2004). However, yield of product prepared from the multi-stage treatment decreased directly with the amount of raw material from 36 to 32% dry weights for 800 and 200 g of the straw, respectively.

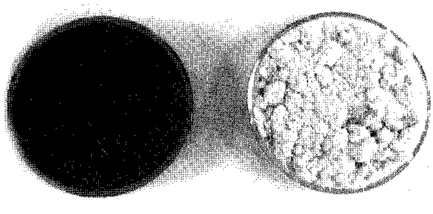
Physical property determination

The multi-stage AHP treatment significantly improved the brightness of rice straw by about 1.7 times (Table 1 and Figure 1). This compared

Table 1. Chemical and physical properties of cellulose powder prepared from rice straw[1]

Rice straw (g/100L)	Cellulose (% dry basis)	Yield (%)	L*	a*	b*	WHC (g water/g dry sample)	OBC (g oil/g dry sample)	Packed density[(ns)2] (g/cc)
Blank	$45.66^e \pm 1.39$	-	$49.98^d \pm 0.01$	$5.95^a \pm 0.01$	$23.46^a \pm 0.01$	$6.32^c \pm 0.54$	$3.75^d \pm 0.40$	0.42 ± 0.01
200	$89.66^a \pm 2.21$	$32.07^b \pm 1.75$	$85.03^a \pm 0.53$	$0.78^c \pm 0.18$	$14.12^d \pm 0.14$	$12.70^a \pm 1.88$	$9.25^a \pm 0.91$	0.42 ± 0.01
400	$84.58^b \pm 2.88$	$33.13^{ab} \pm 1.25$	$83.65^b \pm 0.17$	$0.55^c \pm 0.33$	$15.14^{cd} \pm 1.00$	$12.32^a \pm 0.15$	$8.72^{ab} \pm 0.35$	0.42 ± 0.13
600	$77.67^c \pm 0.83$	$33.94^{ab} \pm 1.17$	$76.94^c \pm 3.46$	$0.80^c \pm 0.54$	$17.09^b \pm 1.09$	$11.18^b \pm 0.01$	$7.28^b \pm 0.14$	0.41 ± 0.01
800	$71.67^d \pm 0.32$	$35.74^a \pm 1.74$	$77.44^c \pm 3.09$	$1.53^b \pm 0.53$	$16.36^{bc} \pm 1.94$	$11.49^b \pm 0.64$	$5.79^c \pm 0.24$	0.41 ± 0.03

Note: Column heading are as follows: WHC, water holding capacity; and OBC, oil-binding capacity
[1] Values are means of triplicate samples (mean ± SD, N = 3)
[2] ns = non-significant difference at $P < 0.05$
[a-e] Means within a column with different superscripts are significantly different at $P < 0.05$



(a) (b)

Figure 1. The brightness and color derived from the multi-stage AHP treatment on rice straw characteristic: (a) native rice straw, and (b) prepared cellulose powder.

favorably with an increase in the brightness of 1.2 times found by Sangnark and Noomhorm (2004), after a single stage treatment of rice straw. In the present study, the heating process combined with the multi-stage AHP treatment increased the bleaching action of hydrogen peroxide (Vail, 1991). Further brightness of the straw increased from about 77 to 85 when the amount of raw material to AHP solution was reduced from 800 to 200. After the AHP-treatment at lower ratio, redness (+a*) was less by about 87% while yellowness (+b*) was less by about 40% when compared with untreated straw.

By the multi-stage AHP treatment, WHC of straw increased significantly by 100%. In comparison with the single stage AHP-treatment, WHC of rice straw increased only 90% (Sangnark and Noomhorm, 2004). Dreher (1987) demonstrated that high water holding capacity of dietary fiber not only increased viscosity of intestinal juices, but also had a wide application in foods. Gould et al. (1989a) explained that the application of mechanical shears, provided by conventional apparatus, could cause a modification of fiber component structure. The hydrogen-bonding pattern between cellulose chains was disrupted, and the free hydroxyl group became available for binding molecules of water, thereby enhancing the WHC of cellulose.

OBC of the straw also increased from about 3.8 to 9.3 g oil/g dry sample. Comparison with the results of Sangnark and Noomhorm (2004), this study indicated that OBC of the straw also increased with reaction time from about 3 to 7 g oil/g dry sample.

Packed density of the prepared cellulose was about 0.4 g/cc and was independent of the amount of rice straw used in the multi-stage AHP-treatment. Sangnark and Noomhorm (2003 a) found that packed density of sugarcane bagasse prepared from a single stage of AHP-treatment was about 1.1 g/cc.

In the present study, cellulose composition and WHC of prepared cellulose from 200 g of rice straw was improved by the multi-stage AHP-treatment. The same procedure was followed to prepare cellulose from strips of straw.

Effect of particle sizes of prepared cellulose on their physical properties

Particle size of the prepared cellulose was mostly in the range of 0.15-0.3 mm diameter and over 55% of the particles were greater than 0.15 mm, while only 6% were in the range of 0.075-0.106 mm (Table 2).

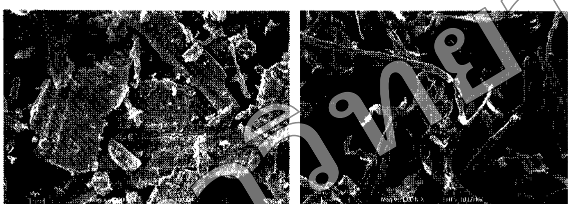
Color of the smaller particles tended to be brighter than the larger particles. For examples, the brightness of particles less than 0.075 mm was about 84, while that of 0.3-0.5 mm particles was about 80. This might be due to the tighter packing of the finer particles resulting in a better reflection of incident light making the smaller particles appear brighter (Kruger and Reed, 1988; Al-Hooti et al., 2000). While redness of prepared cellulose tended to be decreased directly with particle size reduction, from 0.90 to 0.16 for the 0.3-0.5 mm particles and the 0.106- 0.075 mm particles, respectively.

WHC of the prepared cellulose varied directly with particle size (p<0.05). Thus, particles of 0.3-0.5 mm retained about 15 g water/g dry sample, whereas those of < 0.075 mm had about 11 g water/g dry sample. The same pattern of

Table 2. Physical properties of various particle sizes of prepared cellulose[1] determined by various methods.

Particle sizes (mm)	Particle size distribution (%)	L*	a*	b*	WHC (g water/g dry sample)	OBC (g oil/g dry sample)	Packed density (g/cc)
0.3 - 0.5	$25.26^{b} \pm 0.12$	$80.38^{d} \pm 0.44$	$0.90^{a} \pm 0.19$	$17.51^{a} \pm 0.70$	$15.11^{a} \pm 0.01$	$12.09^{a} \pm 0.21$	$0.41^{e} \pm 0.01$
0.15 - 0.3	$31.83^{a} \pm 0.29$	$81.83^{c} \pm 0.20$	$0.44^{b} \pm 0.08$	$17.12^{a} \pm 0.72$	$14.67^{b} \pm 0.11$	$11.22^{b} \pm 0.17$	$0.43^{d} \pm 0.01$
0.106 - 0.15	$10.82^{c} \pm 0.60$	$82.74^{b} \pm 0.10$	$0.16^{c} \pm 0.03$	$18.25^{a} \pm 0.49$	$14.28^{c} \pm 0.28$	$10.73^{c} \pm 0.24$	$0.44^{c} \pm 0.01$
0.075 - 0.106	$6.03^{d} \pm 0.36$	$82.63^{b} \pm 0.42$	$0.16^{c} \pm 0.03$	$17.99^{a} \pm 0.55$	$12.29^{d} \pm 0.04$	$10.36^{c} \pm 0.23$	$0.46^{b} \pm 0.01$
<0.075	$26.06^{b} \pm 0.76$	$83.80^{a} \pm 0.61$	$0.48^{b} \pm 0.02$	$14.75^{b} \pm 0.43$	$10.91^{e} \pm 0.04$	$6.79^{d} \pm 0.42$	$0.48^{a} \pm 0.01$

Note: Column heading are as follows: WHC, water holding capacity; and OBC, oil-binding capacity
[1] Values are means of triplicate samples (mean ± SD, N = 3)
[a-e] Means within a column with different superscripts are significantly different at $P < 0.05$



(a) (b)

Figure 2. Scanning electron micrographs at the magnification of 1,000X: (a) native straw, and (b) prepared cellulose powder

change was observed with a reduction of particle sizes. For example, Sangnark and Noomhorm (2003a) indicated that WHC of microcrystalline cellulose (Solka Floc® 900) increased directly with particle size, from 6 to 14 g water/g sample for particles < 0.075 mm and those of 0.3-0.5 mm, respectively. Kirwan et al. (1974) suggested that in the absence of matrix structure (microcrystalline cellulose), relative surface area and the total amount of water held by fiber varies inversely with particle size. However, some experimental parameters such as stirring could alter the physical structure of fibers and result in large changes in WHC and OBC.

OBC of the prepared cellulose decreased significantly ($p < 0.05$) with a reduction in particle size, from 12 to 7 g oil/g dry sample for the 0.3-0.5 mm and < 0.075 mm particle, respectively. These results were similar to those by Sangnark and Noomhorm (2003a), who found that OBC of Solka Floc® 900 decreased with particle size, from 14 to 4 g oil/g dry sample for particles with diameters ranging from 0.3-0.5 mm and those < 0.075 mm, respectively.

Packed density of prepared cellulose increased inversely with particle size ($p < 0.05$) ranging from 0.41 to 0.48 g/cc for those of 0.3-0.5 mm and those < 0.075 mm diameter, respectively. The results of Cadden (1987) showed that with a decrease in mean particle size of microcrystalline cellulose from 0.05 mm to 0.02 mm, particle density increased from 1.47 to 1.56 g/cc, respectively.

Effect of the multi-stage AHP treatment on structure of straw

The surface structure of the rice straw and prepared cellulose were examined by scanning electron microscopy. At magnifications of 1,000x, rice straw appeared as tightly packed sheet-like pieces of bark (Figure 2a). When the multi-stage AHP treatment was applied to remove the outer surface layer of rice straw, individual fiber the bundles were released (Figure 2b). Compared with the observations of Sangnark and Noomhorm (2003b), the surface structure of prepared cellulose from the multi-stage AHP treatment was much smoother and more thoroughly fibrous than the product from single-stage treatment.

Effect of particle sizes of prepared cellulose on yeast-raised doughnut properties

Quality of yeast-raised doughnuts was significantly depressed by the addition of 5% prepared cellulose, especially when it consisted of the coarser particles ($p < 0.05$, Table 3). Brightness (L* value) surface and interior color of substitution doughnut decreased 14 and 11%, respectively when compared with commercial doughnuts. This is caused by the color of the prepared cellulose. In comparison, L* value of white pan bread, which was substituted by 5% product from the single-stage AHP treatment, decreased only 5% when compared with control bread. This might be due to differences in the manner the product reflected, resulting in a change in brightness. Brightness and redness of doughnuts were dramatically affected by the particle size distribution of the prepared cellulose. For examples, brightness of the surface and interior of the doughnuts decreased directly with particle size reduction, from 67 and 76 to 60 and 72, respectively, for the 0.3-0.5 mm and < 0.075 mm prepared cellulose particles. This likely reflects the greater oil binding capacity of the bigger particles increasing product gloss and a higher light reflection.

Doughnut firmness was twice that of commercial doughnuts when particle size of the prepared cellulose was 0.3-0.5 mm, and 1.25 times when particles were < 0.106 mm. Doughnut springiness was reduced by an additional 5% of the prepared cellulose in each particle size. The coarsest particles had a greater affect than the smaller size. Springiness of the 0.3-0.5 mm particle size treatment was 54% and that of the < 0.15 mm was 56% while that of whole flour was 59%. Hoseney (1994) suggested that there was an interaction between gelatinized starch and gluten dough. This interaction caused the dough to be more elastic and produced the gas continuous-

Table 3. Effect of various particle sizes of prepared cellulose on physical properties of yeast-raised doughnut[1]

Particle sizes (mm)	Surface color			Interior color			Texture	
	L*	a*	b*(ns)2	L*	a*	b*(ns)2	Firmness (N)	Springiness (%)
Blank	$69.81^{a} \pm 4.03$	$7.23^{b} \pm 2.13$	29.12 ± 7.84	$80.23^{a} \pm 2.03$	$2.16^{b} \pm 0.29$	19.75 ± 1.11	$10.10^{e} \pm 1.40$	$58.63^{a} \pm 0.10$
0.3 - 0.5	$67.32^{ab} \pm 6.46$	$8.48^{ab} \pm 3.30$	29.30 ± 5.67	$75.54^{b} \pm 2.58$	$3.65^{ab} \pm 0.82$	22.97 ± 3.01	$20.40^{a} \pm 1.64$	$53.66^{c} \pm 0.66$
0.15 - 0.3	$67.33^{ab} \pm 3.26$	$6.45^{c} \pm 2.20$	31.59 ± 2.25	$73.15^{bc} \pm 1.07$	$2.72^{b} \pm 0.29$	22.29 ± 0.46	$17.90^{b} \pm 0.91$	$55.89^{b} \pm 2.25$
0.106 - 0.15	$64.68^{abc} \pm 0.79$	$9.73^{a} \pm 0.88$	33.62 ± 11.0	$72.39^{bc} \pm 4.04$	$3.54^{ab} \pm 1.94$	24.57 ± 2.38	$15.28^{c} \pm 0.61$	$55.33^{b} \pm 1.00$
0.075 - 0.106	$62.77^{bc} \pm 1.12$	$10.45^{a} \pm 0.49$	36.71 ± 1.13	$71.49^{c} \pm 3.13$	$3.92^{a} \pm 2.77$	25.79 ± 0.23	$12.63^{d} \pm 0.60$	$55.67^{b} \pm 1.53$
< 0.075	$59.97^{c} \pm 2.19$	$10.00^{a} \pm 1.27$	32.74 ± 3.20	$71.58^{c} \pm 0.89$	$3.75^{ab} \pm 0.53$	21.17 ± 1.00	$12.81^{d} \pm 1.08$	$55.04^{b} \pm 1.12$

Note: [1] Values are means of triplicate samples (mean ± SD, N = 3)

[2] ns = non-significant difference at $P < 0.05$

[a-d] Means within a column with different superscripts are significantly different at $P < 0.05$

Table 4. Effect of various particle sizes of prepared cellulose on sensory properties of yeast-raised doughnut[1]

Particle sizes (mm)	Color	Flavor	Texture	Overall acceptability
Blank	$7.10^{a} \pm 1.48$	$6.98^{a} \pm 1.19$	$6.95^{a} \pm 1.34$	$7.10^{a} \pm 1.22$
0.3 - 0.5	$6.30^{b} \pm 1.07$	$5.88^{b} \pm 1.47$	$5.65^{d} \pm 1.23$	$5.90^{cd} \pm 1.10$
0.15 - 0.3	$6.25^{b} \pm 1.10$	$5.98^{b} \pm 1.10$	$5.78^{cd} \pm 1.23$	$5.88^{d} \pm 1.24$
0.106 - 0.15	$6.20^{b} \pm 1.24$	$5.88^{b} \pm 1.49$	$5.93^{bcd} \pm 1.31$	$5.93^{cd} \pm 1.27$
0.075 - 0.106	$6.05^{b} \pm 1.45$	$5.95^{b} \pm 1.04$	$6.25^{bc} \pm 0.87$	$6.65^{b} \pm 0.92$
<0.075	$5.93^{b} \pm 1.47$	$5.95^{b} \pm 1.41$	$6.30^{b} \pm 1.22$	$6.33^{bc} \pm 0.89$

Note: [1] Values are means of forty scores for each sensory characteristic (mean ± SD, N = 40)
[a-d] Means within a column with different superscripts are significantly different at $P < 0.05$

sponge structure of bakery products after heating. However, gluten content was reduced by other components, such as non-wheat flour and non-starch residue polysaccharides and might cause an adverse effect on doughnut texture in terms of firmness and springiness.

Sensory evaluation of the color characteristics of doughnuts decreased from 7.1 to 6.0 with the 5% prepared cellulose addition indicating a change in category from moderately like to slightly like (Table 4). However, particle size of prepared cellulose did not affect color acceptability of doughnuts. Doughnut flavor with various particle sizes of prepared cellulose were evaluated by the panels to be slightly similar, scoring 6, and showed non-significant differences among the various particle size additions of doughnut as color score. Doughnuts were judged to decrease in texture as cellulose particle size increased. Particle sizes of prepared cellulose in the range of 0.3-0.5 mm scored 5.7 compared to 6.3 when the particles were < 0.106 mm, and the overall acceptability score was in the same range as the texture score.

Yeast-raised doughnut quality by objective and subjective tests increased inversely with particle size of prepared cellulose. The results suggest that it might be possible to add the < 0.106 mm particle of prepared cellulose in the doughnut with an appreciable effect on its quality. However, the < 0.075 mm particles absorbed less oil than the 0.075-0.106 mm by about 51%. Therefore, cellulose particle size less than 0.075 mm was selected for further study.

Effect of prepared cellulose and water content on yeast-raised doughnut properties

Doughnut firmness increased with prepared cellulose addition of 15% to twice that with 5% addition (Figure 3). Water addition significantly reduced doughnut firmness. For example, at 10%

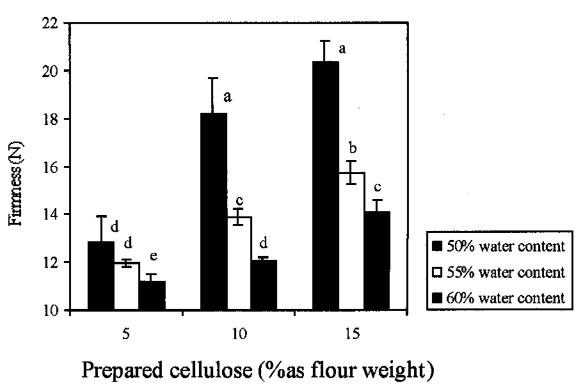


Figure 3. Diagram shows effects of prepared cellulose and water content on firmness of yeast- raised doughnut.

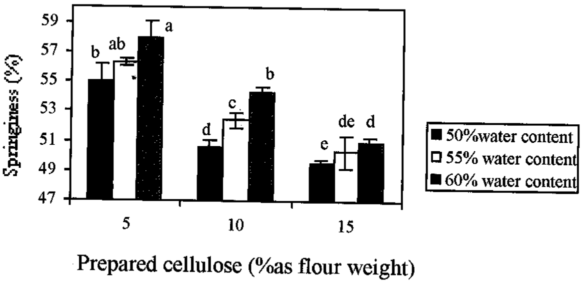


Figure 4. Diagram shows effects of prepared cellulose and water content on springiness of yeastraised doughnut.

of prepared cellulose addition, firmness of doughnut was decreased 50% by 60% of water addition. Hoseney (1994) explained that the appropriate water content caused the complete starch gelatinization and flexibility of starch-gluten matrix of bakery products. Therefore, the appropriate water content is important for doughnut texture. Springiness of doughnuts increased inversely with prepared cellulose addition. However, increasing water content in doughnut formula could significantly improve flexibility of doughnuts in term of springiness (Figure 4). For example, with the addition of 10% prepared cellulose, springiness of doughnuts increased from 51 to 54% when water content was increased from 50 to 60%, respectively.

Sensory testing indicated that the addition of prepared cellulose from 5 to 15% with an increase of water content from 55 to 60% did not significantly affect doughnut color and flavor when compared with control ($p < 0.05$, Table 5). The characteristics of the 15% prepared cellulose were the least acceptable in terms of texture and overall acceptability at $p < 0.05$. With the addition of 55 and 60% water content the doughnut characteristics received scores of 5 to 5.7, indicating they were neither liked nor disliked. Prepared cellulose additions of 5% along with 55 or 60% water produced acceptability ratings similar to those for controls, with the scores around 7 or moderately liked. Finally, when prepared cellulose was added at 10% along with 60% water, all doughnut characteristics were around 6.5 to 7, indicating slightly to moderately like.

Table 5. Effect of prepared cellulose and water content on sensory properties of yeast-raised doughnut[1]

Treatments	Color $^{(ns)2}$	Flavor $^{(ns)2}$	Texture	Overall acceptability
Blank	6.88 ± 1.13	7.6 ± 0.92	7.50^{a} ± 0.93	7.63^{a} ± 0.74
5%PC, 55%WC	6.63 ± 1.06	7.25 ± 0.71	6.63^{a} ± 0.92	6.98^{a} ± 0.83
10%PC, 55%WC	6.38 ± 0.74	7.00 ± 0.76	6.05^{ab} ± 0.71	6.25^{ab} ± 0.53
15%PC, 55%WC	6.25 ± 1.04	6.63 ± 0.92	5.52^{b} ± 0.66	5.13^{b} ± 0.64
5%PC, 60%WC	6.75 ± 0.89	7.38 ± 0.52	6.88^{a} ± 0.25	7.38^{a} ± 0.45
10%PC, 60%WC	6.50 ± 0.53	7.13 ± 0.64	6.58^{a} ± 0.93	6.75^{a} ± 1.04
15%PC, 60%WC	6.38 ± 0.52	6.75 ± 0.71	5.70^{b} ± 0.41	5.08^{b} ± 0.74

Note: PC, prepared cellulose; WC, water content.

[1] Values are means of forty scores for each sensory characteristic (mean ± SD, N = 40)

[2] ns = non-significant difference at $P < 0.05$

[a-d] Means within a column with different superscripts are significantly different at $P < 0.05$

CONCLUSIONS

Multi-step AHP-treatment affected the chemical and physical properties of rice straw. Color in terms of brightness, WHC and OBC increased significantly with cellulose purity. The most suitable multi-step AHP-treatment for rice straw quantity was at 200 g/100L of solution. WHC and OBC of prepared cellulose decreased directly with particle size reduction, while density varied inversely. Doughnut quality by objective and subjective tests increased with particle size reduction. The results suggest that it might be possible to add 10% of the <0.075 mm prepared cellulose particle along with 60% water content in yeast-raised doughnut without an appreciable effect on its quality.

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REFERENCES

Al-Hooti, S.N., Sidhu, J.S., and Al-Saqer, J.M. 2000. Utility of CIE Tristimulus system in measuring the objective crumb color of high-fiber toast bread formulations. *Journal of Food Quality* 23:103-116.

Ang, J.F. and Miller, W. B. 1991. Multiple functions of powdered cellulose as food ingredient. *Cereal Food World* 36:558-562.

Ang, J.F. 1991. Water retention capacity and viscosity effect of powdered cellulose. *Journal Food Science* 56:1682-1684.

Cadden, A.M. 1987. Comparative effects of particle size reduction on physical structure and water binding properties of several plant fibers. *Journal of Food Science* 52:1595-1631.

CODEX. 1996. *Food Chemical Codex Committee on Food Chemicals Codex* (4 th, ed.). pp. 96-97. National Academy Press, Washington, D.C.

Dreher, M.L. 1987. *Handbook of Dietary Fiber: An Applied Approach.* Marcel Dekker, New York and Basel.

EL-Masry, H.G. 1983. Utilization of egyptian rice straw in production of cellulase and microbial protein: Effect of various pretreatments on yields of protein and enzyme activity. *Journal of the Science of Food Agriculture* 34:725-732.

Gould, J.M., Jasberg, B.K., Dexter, L.B., Hsu, J.T., Lewis, S.M., and Fahey, G.C. 1989a. High-fiber, noncaloric flour substitute for baked foods. Properties of alkaline peroxide-treated lignocellulose. *Cereal Chemistry* 66:201-205.

Gould, J.M., Jasberg, B.K., and Cote, G.L. 1989b. Structure-function relationships of alkaline-peroxide treated lignocellulose from wheat straw. *Cereal Chemistry* 66:213-217.

Hoseney, R.C. 1994. Yeast- leavened products. In *Principles of Cereal Science and Technology (2^{nd}, ed.).* pp 229-270. American Association of Cereal Chemistry, St. Paul, MN.

Kadla, J.F. and Gillbert, R.D. 2000. Cellulose structure: A review. *Cellulose Chemistry and Technology* 34:197-216.

Kirwan, W.O, Smith, A.N., McConnel, A.A., Mitchell, W.D., and Eastwood, M.A. 1974. Action of different bran preparations on colonic function. *British Medical Journal* 4:187-189.

Kruger, J.E. and Reed, G. 1988. Enzymes and color. In *Wheat Chemistry and Technology* (Edited by Pomeranz Y), pp. 447-500. American Association of Cereal Chemist, St. Paul, MN.

Prakongpan, T., Nitithamyong, A., and Luangpituksa, P. 2002. Extraction and application of dietary fiber and cellulose from pineapple cores. *Journal of Food Science* 67:1308-1312.

Pyler, E.J. 1973. *Baking science and technology.* (Volume 2). pp. 1003-1007. Siebel Publishing Company, Chicago, ILL.

Sangnark, A. and Noomhorm, A. 2003a. Effect of particle sizes on functional properties of dietary fibre prepared from sugarcane bagasse. *Food Chem*istry 80:221-229.

Sangnark, A. and Noomhorm, A. 2003b. Effect of particle sizes on in-vitro calcium and magnesium binding capacity of prepared dietary fibers. *Food research International* 36:91-96.

Sangnark, A. and Noomhorm, A. 2004. Chemical, physical and baking properties of dietary fiber prepared from rice straw. *Food Research International* 37:66-74.

Spiller, G.A. and Amen, R. J. 1976. Dietary fiber in human nutrition. *Critical Reviews in Food Science and Nutrition* 7:39-70.

Stable Micro System Ltd. 1995. *TA-XT2 Application Study: Measure of firmness and springiness of cake, method REF CAK1/P36R.*, Stable Micro System: London.

Sundhagul, M. and Attasampunna, P. 2002. "Hypertext Transfer Protocol (HTTP)", CERN, September, 2002. (*http://www.unu.edu.unupress.unupbooks.80362e.80362E0.htm.*).

Theander, O. 1977. The chemistry of dietary fibers. *Nutrition Reviews* 35:23-30.

Vail, J.W. 1991. Process for recovery of cellulose. *U.S. patent no.5,057,334.* Patented October, 15.