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Effect of particle sizes on functional properties of dietary fibre prepared from sugarcane bagasse

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Abstract

Alkaline hydrogen peroxide (AHP) treatment affected physical and chemical properties of sugarcane bagasse (SB). AHP treatment can improve all its physical properties. The brightness, water-holding capacity (WHC), and oil-binding capacity (OBC) of SB were increased by 34, 96, and 55%, respectively. Lignin was removed from SB by 53%. Colour of Solka Floc® 900, a commercial dietary fibre, was pure white ($L=93.51$); WHC and OBC were 8.61 g water/g sample and 7.34 g oil/g sample, respectively. The results showed a highly positive correlation between particle size reduction of each dietary fibre (DF), WHC and OBC. While density showed a negative correlation, densities of AHP-SB and Solka Floc® 900 were increased, with particle size reduction, from 1.06 to 1.34 and from 1.09 to 1.28, respectively. At 5% of AHP-SB and Solka Floc® 900 substitution in bread, reductions of loaf volume and softness of bread were observed in direct opposition to particle size reduction. The most acceptable breads contained 5% of AHP-SB and Solka Floc® 900 when the particle sizes were <0.075 and <0.106 mm, respectively.

Keywords: Alkaline hydrogen peroxide; Dietary fibre; Functional properties; Particle sizes; Sugarcane bagasse

1. Introduction

The beneficial effects of dietary fibre (DF) for human health have been widely reported (Champ & Guillon, 2000; Reddy, 1982; Schneeman, 1998; Tarpila, Miettinen, & Metsaranta, 1978) with recommendations for consumption ranging from 30 to 45 g per day (Schweizer & Wursch, 1991; Spiller, 1986; Stephen, 1981). This has prompted efforts to add DF to food products. But negative effects have been observed when unprocessed lignocellulose materials, such as cereal bran or vegetable pulps, are added to formulations for baked goods by a loss of baked volume and a gritty texture (Dubois, 1978; Titcomb & Juers, 1986). Lignocellulose materials do not hydrate well and hence do not soften or integrate well with dough or batter (Gould, Jasberg, Dexter et al., 1989). Improved hydration properties of lignocellulose materials were demonstrated after treatment with alkaline hydrogen peroxide (AHP) (Gould, 1987, 1989). This process not only reduces much of the lignin content but also the stirring, which is an integral part of the process, opens the fibre structure by mechanical shear, making available free hydroxyl groups of cellulose to bind with water. Application of AHP to wheat straw allowed its application without loss of baking performance or sensory quality (Jasberg, Gould, & Warner, 1989; Jasberg, Gould, Warner, & Navickis, 1989).

Chemical components including cellulose, hemicellulose, and lignin significantly related to physical properties of DF (Grigelmo-Miguel, Gorinstein, & Martin-Belloso, 1999; Larrea, Grossmann, Beleia, & Tavares, 1997). Some physical properties of DF, such as water holding capacity (WHC), oil binding capacity (OBC), apparent density, and particle size distribution, were examined with a view to increasing its use in food products (Abdul-Hamid & Luan, 2000; Femenia, Lefebvre, Thebaudin, Robertson, & Bourgeois, 1997; Sidhu, Al-Hooti, & Al-Saqer, 1999).

In Thailand, sugarcane bagasse (BA) is an extremely abundant waste product from sugar production, estimated at 14 million tons per annum (Agricultural Statistic

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Center of Thailand, 1999). Normally, the BA is used for fertilizer and cattle feed. However, the large amount of DF in BA (Fernandez, Borroto, Rodriguez, & Beltran, 1996) makes it an ideal candidate for DF in health food. The objectives of this study were to examine how AHP treatment affects the functional (physical and chemical) properties of DF from BA and the effect of particle size of the treated material on its physical and baking properties.

2. Materials and methods

2.1. Material

BA was provided by a sugar production factory, Kaset Thai Co., Ltd., located in Nakomsawan province, Thailand. The BA was washed in flowing tap water, sun-dried, and stored at approximately 10 °C until use.

Solka Floc® 900, a commercial DF, was supplied from Intergood Co., Ltd., Bangkok, Thailand. The material is a naturally fibrous, 99% pure DF and contains approximately 97% cellulose that is a functionally flavourless, odourless and a versatile, pure white powder. In screen analysis, less than 10% of the material stays on a coarse-size sieve (sieve opening 0.425 mm), more than 50% of the material can pass through a medium size sieve (sieve opening 0.3 mm) and more than 30% passes through a fine screen (sieve opening 0.075 mm).

2.2. AHP treatment

A sample of 50 g BA was treated with 5000 ml of 1% (W/V) alkaline hydrogen peroxide solution for 12 h as described in elsewhere (Gould, 1987, 1989). After neutralization with 6 N HCl, the material was collected by filtration, washed with water, and dried in a forced air-oven at 60 °C for 4 h. Then, the treated material was ground in a centrifugal mill (10,000 rpm, model ZM1000, Retch, Germany) fitted with 0.5 mm screen.

2.3. Analytical method

Cellulose, hemicellulose A and B, and lignin components of untreated BA and alkaline hydrogen peroxide treated bagasse (AHP-BA) were determined as previously described (Claye, Idouraine, & Weber, 1996).

2.4. Particle size distribution

Ground samples of BA, AHP-BA and Solka Floc® 900 each weighing approximately 30 g were separated according to particle size using a sieve shaker (Model VE 100, Retch, Germany). Mesh size of sieves was 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 additional 5 min. The residue remaining on each sieve was weighed and expressed as a percent of the original sample weight.

2.5. Physical properties of prepared dietary fibre

Colour differences among treatments were determined using a Color-Guide Meter (Model 45/0, BYK-Gardner, Germany). Three values of L, a, and b were measured where $L=100$ (white), $L=0$ (black); $+a=$red, $-a=$green; and $+b=$yellow, $-b=$blue.

Particle density was determined by displacement in kerosene, as DF particles are insoluble in this liquid (Mohsenin, 1970). Firstly, density of kerosene was determined by comparing the weight of 50 ml kerosene with that of distilled water in a pycnometer at 26.5 °C. Secondly, 5 g of each DF were placed in the pycnometer to which kerosene was added until the 50 ml bottle was completely filled. The bottle was then weighed at the same temperature. Sample density was determined as follows:

$$\text{Sample density} = \frac{\text{density of kerosene} * \text{ weight of sample}}{\text{weight of kerosene displaced by the sample}}$$

WHC of the DF was determined using the method of Gould, Jasberg, and Cote (1989) with some modifications. A dried sample (3 g) was mixed with an excess of deionized and distilled water and allowed to hydrate for 2 h. The excess water was then removed by allowing the wet sample to drain 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 mg) in a forced-air oven (110 °C). WHC was defined as follows:

$$\text{WHC} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}}$$

OBC was determined by the method of Caprez, Arrigoni, Amado, and Neukom (1986). A dried sample (5 g) was mixed with soybean oil in a centrifugal tube and left for 1 h at room temperature (25 °C). The mixture was then centrifuged at 1500×g for 10 min the supernatant decanted and the pellet recovered by filtration through a nylon mesh. OBC was expressed as follows:

$$\text{OBC} = \frac{\text{pellet weight} - \text{dry weight}}{\text{dry weight}}$$

2.6. Baking performance

A baking test was carried out in which 5% DF, from both AHP-BA and Solka Floc® 900, was added to the bread formulation. The basic straight dough-breadmaking method (AACC, 1995) was used with a slight modification. The ingredients for a single loaf (215 g) formulation contained 120 g flour, 78 g water, 7 g sucrose, 5 g shortening, 2.5 g nonfat dry milk, 1.5 g salt, and 1 g active dry yeast powder.

Fermentation was conducted at 40 °C for 115 min with the first dough punch after 20 min, second after an additional 15 min, and molding after an additional 80 min. Baking was done at 200 °C for 30 min. After baking, the loaf was removed from the pan and allowed to cool to room temperature for 1 h and then packed in a moisture- and vapour-proof polyethylene bag. The packed loaf was kept at room temperature overnight for subsequent determination of baking properties and sensory evaluation.

2.7. *Determination of dough and bread properties*

2.7.1. *Dough expansion*

Dough prepared for breadmaking was divided and weighed in 50±0.01 g samples for a dough expansion test. Dough samples were rounded, sheeted, and molded as in the baking test to make a cylindrical shape and inserted into a 250 ml glass cylinder. Each piece of dough was compressed to 70 ml before testing.

Cylinders were placed in a cabinet at 40 °C for 20 min. Dough volume was recorded every 10 min for 110 min or until a constant dough volume occurred.

2.7.2. *Loaf volume*

Weight and volume were measured 1 h after removal of bread loaves from the oven. Loaf volume was determined by the sesame seed displacement method and specific volume was obtained by dividing volume by loaf weight.

2.7.3. *Crumb colour*

Each loaf of bread was cut into slices, each 2.5 cm in thickness. Six samples were collected from the middle of each crumb for colour measurement. A replication was represented by the average of six samples (Al-Hooti, Sidhu, & Al-Saqer, 2000).

2.7.4. *Bread texture*

Bread firmness was determined according to the standard method published by AACC (Method 74-09, AACC, 1986) using the Texture Analyser (TA-XT2) of Stable Micro systems Ltd.

Springiness was determined by adaptation of the AACC method 74-09 into a 'Hold Until Time' test by using the Texture Analyser (TA-XT2). Two slices of bread were stacked and compressed with a 3.5 cm diameter cylindrical probe using the same speed as firmness measurement to 40% strain, held for 60 s, and then removed. The elastic recovery or springiness values were determined as a ratio of constant force during time holding to peak force before time holding.

2.7.5. *Sensory evaluation*

The composite flour breads were evaluated for acceptability of colour, aroma, grain, taste, texture, and overall preference by the nine-point hedonic scale, where 9 is extremely liked and 1 extremely disliked. The 20 panellists were members of a group of food science students, ranging in age from 22 to 25 years, with 16 being female.

Immediately before sensory testing, loaves were sliced into 2.5 cm thick slices. The end slices were discarded and 4×4 cm squared pieces were prepared from each slice and immediately placed in plastic boxes. Each box was given a three-digit code number before testing.

2.8. *Statistical analysis*

The experimental data were analyzed statistically by analysis of variance, for statistical significance ($P = 0.05$) using Duncan's Multiple Range Test (Statgraphics, Version 7, Manngistics, Inc., MD, USA) and inferences were reported at the appropriate place.

3. Results and discussion

3.1. *Effect of alkaline hydrogen peroxide treatment*

Brightness of BA increased 34% as a result of treatment with hydrogen peroxide, which acted as a bleaching agent (Table 1). Similar results were observed earlier by Chou, Garrison, and Lewis (1990) and Schmidt (1994). Density of BA decreased from 1.30 to 1.10 when

Table 1
Physical properties of bagasse[a] (SB), alkaline hydrogen peroxide-treated bagasse (AHP-SB) and Solka Floc® 900

Samples	Colour[b]			Density[b] (g/ml)	WHC[b] (g water/g dry fibre)	OBC[b] (g oil/g dry fibre)
	L	*a*	*b*			
SB	57.89c	3.47a	15.6b	1.30a	4.98c	3.26c
AHP-SB	77.49b	0.96b	22.70a	1.10b	9.76a	5.06b
SolkaFloc® 900	93.51a	−0.48c	3.52c	1.12b	8.61b	7.34a

[a] Values are means of triplicate reading.

[b] Means within a column with different letters are significantly different at $P \leqslant 0.05$.

treated with AHP. This might be due to a loosening of the structure of BA by continuous stirring, as well as chemical reactions during AHP-treatment. WHC and OBC of AHP-BA significantly increased 2 and 1.6 times, respectively, when compared with raw material ($P<0.05$). These increases are attributed to the destruction of lignin (Table 2) and physical swelling as a consequence of alkaline treatment (Larrea, Grossmann, Beleia, & Tavares, 1997; Ning, Villota, & Artz, 1991). WHC and OBC have been widely studied in food functionality, due to their importance in foods. Water affects starch gelatinization, protein denaturation and yeast activation during the baking of bread while fat and oil increase tenderness and mouthfeel of foods (Pomeranz, 1985).

Colour of Solka Floc® 900 was pure white ($L=93.51$). Its density was not significantly different from AHP-BA ($P<0.05$). WHC was less than AHP-BA by 13% and OBC was more than the BA by 44%. These differences likely reflect the different chemical compositions and distributions of particle sizes of the two materials.

Cellulose and hemicellulose B content of the fibre both appear to have increased approximately 19 and 26% in weight, respectively. However, this change is more a reduction in the other components than a real increase in cellulose and hemicellulose B, a conclusion also reached by Larrea et al. (1997). Hemicellulose A was degraded after AHP-treatment, which is in agreement with the study of Doner and Hicks (1997).

Table 2
Effect of alkaline hydrogen peroxide (AHP) treatment on chemical composition of bagasse[a] (% dry basis)

Samples	Cellulose[b]	Hemicellulose A[b]	Hemicellulose B[b]	Lignin[b]
BA	45.25b	7.39a	19.29b	18.65a
AHP-BA	53.28a	–	24.33a	8.84b

[a] Values are means of triplicate reading.
[b] Means within a colunm with different letters are significantly different at $P\leqslant 0.05$.

Table 3
Particle size distribution of the fibres[a]

Particle sizes (mm)	AHP-SB[b] (%)	Solka Floc® 900[b] (%)
⩾0.3	24.17±1.93b	4.31±0.36e
0.3–0.15	33.11±0.76a	28.33±0.65b
0.15–0.106	15.74±0.52c	14.07±0.26d
0.106–0.075	9.03±0.51d	16.79±0.41c
<0.075	17.20±1.43c	35.95±1.31a

[a] Values are means of triplicate reading.
[b] Means within a column with different letters are significantly different at $P\leqslant 0.05$.

3.2. Effect of particle sizes of dietary fibres on physical properties

Particle size of the AHP-BA material tended to be greater than that of Solka Floc® 900 (Table 3). Over 50% of the particles of the AHP-BA material were greater than 0.15 mm, while only 32% of Solka Floc® 900 particles were greater than this. About 66% of the sample had particles under 0.15 mm which was in agreement with the specifications.

Typically, a decrease in DF particle size was associated with an increase in density ($R^2=0.93$ for AHP-BA, and $R^2=0.99$ for Solka Floc® 900, Fig. 1) and reduction in WHC (Fig. 2) and OBC (Fig. 3). Parrott and Thrall (1978), Mongeau and Brassard (1982) and Auffret, Ralet, Guillon, Barry, and Thaibault (1994) reported similar results. In contrast, Fleury and Lahaye (1991) reported that the smaller particle size of *Laminaria digitata* (kombu breton) was associated with higher water uptake and OBC. Kirwan, Smith, McConnel, Mitchell, and Eastwood (1974) suggested that, in the absence of matrix structure (microcrystalline cellulose), relative surface area and the total amount of water held by fibre varies inversely with particle size. But experimental parameters, such as stirring, could alter the physical structure of fibres and result in large changes in WHC and OBC.

3.3. Effect of particle sizes of dietary fibres on dough and bread properties

3.3.1. AHP-BA

Substitution of 5% AHP-BA was associated with a decrease in the quality of dough. We suggest that wheat dough expanded at a faster rate than the AHP-BA substitution dough particularly with the coarser particles of AHP-BA (Fig. 4). For example, when the particle size of AHP-BA was more than 0.3 mm, dough expansion was reduced by 15%, compared to only 2% when particles were less than 0.075 mm, both relative to that for 100% wheat dough. This might be due to greater absorption of water by coarse than fine particles (Fig. 2) effecting yeast action and gluten structure during dough development. Further, the structure of larger particles may inhibit dough development more than the finer particles.

The firmness of AHP-BA bread was increased fourfold and loaf volume was reduced by 10% when compared with 100% wheat bread (Table 4). This might be due to impaired carbon dioxide retention resulting from dilution of gluten content and changes in crumb structure (Pomeranz, Shogren, Finney, & Bechtel, 1977). The quality of bread also increased with particle size reduction. The specific volume of AHP-BA-substituted bread was greater by about 12% between the coarsest and the finest particles. Substitution bread, made using smaller particles, was more tender and elastic than the coarser

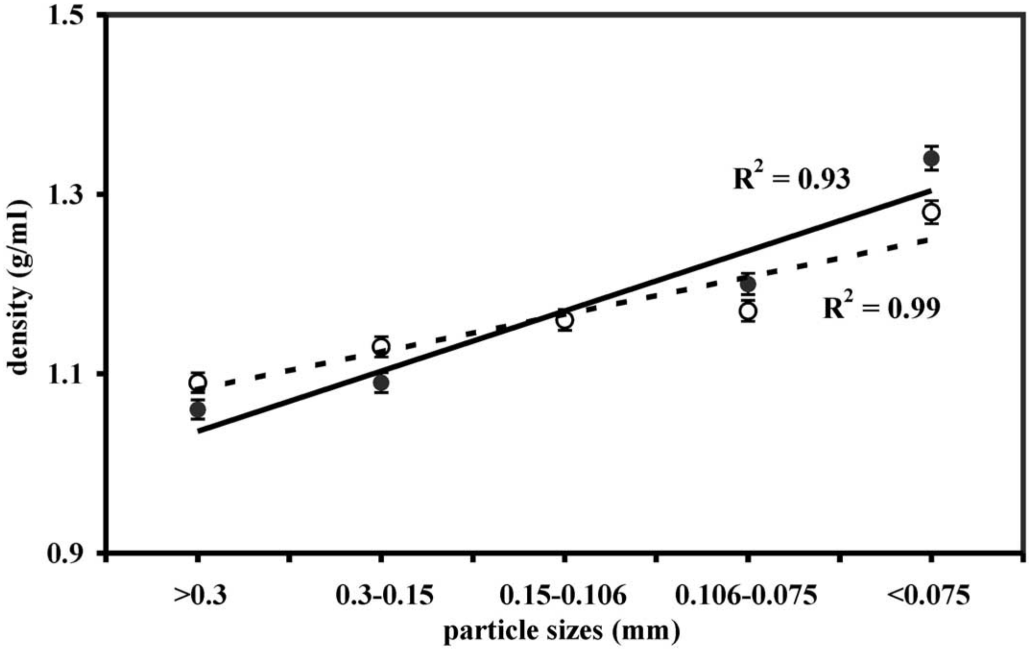

Fig. 1. Effect of particle sizes on density of alkaline hydrogen peroxide (AHP)-treated bagasse (closed symbols with solid line) and Solka Floc® 900 (open symbols with dashed line).

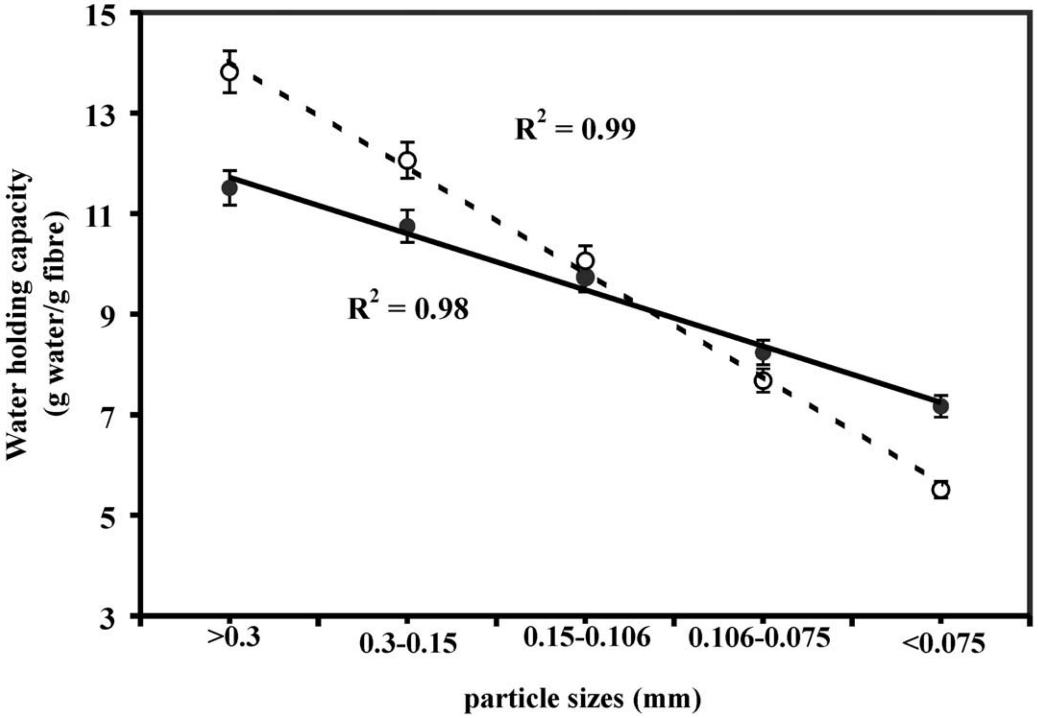

Fig. 2. Effect of particle sizes on water holding capacity (WHC) of alkaline hydrogen peroxide (AHP)-treated bagasse (closed symbols with solid line) and Solka Floc® 900 (open symbols with dashed line).

treatment. Colour of bread was not dramatically effected by the substitution or particle size distribution. It is thus evident that the incorporation of small particles of AHP-BA is helpful in overcoming the otherwise deleterious effects on bread quality.

The score for each sensory parameter decreased after 5% substitution in bread and the most organoleptic characteristics increased with particle size reduction (Table 5). Most characteristics, including texture, and overall acceptability, were moderately liked with a mean

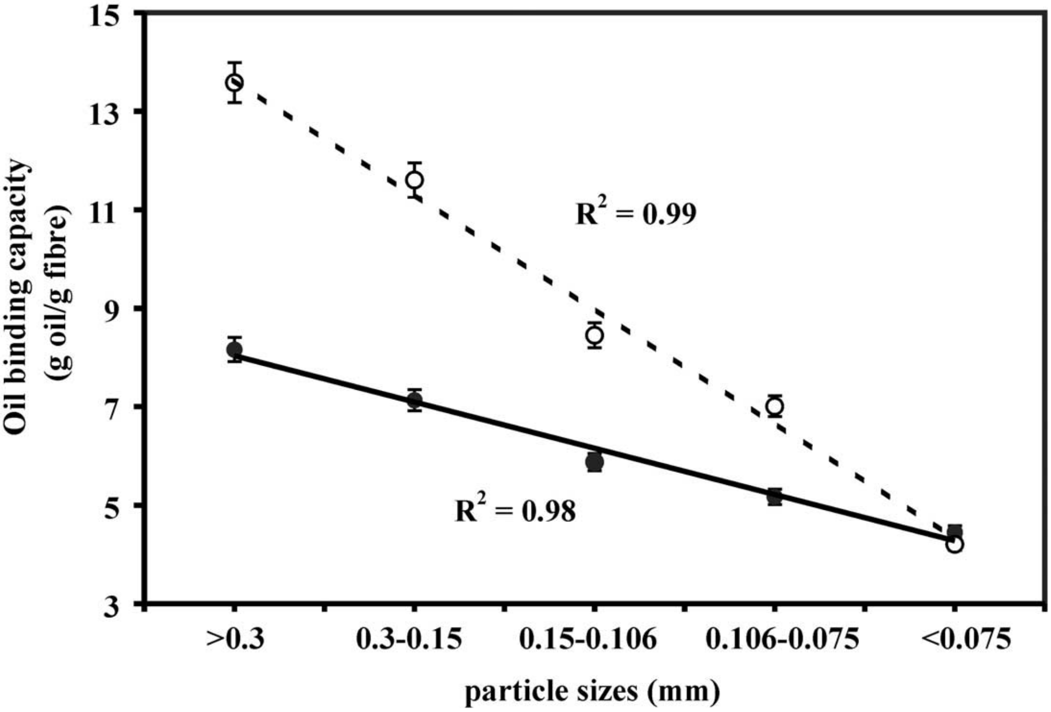

Fig. 3. Effect of particle sizes on oil binding capacity (OBC) of alkaline hydrogen peroxide (AHP)-treated bagasse (closed symbols with solid line) and Solka Floc® 900 (open symbols with dash line).

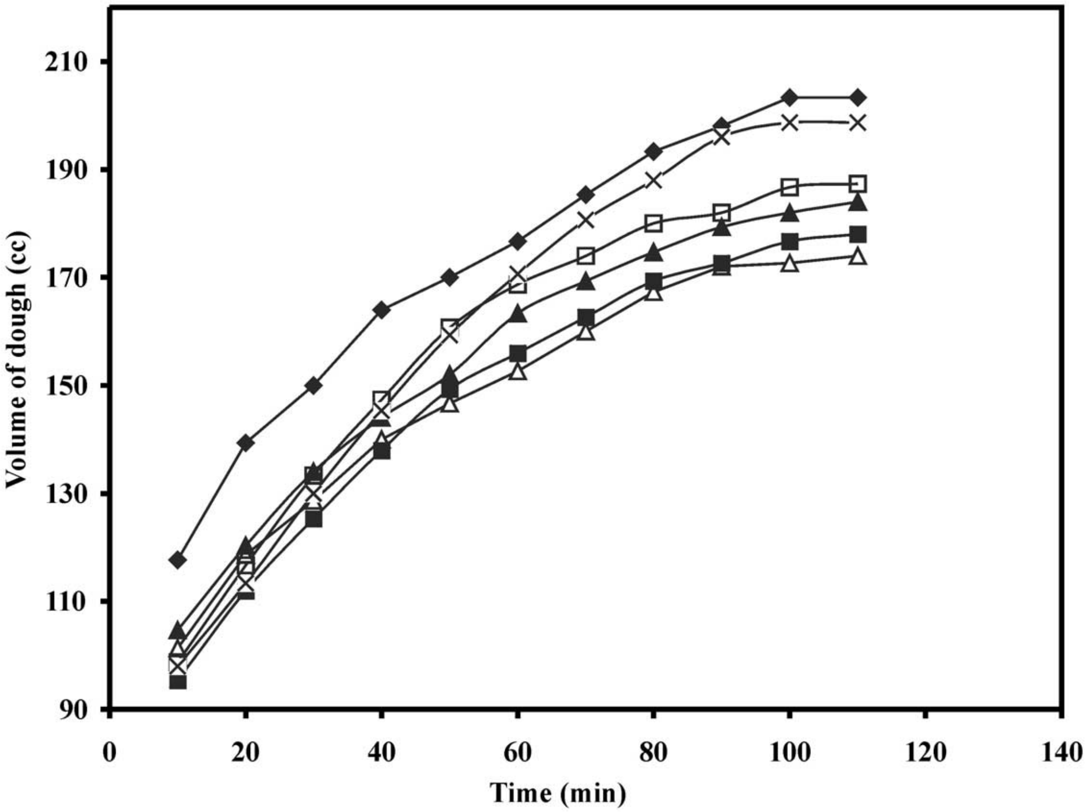

Fig. 4. Effect of particle sizes on volume expansion of dough by 5% substitution alkaline hydrogen peroxide (AHP)-treated bagasse. Particle sizes are indicated as ◆ (control), △ (⩾0.3 mm), ■ (0.3–0.15 mm), □ (0.15–0.106 mm), ▲ (0.106–0.075 mm) and × (<0.075 mm).

Table 4
Effect of particle sizes of alkaline hydrogen peroxide-treated bagasse (AHP-SB) on bread properties[a]

Particle sizes (mm)	Volume (ml)	Specific volume (ml/g)	Bread properties[b]		*L*	*a*	*b*
			Firmness (g)	Springiness (%)			
100% wheat	896.4la	4.62a	245.63a	58.83a	72.55b	0.55c	11.74c
⩾0.3	800.73e	4.16e	974.50f	50.95c	72.79ab	2.59ab	17.65c
0.3–0.15	835.13d	4.39d	840.80e	51.20c	74.47a	2.07b	18.63b
0.15–0.106	852.47c	4.48c	753.40d	53.65b	72.18b	2.40ab	18.60b
0.106–0.075	865.43b	4.53b	596.30c	53.28b	71.23b	2.77a	18.56b
<0.075	886.19a	4.65a	535.77b	53.30b	71.87b	2.84a	20.04a

[a] Values are means of triplicate reading.

[b] Means within a column with different letters are significantly different at $P \leqslant 0.05$.

Table 5
Sensory scores of alkaline hydrogen peroxide-treated bagasse (AHP-SB) supplemented breads[a]

Particle sizes (mm)	Bread characteristics[b]					
	Grain	Crumb colour	Aroma	Taste	Texture	Overall acceptability
100% wheat	7.6a	8.40a	7.30a	7.65a	7.9a	8.0a
⩾0.3	6.15c	6.10cd	6.0c	6.10cd	5.35e	5.55e
0.3–0.15	6.15c	6.25bcd	6.0c	5.85d	5.60de	5.30e
0.15–0.106	6.85b	6.0d	6.10c	6.20cd	5.85d	6.10d
0.106–0.075	6.80b	6.60bc	6.25bc	6.5c	6.50c	6.60c
<0.075	7.10ab	6.80b	6.75b	7.05b	7.15b	7.15b

[a] Average of 20 scores for each sensory characteristic.

[b] Means within a column with different letters are significantly different at $P \leqslant 0.05$.

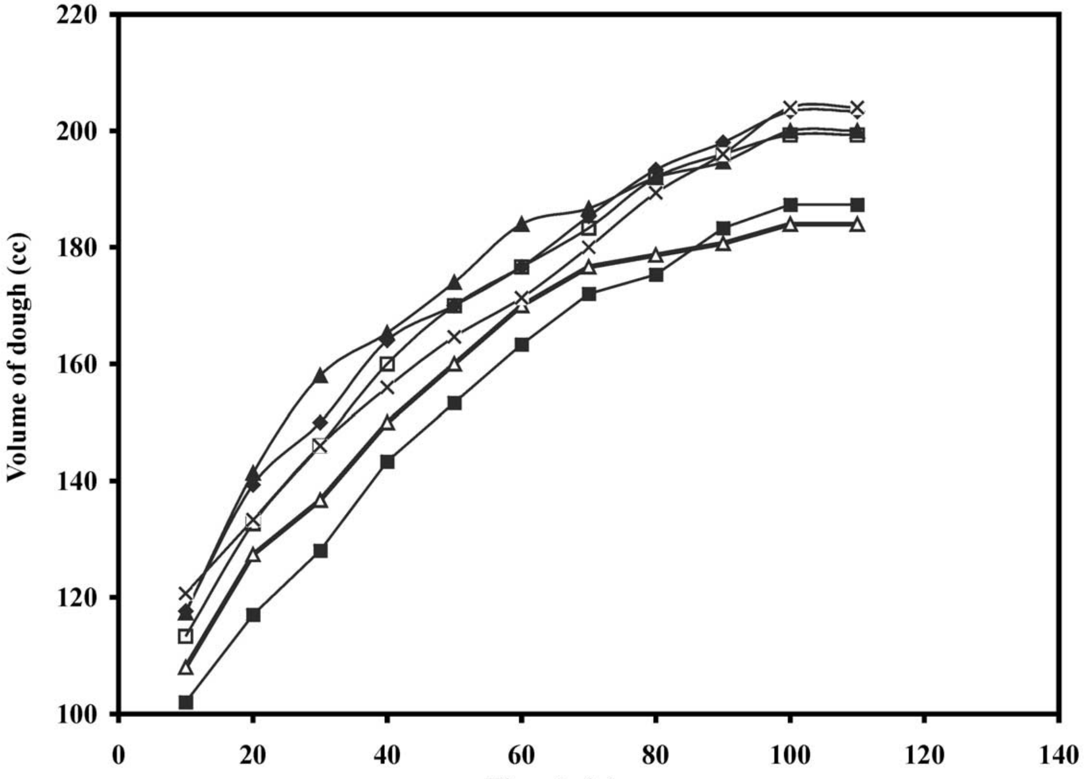

Fig. 5. Effect of particle sizes on volume expansion of dough by 5% substitution SolkaFloc® 900. ◆ (control), △ (⩾0.3 mm), ■ (0.3–0.15 mm), □ (0.15–0.106 mm), ▲ (0.106–0.075 mm) and × (<0.075 mm).

Table 6
Effect of particle sizes of Solka Floc® 900 on bread properties[a]

Particle sizes (mm)	Volume (ml)	Specific volume (ml/g)	Bread properties[b]		L	a	b
			Firmness (g)	Springiness (%)			
100% wheat	896.41a	4.62a	245.63a	58.83a	72.55a	0.55bcd	11.74bc
$\geqslant 0.3$	735.28e	3.84d	743.70d	50.87b	76.47b	0.47cd	12.44ab
0.3–0.15	822.09d	4.28c	436.73c	50.77b	76.07b	0.77abc	12.58a
0.15–0.106	846.58c	4.46b	413.0c	50.73b	75.26b	0.99a	12.61a
0.106–0.075	858.63bc	4.41b	330.17b	51.20b	75.52b	0.95ab	12.27abc
<0.075	866.72b	4.41b	315.93b	51.57b	74.99b	0.21d	11.53c

[a] Values are means of triplicate reading.

[b] Means within a column with different letters are significantly different at $P \leqslant 0.05$.

Table 7
Sensory scores of Solka Floc® 900-supplemented bread[a]

Particle sizes (mm)	Bread characteristics[b]					
	Grain	Crumb colour	Aroma	Taste	Texture	Overall acceptability
100% wheat	7.4a	7.35ab	7.05a	7.65a	7.55a	7.8a
$\geqslant 0.3$	5.7d	7.05bc	6.5b	6.05d	5.1d	5.8d
0.3–0.15	5.75cd	6.8c	6.8ab	6.88c	5.7c	6.05d
0.15–0.106	6.2bc	7.2b	6.55b	6.95bc	6.4b	6.65c
0.106–0.075	6.65b	7.35ab	7.0a	7.2bc	7.15a	7.15b
<0.075	7.2a	7.55a	6.75ab	7.35ab	7.25a	7.5ab

[a] Average of 20 scores for each sensory characteristic.

[b] Means within a column with different letters are significantly different at $P \leqslant 0.05$.

value of 7 when particles of AHP-BA were less than 0.075 mm. Thus, it appears AHP-BA may be successfully incorporated into bread without negatively impacting texture and overall acceptability, if added as the small particles, ideally under 0.075 mm diameter.

3.3.2. *Solka Floc® 900*

Dough expansion of 5% Solka Floc® 900 in various particle sizes was measured in terms of dough volume every 10 min. After proofing for 130 min, the particle sizes with less than 0.15 mm substitution and control treatment did not distinctly affect the volume of dough (Fig. 5). This may be due to the homogeneous structure of highly purified cellulose, which is the main component of Solka Floc® 900. The specific volumes of breads made by using particles of Solka Floc® 900 in the range of 0.15–0.106, 0.106–0.075 and less than 0.075 mm were not significantly different, while a significant difference was found in specific volumes of breads made using >0.3 mm particles and bread made with 100% wheat flour (Table 6). Firmness of the bread was increased when some wheat flour was substituted with Solka Floc® 900. Further, the firmness increased with particle size of the Solka Floc® 900, being 1.3 and 3.0 times harder when particles were <0.106 mm and $\geqslant 0.5$ mm, respectively. Brightness of bread was increased a little because colour of this commercial dietary fibre is pure white. Most sensory characteristics of bread, including texture, aroma and overall acceptability, were moderately liked when Solka Floc® 900 particles were less than 0.106 mm (Table 7). So it may be possible to substitute the less than 0.106 mm particle Solka Floe® 900 into bread without impacting on bread characteristics.

4. Conclusions

Results of the experiment, confirmed that alkaline hydrogen peroxide (AHP) treatment affected the functional properties of BA. Colour in term of brightness, WHC and OBC, were all increased significantly with lignin elimination. Particle size reductions of AHP-BA and Solka Floc® 900 were highly positive correlated with their WHC and OBC but negatively correlated with their density. Bread quality, by objective and subjective test, increased with particle size reduction. From the result, it might be possible to add the less than 0.075 mm and 0.106 mm particles of APH-BA and Solka Floc® 900, respectively to breads without a great effect on their quality.

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