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Physical and Functional Properties of Banana Pseudostem Flour and its Effect on the Quality (Texture and Microstructure) of Formulated Bread

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ABSTRACT

The objectives of this study were to compare physical and functional properties of banana pseudostem flour (BPF) with commercial wheat flour (CWF). The texture and microstructure qualities of composite breads formulated with partial substitution (10%) of CWF by BPF, as well as the addition of hydrocolloids, *i.e.* xanthan gum or sodium carboxymethyl cellulose (Na CMC), were also investigated. The microstructure of the bread crumb was evaluated using scanning electron microscope. When compared to CWF, water and oil holding capacities for BPF was significantly ($p < 0.05$) higher, whereas bulk density, water activity, and lightness (CIE L^*) value for BPF was significantly ($p < 0.05$) lower. Bread formulated with BPF without addition of hydrocolloids showed harder bread crumb than the bread containing BPF and hydrocolloids. However, the addition of Na CMC into the composite bread formulation showed to improve the crumb softness, whereby the crumb appeared to have more continuous protein network and larger gas cells. Therefore, composite bread with added Na CMC is suitable to be utilized in processing of good quality bread.

Keywords: Banana pseudostem flour**,** bread**,** functional properties**,** texture profile analysis**, s**canning electron microscopy

ABSTRAK

Tujuan kajian ini adalah untuk membandingkan sifat-sifat fizikal dan fungsian tepung batang pisang (BPF) dengan tepung gandum komersial (CWF). Kualiti tekstur dan mikrostruktur roti komposit yang diformulasi dengan penggantian-separa (10%) CWF oleh BPF, serta penambahan hidrokoloid, iaitu gam xanthan atau natrium karboksimetil selulosa (Na CMC), juga telah dikaji. Mikrostruktur isi roti telah dinilai dengan menggunakan mikroskop elektron pengimbas. Berbanding dengan CWF, keupayaan menampung air dan minyak bagi BPF adalah lebih tinggi secara signifikan (p <0.05), manakala ketumpatan pukal, aktiviti air, dan nilai kecerahan (CIE L^*) bagi BPF adalah lebih rendah secara signifikan (p <0.05). Roti diformulasi dengan BPF tanpa penambahan hidrokoloid menunjukkan lebih keras isi roti berbanding dengan roti mengandungi BPF dan hidrokoloid. Penambahan Na CMC ke dalam formulasi roti komposit meningkatkan kelembutan isi roti, di mana isi roti tersebut menampakkan rangkaian protein yang lebih selanjar dan sel-sel gas yang lebih besar. Oleh itu, roti komposit dengan tambahan Na CMC adalah sesuai untuk digunakan dalam pemprosesan roti yang berkualiti baik.

Kata Kunci: Tepung batang pisang, roti, sifat-sifat fungsian, analisis profil tekstur, imbasan mikroskp elektron

INTRODUCTION

White bread is considered to be a good source of energy required for human body growth (Mastromatteo *et al.*, 2013). However, bread might not be able to fulfill all the requirements of macro- and micronutrients, which are required for normal functioning of the human body (Nilufer-Erdil *et al.*, 2012). Hence, people who continuously consume wheat bread could be prone to malnutrition (Fitzgerald *et al.*, 2014).

Nowadays, owing to the advancement in technology, the idea of composite flour is being applied in innovating novel composite bakery products. According to Dendy (2001), composite flour is a blend of wheat flour and non-wheat flour to produce wheat based bakery products. The non-wheat flour can be obtained from utilization of locally available agricultural sources, such as: banana, mango pulp, mango peel, chickpea, and yam (Juarez-Garcia *et al.*, 2006; Noor Aziah *et al.*, 2011; Rizzello *et al.*, 2014; Amandikwa *et al.*, 2015). Many research works have been conducted by bakery technologists on bread making with partial substitution of wheat by non-wheat materials to improve the functional, textural, and nutritional properties of the baked products (Juarez-Garcia *et al.*, 2006; Noor Aziah *et al.*, 2011; Rizzello *et al.*, 2014; Amandikwa *et al.*, 2015).

Banana is one of the highly consumed fruits in the world, with a global annual production of 114 million metric tons in 2014 (FAOSTAT, 2017). In Malaysia, annual production of banana in 2014 was 303 thousand metric tons (FAOSTAT, 2017). The main residues after harvesting bananas are the leaves and trunks, which represent approximately 88% by weight of the plant (Elanthikkal *et al.*, 2010). After harvesting the fruit, the bare pseudostems are cut and thrown away as waste, which may exceed few hundred metric tons in the plantations. Data from FAOSTAT (2012) reported that the world production of banana pseudostem is increasing, from 8.60 million metric tons in 2000 to a staggering 13.53 million metric tons in 2009, a 57% increase over a decade.

Since banana pseudostem is an underutilized waste material produced abundantly from worldwide agricultural sector, it is rationale to process banana pseudostem into flour for utilization as composite flour. However, it has been reported that the use of composite flour in bread could cause reduction in the protein content and subsequently weaken the gluten structure, which is of utmost importance in maintaining a products quality, *i.e.* dough elasticity (Van Dyck *et al.*, 2013). Fortunately, the addition of hydrocolloids in food can improve and modify the texture of the food by influencing the dough rheological performance (Angioloni and Collar, 2012).

In our previous work, we found that banana pseudostem flour (BPF) contains good amount of dietary fiber (29.92%) but low in protein (0.89%) (Abdul Aziz *et al.*, 2011). According to Dobraszczyk (2001), the quantity of the protein in the form of gluten is important in relation to gas-retention properties of bread doughs during baking. This will subsequently influence to the physical properties (*i.e.*, texture) of the end products. However, the effect of using BPF for the partial replacement of commercial wheat flour (CWF) for the bread production on its textural is yet to be investigated. It should be noted that texture properties of a product are an important parameter that can influence the overall quality of bread. Determination of the microstructure of the bread dough and crumb could help to explain the structure in relation to the texture and physical appearance of the end products. Hence, the main objective of this work was to evaluate the texture and microstructure qualities of composite breads formulated with partial replacement of BPF and hydrocolloids.

MATERIAL AND METHODS

Flour processing

Outer skin layer of banana (*Musa acuminata* X *balbisiana* cv. Awak) pseudostem was peeled manually, followed by washing under running tap water. The cleaned pseudostem was dried in a ventilated dryer at 60 °C for 16 h until moisture content achieved 10 ± 2%. A kitchen blender was used to grind the dried pseudostem before being sieved through a 355 µm mesh sieve. The yield of the processed banana pseudostem flour (BPF) was calculated by dividing the mass of BPF with the mass of raw banana pseudostem. The BPF was than kept in an airtight plastic container and stored at ambient temperature prior to analysis.

Bread preparation

Formulations for the four types of bread are shown in Table 1. The decision on the level of substitution (at 10% level) of BPF for wheat flour was according to our preliminary study. A good dough formation and bread structures can be achieved through substitution level not more than 10%. The total amount of water was computed according to the Farinograph water absorption method (AACC, 2000). A sponge was prepared by mixing the ingredients of CWF, sugar, instant yeast, and a portion amount of water. The sponge mixture was then further mixed into the main ingredients (CWF, sugar, milk powder, improver, shortening, salt, xanthan gum or sodium carboxymethyl cellulose (Na CMC), and water) in a mixer (Spar mixer SP-800, Ta-Li City, Taichung Hsien, Taiwan) until a smooth and elastic dough was formed. The prepared dough was then fermented in the proofer at a temperature of 37 °C for 40 min. The dough was then molded manually and proofed for another 1 h before baked at 180 °C for 20 min in an oven. All loaves were cooled at room temperature for 1 h prior to analysis.

Table 1. Formulations of BCtr, B10BPF, B10BPFXG, and B10BPFCMC[a]

Ingredients	Bctr	B10BPF	B10BPFXG	B10BPFCMC
Sponge preparation				
Icing sugar (g)	15	15	15	15
Instant yeast (g)	7.6	7.6	7.6	7.6
Wheat flour (g)	50	50	50	50
Water (g)	100	100	100	100
Dough preparation				
Bread flour (g)	350	350	350	350
BPF (g)	-	40	40	40
Brown sugar (g)	20	20	20	20
Milk powder (g)	16	16	16	16
Improver (g)	9	9	9	9
Salt (g)	5	5	5	5
Shortening (g)	28	28	28	28
Water (g)	140	196	193	187
XG[b] (%)	-	-	0.8	-
Na CMC[b] (%)	-	-	-	0.8

[a]BCtr, bread of commercial wheat flour (control); B10BPF, BCtr substituted with 10% banana pseudo-stem flour (BPF); B10BPFXG, B10BPF with XG addition; B10BPFCMC, B10BPF with Na CMC addition; XG, xanthan gum; Na CMC, sodium carboxymethyl cellulose
[b]Based on total flour weight basis
Indicates without ingredient

Water holding capacity and oil holding capacity

Dried sample (0.5 g) was weighed into a centrifuge tube containing 30 mL of distilled water (WHC) or 10 mL of commercial cooking oil (OHC). The suspension was then stirred at room temperature for 24 h (WHC) or 30 min (OHC) and centrifuged at 2,000 × *g* for 30 min. The supernatant was then decanted and the residue in the centrifuge tube was weighed. The WHC and OHC of the sample were expressed as g of water per g of dry sample and g of oil per g of dry sample, respectively (Chau and Huang, 2003).

Bulk density

The flour samples (approximately 2 g) were weighed into a 10 mL graduated cylinder and then the bottom of the cylinder was gently tapped on a laboratory bench for several times until there was no further diminution of the sample level. The bulk density was expressed as mass of sample per volume of sample (g/mL) (Kaur *et al.*, 2007).

Water activity (a_w)

Water activity of the flour was measured using a Decagon's Aqualab Series 3 water activity meter (Pullman, WA) at 25 °C. About 2 g of flours was evenly placed into plastic cells and the reading was then recorded when the equilibration was achieved.

Color analysis

The color of the flours was measured using a Minolta colorimeter (CM-3500d Osaka, Japan). Flour was illuminated with D65 artificial daylight (10° standard angle). The spectrophotometer was prior calibrated before conduct sample analysis. The values of the color attributes such as *L**: *Hunter* Lightness, *b**: yellowness (positive value) or blueness (negative value), *a**: redness (positive value) or greenness (negative value), hue angle (angle 0° to 360°), and chroma were recorded using Spectramagic software version V.3.61G (Minolta Co., Ltd, Cyber Chrome, Inc.).

Texture profile analysis

The texture profile of the bread crumb was determined using a texture analyzer TA–XT2i (Model TAHDI, Stable Microsystem, Surrey, UK) (AACC, 2000). A cube shaped crumb (2.5 cm × 2.5 cm × 2.5 cm) sample was cut from the middle of the bread using bread knife. The cube shaped crumb was then placed centrally beneath the cylinder probe [P/36 R cylinder probe (36.0 mm)] to begin the compression. The compression test (compressed to 60% of its original height) was selected in the texture analysis using a 5 kg load cell. The data was recorded using Texture Expert Version 1.05 Software (Stable Micro System Ltd, Surrey, UK.).

Scanning electron microscope

The microstructure of various types of dough and bread crumbs was recorded using Leo Supra 50vP Field Emission scanning electron microscope (SEM) (Carl-Zeiss SMT, Oberkochen, Germany) equipped with Oxford INCA 400 energy dispersive x-ray microanalysis system. The lyophilized samples were sliced into thin layers and then placed on a round aluminum stub with double sided tape and sputter coated with gold (30 nm thick) to prevent electrical discharge during scanning by using polar instrument (Palaron SC515 sputter coater).

Statistical analyses

Statistical analyses were conducted using Statistical Package for the Social Science (SPSS) 14.0 software (SPSS Inc., Chicago, IL, USA). All the results obtained in the present study are represented as mean values of three individual replicates ($n = 3$) ± standard deviation. The significant differences between mean values of flour samples were determined by independent t-test at a significance level of $p < 0.05$. Meanwhile, significant differences between the mean values in the bread sample analyses were determined using analysis of variance (ANOVA) and Duncan's multiple range test at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Yield, Water holding capacity and oil holding capacity

The yield of the flour processed from banana pseudostem was 5.83% (Table 2). The low amount of flour yield was primarily attributed to the high water content characteristic of banana pseudostem. As reported by Feriotti and Iguti (2011), banana pseudostem is made up of approximately 90% of water.

The water holding capacity (WHC) and oil holding capacity (OHC) of commercial wheat flour (CWF) and banana pseudostem flour (BPF) are presented in Table 2. CWF and BPF had WHC of 1.87 and 10.66 g of water per g of dry matter, respectively. The value of WHC in BPF was higher than the dietary fibers of oat bran (2.10 of water per g of dry matter), rice bran (4.89 of water per g of dry matter), wheat bran (5.03 g of water per g of dry matter), and yam flour (3.10–3.90 of water per g of dry matter) (Chen *et al.*, 1988; Abdul-Hamid and Luan, 2000; Amandikwa *et al.*, 2015). Thus, the processed BPF was able to bind more water than these flours. In contrast, BPF has a similar value of WHC with apple fiber (*i.e.* 9.36 g of water per g of dry matter) as reported by Chen *et al.* (1988). This could be attributed to the fact that stem and fruit fibers have different structure of cell wall components (Chen *et al.*, 1988).

The OHC is another important functional property in food ingredients. Results showed, BPF to have significantly ($p < 0.05$) higher OHC (*i.e.* 5.48 g of oil per g of dry matter) as compared to that of CWF (*i.e.* 1.35 g of oil per g of dry matter). This could be attributed to the differences in physical and chemical properties between CWF and BPF. These results indicated that BPF have higher OHC value than that of dietary fiber obtained from rice bran, *i.e.* 1.29 g of oil per g of dry matter (Abdul-Hamid and Luan, 2000). According to Thebaudin *et al.* (1997), the insoluble dietary fibers can hold oil up to five times of its weight. The characteristic of high OHC of the raw material is very important in fried food, especially cooked meat products, whereby high OHC can enhance the holding of oil, which is often lost during cooking. Thus, this could be beneficial to improve the cooking yield and retention of flavor.

Table 2. Yield of banana pseduo-stem flour, functional properties and physical characteristics of commercial wheat flour and banana pseudo-stem flour[a,b,c]

Parameter	CWF	BPF
Yield (%)	ND	5.83 ± 0.29
Functional properties		
WHC (g of water/g of dry matter)	1.87 ± 0.13[b]	10.66 ± 0.54[a]
OHC (g of oil/g of dry matter)	1.35 ± 0.13[b]	5.48 ± 0.07[a]
Physical properties		
Bulk density (g/mL)	0.79 ± 0.02[a]	0.43 ± 0.01[b]
Water activity (a_w)	0.56 ± 0.01[a]	0.48 ± 0.00[b]
*L**	89.87 ± 0.03[a]	76.67 ± 0.35[b]
*a**	0.25 ± 0.01[b]	3.32 ± 0.09[a]
*b**	8.42 ± 0.02[b]	17.04 ± 0.19[a]
Chroma	8.42 ± 0.02[b]	17.36 ± 0.20[a]
Hue angle	88.29 ± 0.10[a]	78.98 ± 0.21[b]

[a]Values with different superscripts within the same row are statistically significant from each other ($p < 0.05$)
[b]Presented data are mean value of three replications ± standard deviation
[c] WHC: water holding capacity; OHC: oil holding capacity; *L**: lightness; *a**: red/ green; *b**: yellowness/ blue; CWF: commercial wheat flour; BPF: banana pseudo-stem flour; ND: not determined

Bulk density, water activity (a_w), and color measurement

According to Giami *et al.* (2000), bulk density is an important factor that determines the packaging process during flour transportation. High bulk density value would facilitate close packing of the flour. Thus, improved the handling of large quantities of the flour. However, results of the bulk density measurements showed CWF has significantly ($p < 0.05$) higher bulk density than that of BPF (Table 2). Significantly ($p < 0.05$) lower bulk density in BPF could be credited to the heat treatment applied during the flour processing. This is in agreement with the findings by Giami *et al.* (2000), who reported that the heat treatment reduces the bulk density of the African breadfruit seed flour.

Water activity (a_w) is a vital parameter required to monitor a food products quality and safety (Markova and Wadsö, 1998). In this study, the water activity of CWF was found to be significantly ($p < 0.05$) higher than the BPF (Table 2). The significantly ($p < 0.05$) lower a_w of BPF can be used to indicate slower enzymatic activities and growth of microorganisms in BPF as compared to CWF. Thus, BPF could have a relatively longer shelf life than that of CWF.

Visual observation on the color of banana pseudostem flour showed to be brownish in color, whilst CWF has a much lighter color (Fig. 1A and B, respectively). The qualitative results are in the accordance to the quantitative results obtained from the spectrophotometer (Table 2). The CWF showed significantly ($p < 0.05$) higher value for lightness than the BPF. This can be attributed to the heat processing, *i.e.* boiling and drying steps, which was used during the BPF production. According to Guiné and Barroca (2012), pheophytinization could occurred during heating process of flour production, which causes the color of the flour to change from light green to brown.

The BPF produced in the present study was shown to be reddish and yellowish in color (a^* = 3.32 and b^* = 17.04), which differ significantly ($p < 0.05$) with the CWF (a^* = 0.25 and b^* = 8.42) (Table 2). This indicated that CWF presented a much lesser intensity of redness and yellowness than BPF. According to Guiné and Barroca (2012), the drying process could result in the change of color of final product, *i.e.* to pale yellow, owing to the nonenzymatic reaction and decomposition of chlorophyll and other pigments. The results for chroma and hue angle of BPF showed to be significantly ($p < 0.05$) higher than CWF (Table 2). The hue angle of the flour indicated a shift toward the yellow quadrant.

The flour color positively influences the crumb color of the end product. The incorporation of BPF contributed to the adverse color of the crumb (Fig. 1C–F). Freeze drying could cause a more pronounced lightening to the product surface and lesser loss of green color (Guiné and Barroca, 2012). However, the high cost of processing using freeze drying make this process unfavorable, unless it involves premium ingredients or products.

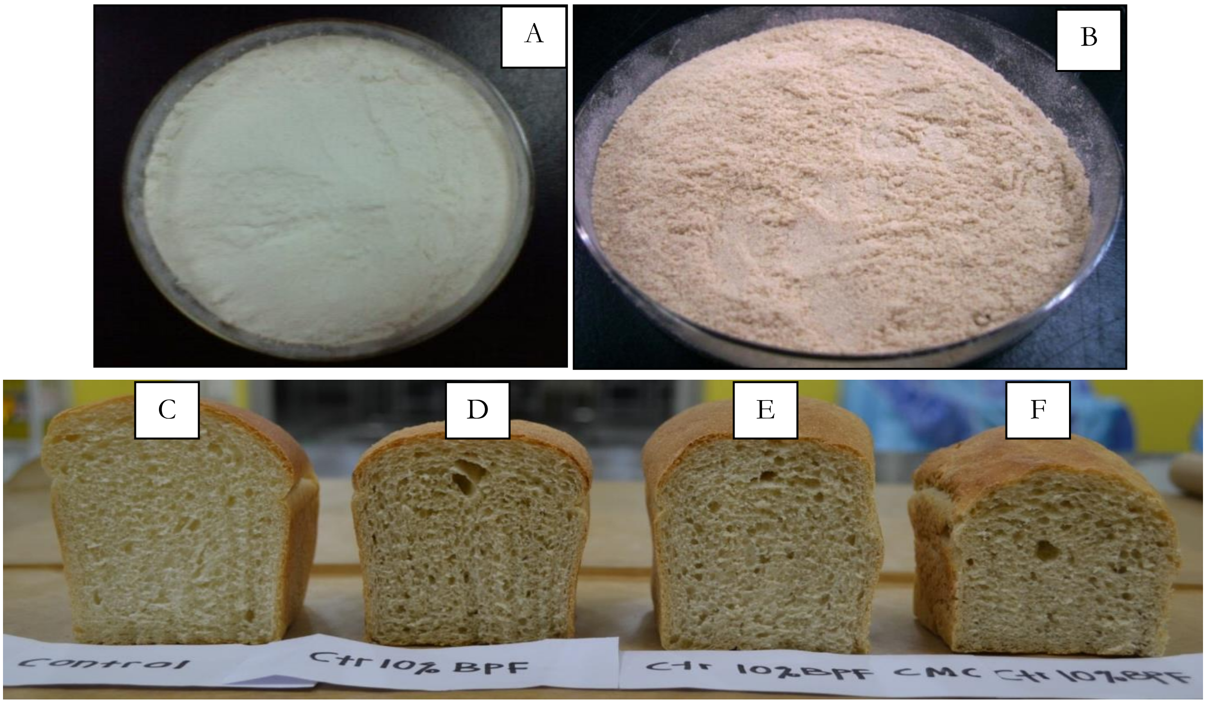

Figure 1. Visual observation of flours: (A) commerical wheat flour; (B) processed banana pseudostem flour, and bread prepared with different formulations: (C) BCtr, (D) B10BPF, (E) B10PBFCMC, and (F) B10BPFXG. BCtr, bread prepared with 100% commercial wheat flour (control); B10BPF, BCtr substituted with 10% banana pseudostem flour; B10BPFXG, B10BPF with xanthan gum; B10BPFCMC, B10BPF with sodium carboxymethyl cellulose.

Texture profile analysis of bread samples

Crumb firmness (expressed as hardness by TPA) was strongly influenced by the composite flour and the type of added hydrocolloids. Fresh composite breads prepared with partial replacement of BPF, *i.e.* B10BPF, and with added xanthan gum (XG), *i.e.* B10BPFXG were significantly ($p < 0.05$) firmer than the BCtr (Table 3). However, the addition of 0.8% sodium carboxymethyl cellulose (Na CMC) into composite bread (B10BPFCMC) ($p < 0.05$) significantly reduced the firmness of bread crumb, making it at par with BCtr. In general, crumb firmness is mainly attributed to the presence of amylose and amylopectin matrix in the starch remnants that can cause recrystallization and contribute to overall bread texture (Schiraldi and Fessas, 2000). According to Noor Aziah *et al.* (2011), firmness in bread can be attributed to the interactions between fibrous materials with gluten.

Table 3. Texture profile analysis of BCtr, CWF substituted with 10% BPF and hydrocolloid added breads[a,b, c]

Parameter	BCtr	B10BPF	B10BPFXG	B10BPFCMC
Hardness (g)	208.88 ± 13.47[b]	460.33 ± 74.28[a]	376.47 ± 52.08[a]	237.78 ± 42.69[b]
Springiness	0.95 ± 0.01[a]	0.89 ± 0.01[b]	0.87 ± 0.01[c]	0.88 ± 0.00[bc]
Cohesiveness	0.68 ± 0.02[a]	0.62 ± 0.01[c]	0.64 ± 0.02[bc]	0.65 ± 0.00[b]
Gumminess	142.36 ± 10.63[b]	285.41 ± 41.05[a]	242.86 ± 40.20[a]	155.27 ± 27.17[b]
Chewiness	133.38 ± 13.88[b]	254.92 ± 36.29[a]	211.05 ± 32.97[a]	137.10 ± 23.48[b]

[a]Values with different superscripts within the same row are statistically significant from each other ($p < 0.05$)
[b]Presented data are mean value of three replications ± standard deviation
[c]CWF: commercial wheat flour; BPF: banana pseudo-stem flour; BCtr: white wheat bread (control); B10BPF: BCtr substituted with 10% BPF; B10BPFXG: B10BPF with xanthan gum addition; B10BPFCMC: B10BPF with sodium carboxymethyl cellulose addition.

Results in Table 3 showed that Na CMC reduced crumb firmness of the composite bread, given softer crumb than other BPF incorporated breads. Conversely, the addition of XG increased the firmness of the bread crumb. According to Roach and Hoseney (1995), the firmness of the bread crumb is proportional to the composite flour viscosity. XG is highly effective in increasing dough viscosity and this was reflected in the thickening effect of the XG on the crumb walls (Rosell *et al.*, 2001), hence resulted in firmed and compact bread (Fig. 1F).

Armero and Collar (1996) proposed that hydrocolloids have weakening effect on the starch structure due to their water retention and distribution characteristics. Hydrocolloids can cause retardation of amylose chain associations and decrease in the crumb resistance. However, Biliaderis *et al.* (1997) suggested that hydrocolloids contribute to the rigidity of the crumb due to its reduction in swelling of the starch granules and consequently reduced leaching of the amylose. These effects are dependent on the types of hydrocolloid used.

The springiness of BCtr was significantly ($p < 0.05$) higher than that of B10BPF, B10BPFXG, and B10BPFCMC (Table 3). The significantly lower springiness value in composite breads than the control can be attributed to the protein dilution as reduction of CWF in the bread formulation. The reduction in gluten structure contributes to decrease the ability of dough to hold gasses, which results low expansion of the dough and cause an adverse effect on bread texture, *i.e.* low springiness (Pyler, 1973).

The partial replacement of CWF by BPF had significantly ($p < 0.05$) decreased the cohesiveness of the composite breads. However, there was a slight improvement in the cohesiveness of composite breads added with hydrocolloids. These results indicate that composite breads have low ability to resist to the force between teeth before the bread structure breaks. This was attributed to the substitution of BPF at 10% level interferes with the dough structure, and hence weaken the crumb structure.

Partial substitution of BPF for CWF also resulted in significantly ($p < 0.05$) higher gumminess and chewiness values than those of BCtr. However, no significant differences were found for gumminess and chewiness between B10BPFCMC and BCtr. Similar trends were observed by Wang *et al.* (2002), who reported that an increase in crumb chewiness and gumminess parameters on partial replacement of wheat flour by other fibers (from carob fiber, inulin, and pea fiber) during bread making.

Scanning electron microscope (SEM) of bread samples

Transformation of bread structure from foam (*i.e.* dough) into an open sponge (*i.e.* crumb) was observed in the present study (Fig. 1 and 2). During fermentation, the expanded gas cells are embedded in a continuous protein matrix surrounding starch granules. The dough phase continues to develop into thin, continuous membranes between adjacent cells until there is insufficient material to maintain the continuity of the matrix and leaving areas with only thin liquid films (Gan *et al.*, 1995; Mastromatteo *et al.*, 2013; Vanin *et al.*, 2009) (Fig. 2A–D).

The composite dough without added hydrocolloids (Fig. 2B) showed lesser and smaller gas cell size than the other bread dough. This can be attributed to the presence of the foreign particles such as fiber from banana pseudostem that could have caused interruption in the formation of gas cells. According to Gan *et al.*

(1995), the surface active materials, such as endogenous flour, proteins, polar lipids, and pentosans, will dissolved in the dough aqueous phase and play an important role in stabilizing the surface films to enable the dough to expand to a larger surface area without rupturing.

All the fermented dough showed dispersion of gas cells in a continuous protein network surrounding starch granules. Qualitative observations at high magnification recorded that the dough of CWF (Fig. 2E) had characteristic structure of well-formed protein matrix with abundant protein strands entrapping large starch granules. However, BPF incorporated dough (Fig. 2F–H), appeared to have a different binding patterns between the protein and starch granules, wherein BPF cell walls appeared to align and form part of the dough structure, with irregular and discontinuous matrix around the starch granules. However, formation of a continuity starch-protein network was disrupted by fiber of banana pseudostem. Thus, it affects the resilience and springiness of the dough during oven spring (Correa *et al.*, 2010).

At low magnification, a cross section of the bread crumb showed characteristic structure of an open sponge with interconnected porous inside large gas cells. A small gas cells were observed to appear along bread crumb surface as well as the large interconnecting cavity was observed in all the bread samples (Fig. 3A–D). When observed into the interior of a gas cell at higher magnification, the continuous protein network, *i.e.* gluten, was observed to be more visible in BCtr (Fig. 3A) than in composite bread without added hydrocolloids (Fig. 3B). In the case of B10BPF and B10BPFXG (Fig. 3B and C, respectively), the starch granules surface was stretched and rolled up into fibrils and formed a veil-like structure in the composite breads.

The B10BPFXG crumb appeared to be lacked of matrix development and has very small gas cells between the protein matrixes. Hence, this could have resulted in bread with a dense structure. However, it was less obvious in the composite bread with added Na CMC (Fig. 3D). The SEM results obtained from the present study concluded that not all types of hydrocolloids are able to form a continuous matrix with starch fragments and stabilized the gas cells, though it has been known to enhance the rheological and bread quality.

Microscopic study showed that the structure of bread crumbs appeared to be damaged and the deformed granules were observed to be entrapped in the swollen starch. Partly gelatinized starch granules were found to be surrounded by the gluten filaments (Fig. 3E–H). This could be attributed to the starch gelatinization that occurred during baking. However, some starch granules preserved their integrity although they appeared to be highly distorted due to the partial gelatinization (Rojas *et al.*, 2000).

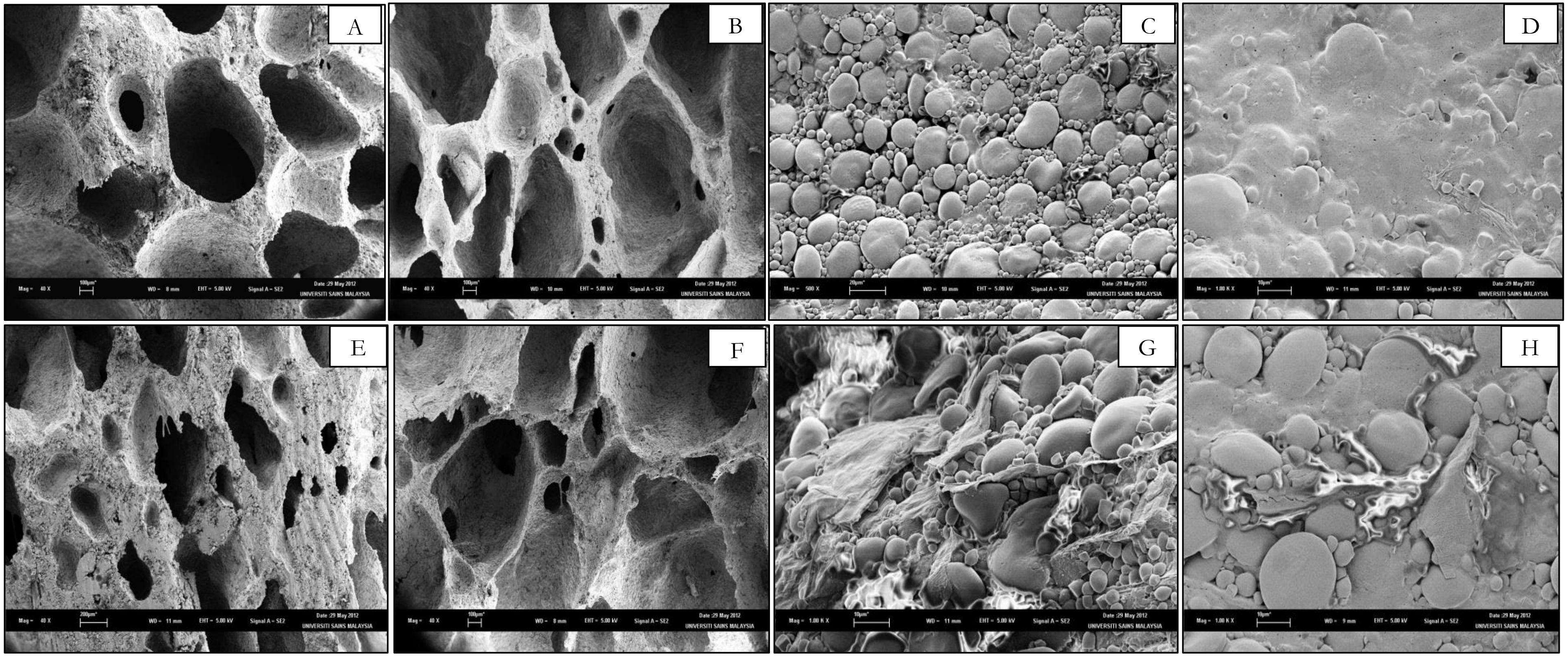

Figure 2. Scanning electron microscope microstructure of the cross section of dough at magnification 40×: (A) BCtr, (B) B10BPF, (C) B10BPFXG, and (D) B10BPFCMC and at magnification 1,000×: (E) BCtr, (F) B10BPF, (G) B10BPFXG, and (H) B10BPFCMC. BCtr, bread prepared with 100% commercial wheat flour (control); B10BPF, BCtr substituted with 10% banana pseudostem flour; B10BPFXG, B10BPF with xanthan gum; B10BPFCMC, B10BPF with sodium carboxymethyl cellulose.

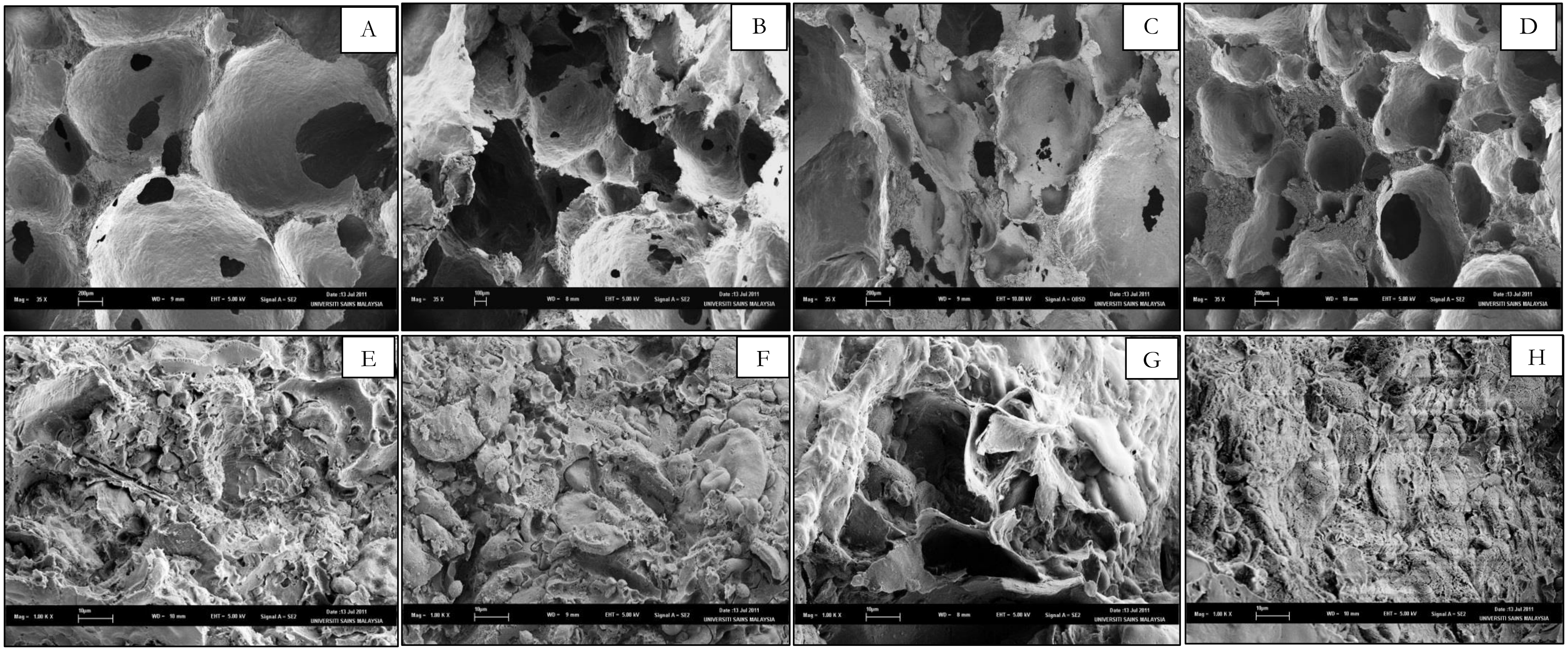

Figure 3. Scanning electron microscope microstructure of the cross section of bread crumb at magnification 35×: (A) BCtr, (B) B10BPF, (C) B10BPFXG, and (D) B10BPFCMC and at magnification 1,000×: (E) BCtr (E), (F) B10BPF, (G) B10BPFXG, and (H) B10BPFCMC. BCtr, bread prepared with 100% commercial wheat flour (control); B10BPF, BCtr substituted with 10% banana pseudostem flour; B10BPFXG, B10BPF with xanthan gum; B10BPFCMC, B10BPF with sodium carboxymethyl cellulose.

CONCLUSION

Banana pseudostem was suitable to be processed into flour due to its low water activity and could be kept for a longer period of time compared to CWF. Physical analyses showed that BPF incorporated breads reduced the quality, *i.e.* softness, of the end products. However, the addition of Na CMC to the composite bread improved the loaf texture. The results obtained from physical analyses was supported by the SEM analysis, whereby BPF incorporated breads had smaller air cells. Hence, based on the findings in the present study, the incorporation of BPF solely was not able to produce a good quality of composite bread due to harder texture. However, Na CMC is recommended to be added into the composite bread for texture improvement. The obtained results are useful in the determination of the suitability of formulations containing BPF for the production of quality composite bread by looking into its microstructure and textural properties.

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REFERENCES

AACC. (2000). Approved methods of the American Association of Cereal Chemists. (10th ed.). St. Paul, Minnesota: AACC.

Abdul Aziz, N. A., Ho, L. H., Azahari, B., Rejeev Bhat, Cheng, L. H. & Mohamad Ibrahim, M. A. (2011). Chemical and functional properties of the native banana (*Musa acuminata* x *balbisiana Colla* cv Awak) pseudo-stem and pseudo-stem tender core flours. *Food Chemistry* **128(3)**: 748–753.

Abdul-Hamid, A. & Luan, S. Y. (2000). Functional properties of dietary fibre prepared from defatted rice bran. *Food Chemistry* **68**: 15–19.

Amandikwa, C., Iwe, M. O., Uzomah, A. & Olawuni, A. I. (2015). Physico-chemical properties of wheat-yam composite bread. *Nigerian Food Journal* **33**: 12–17.

Angioloni, A. & Collar, C. (2012). High legume-wheat matrices: an alternative to promote bread nutritional value meeting dough viscoelastic restrictions. *European Food Research and Technology* **234**: 273–284.

Armero, E. & Collar, C. (1996). Antistaling additive effects on fresh wheat bread quality. *Food Science and Technology International* **2**: 323–333.

Biliaderis, C. G., Arvanitoyannis, I., Izydroczyk, M. S. & Prokopowich, D. J. (1997). Effect of hydrocolloids on gelatinization and structure formation in concentrated waxy maize and wheat starch gels. *Starch-Stärke* **49(7/8)**: 278–283.

Chau, C. F. & Huang, Y. L. (2003). Composition of the chemical composition and physicochemical properties of different fibers prepared from the peel of *Citrus sinensis* L. cv. Liucheng. *Journal of Agricultural and Food Chemistry* **51**: 2615–2618.

Chen, H., Rubenthaler, G. L., Leung, H. K. & Baranowski, J. D. (1988). Chemical, physical, and baking properties of apple fiber compared with wheat and oat bran. *Cereal Chemistry* **65(3)**: 244–247.

Correa, M. J., Añón, M. C., Pérez, G. T. & Ferrero, C. (2010). Effect of modified celluloses on dough rheology and microstructure. *Food Research International* **43**: 780–787.

Dendy, D. A. V. (2001). Composite and alternative flours. In *Cereals and cereal products chemistry and technology*. D. A. V. Dendy & B. J. Dobraszczyk, (eds.). United States: An Aspen Publication. 266–268 pp.

Dobraszczyk, B. J. (2001). Wheat and flour. In *Cereals and cereal products chemistry and technology*. D. A. V. Dendy & B. J. Dobraszczyk, (eds.). United States: An Aspen Publication. 120pp.

Elanthikkal, S., Gopalakrishnapanicker, U., Varghese, S. & Guthrie, J. T. (2010). Cellulose microfibres produced from banana plant wastes: isolation and characterization. *Carbohydrate Polymers* **80**: 852–859.

FAOSTAT (Food and Agriculture Organization of United Nations statistics). (2012). Crops and livestock products, 2012, http://faostat3.fao.org/home/index.html#DOWNLOAD, retrieved 11th October 2012.

FAOSTAT (Food and Agriculture Organization of United Nations statistics). (2017). Production crops: bananas, 2014, http://www.fao.org/faostat/en/#data/QC, retrieved 29th April 2017.

Feriotti, D. G. & Iguti, A. M. (2011). Porposal for use of pseudostem from banana tree (*Musa cavendish*), http://www.icef11.org/content/papers/few/FEW893.pdf, retrieved 1st September 2012.

Fitzgerald, C., Gallagher, E., Doran, L., Auty, M., Prieto, J. & Hayes, M. (2014). Increasing the health benefits of bread: assessment of the physical and sensory qualities of bread formulated using a renin inhibitory *Palmaria palmate* protein hydrolysate. *Food Science and Technology* **56**: 398– 405.

Gan, Z., Ellis, P. R. & Schofield, J. D. (1995). Mini review: gas cell stabilization and gas retention in wheat bread dough. *Journal of Cereal Science* **21**: 215–230.

Giami, S. Y., Adindu, M. N., Akusu, M. O. & Emelike, J. N. (2000). Compositional, functional and storage properties from raw and heat processed African breadfruit (*Treculia Africana* Decne) seeds. *Plant Foods For Human Nutrition* **55**: 357–368.

Guiné, R. P. F. & Barroca, M. J. (2012). Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper). *Food and Bioproducts Processing* **90**: 58–63.

Juarez-Garcia, E., Agama-Acevedo, E., Săyago-Ayerdi, S. G., Rodrĭguez-Ambriz, S. L. & Bello-Pĕrez, L. A. (2006). Composition, digestibility and application in breadmaking of banana flour. *Plant Foods For Human Nutrition* **61**: 131–137.

Kaur, M., Sandhu, K. S. & Singh, N. (2007). Comparative study of the functional, thermal and pasting properties of flours from different field pea (*Pisum sativum* L.) and pigeon pea (*Cajanus cajan* L.) cultivars. *Food Chemistry* **104**: 259–267.

Markova, N. & Wadsö, L. (1998). A microcalorimetric method of studying mould activity as a function of water activity. *International Biodeterioration and Biodegradation* **42**: 25–28.

Mastromatteo M., Guida, M., Danza, A., Laverse, J., Frisullo, P., Lampignano, V. & Nobile, M. A. D. (2013). Rheological, microstructural and sensorial properties of durum wheat bread as affected by dough water content. *Food Research International* **51**: 458–466.

Nilufer-Erdil, D., Serventi, L., Boyacioglu, D. & Vodovotz, Y. (2012). Effect of soy milk powder addition on staling of soy bread. *Food Chemistry* **131**: 1132–1139.

Noor Aziah, A. A., Lee Min, W. & Rajeev Bhat (2011). Nutritional and sensory quality evaluation of sponge cake prepared by incorporation of high dietary fiber containing mango (*Mangifera indica* var. Chokanan) pulp and peel flours. *International Journal of Food Science and Nutrition* **62(6)**: 559–567.

Pyler, L. (1973). Baking science and technology. United States: Siebel Publishing Company.

Rizzello, C. G., Calasso, M., Campanella, D., Angelis, M. D. & Gobbetti, M. (2014). Use of sourdough fermentation and mixture of wheat, chickpea, lentil and bean flours for enhancing the nutritional, texture and sensory characteristics of white bread. *International Journal of Food Microbiology* **180**: 78–87.

Roach, R. R. & Hoseney, R. C. (1995). Effects of certain surfactants on the starch in bread. *Cereal Chemistry* **72(6)**: 578–582.

Rojas, J. A., Rosell, C. M., Benedito de Barber, C., Pérez-Munuera, I. & Lluch, M. A. (2000). The baking process of wheat rolls followed by cryo scanning electron microscopy. *European Food Research and Technology* **212**: 57–63.

Rosell, C. M., Rojas, J. A. & Benedito, C. (2001). Influence of hydrocolloids on dough rheology and bread quality. *Food Hydrocolloids* **15**: 75–81.

Schiraldi, A. & Fessas, D. (2000). Mechanism of staling. In *Bread staling*. C. Pavinee, & Y.V odovotz, (eds.). New York: CRC Press Inc. 2–10 pp.

Thebaudin, J. Y., Lefebvre, A. C., Harrington, M. & Bourgeois, C. M. (1997). Dietary fibres: nutritional and technological interest. *Trends in Food Science and Technology* **81**: 41–48.

Van Dyck, T., Verboven, P., Wevers, M., Claes, J. & Nicolaï, B. (2013). Microstructural heterogeneity of bread. In *InsideFood Symposium*, 9-12 April 2013. Belgium: Leuven. 1–6 pp.

Vanin, F. M., Lucas, T. & Trystram, G. (2009). Crust formation and its role during bread baking. *Trends in Food Science and Technology* **20**: 333–343.

Wang, J., Rosell, C. M. & Benedito de Barber, C. (2002). Effect of the addition of different fibres on wheat dough performance and bread quality. *Food Chemistry* **79**: 221–226.