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Dough mixing and thermal properties including the pasting profiles of composite flour blends with added hydrocolloids

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Abstract

Dough mixing and thermal properties including the pasting profiles of various commercial wheat flour (WF)-banana pseudostem flour (BP)-hydrocolloid blends were determined using a farinograph, differential scanning calorimetry (DSC) and a rapid-visco analyser (RVA). The prepared blends were WF, WF substituted with 10% BP (10BP) and 10BP with added 0.8% w/w (flour weight basis) xanthan gum (XG) or sodium carboxymethylcellulose (CMC) (10BPX and 10BPC, respectively). The dough of 10BP and the doughs containing XG or CMC reduced stability and breakdown time compared with the WF dough. All dough containing BP demonstrated greater water absorption and mixing tolerance index values than the WF dough. The substitution of 10% BP into WF and the addition of hydrocolloids did not significantly affect the conclusion temperature (Tc) of the mixture, but did increased the onset temperature (To), peak temperature (Tp) and decreased the gelatinisation enthalpy change (ΔHg) of the blends. Samples of 10BP, 10BPX and 10BPC significantly decreased ($p<0.05$) the breakdown, final viscosity and setback of the mixtures. These are vital characteristics to understand prior to the development of new formulation for low-calorie, wheat-based products.

Introduction

In recent years, there is a rising demands for high fibre products parallel to the increase in obesity, diabetes and cardiovascular diseases (FAO, 1990). Banana pseudostem flour (BP) has high fibrous components rich in cellulosic material, inorganic compound, dietary fibres, low molecular weight sugars and antioxidant compounds (Cordeiro *et al*., 2004; Adinugraha *et al*., 2005; Oliveira *et al*., 2007; Mukhopadhyay *et al*., 2008; Noor Aziah *et al*., 2011), has potential as functional ingredient for the development of functional food. Recent research indicated that juice extracted from banana pseudostem (*Musa Cavendish*) has potential to be processed as isotonic drink due to the present of high mineral content especially potassium (Feriotti and Iguti, 2011).

Many works was conducted on partial replacement of commercial wheat flour (WF) by fibre rich source such as rice straw, barley, oat, rye, whole wheat, (Sangnark and Noomhorm, 2004; Sabanis *et al*., 2009b; Rosell and Santos, 2010; Ragaee *et al*., 2011;) for the production of composite breads. However, partial substitution of WF for non-wheat flour often associated with handling problems during processing of product which subsequently resulted in poor texture of the finished products due to gluten dilution. Therefore, application of additives such as hydrocolloids is needed as gluten substitutes in composite bakery products (Urlacher and Dalbe, 1992; Friend *et al*., 1993; Guarda *et al*., 2004; Gambuś *et al*., 2007; Sim *et al*., 2009;.

Xanthan gum (XG) and carboxymethylcellulose (CMC) are commonly applied in food industry because at low concentrations, both provide good storage stability, water-binding capacity and aesthetic appeal. XG is known to be compatible with many food components, such as protein, salts, and acids. It gives synergistic effect when mixed with other thickeners such as starch, carrageenan, cellulose derivatives, gelatine and alginates. XG exhibit significant viscoelasticity even at low concentrations (Gambuś *et al*., 2007). XG has pseudoplastic behaviour that is important in bakery products, especially during dough preparation, such as kneading and moulding. It also prevents lump formation during kneading and improves dough homogeneity. The CMC increases dough viscosities and improve extensibility and elasticity in flour doughs (Cota *et al*., 2004). It also

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increases product volume and makes the air cells size and distribution in baked goods more uniform (Nussinovitch, 1997; Sworn, 2000). The CMC has high ability to hold water as moisture binder during baking and storage. This characteristic reduces staling and moisture loss during storage and resulted in positive effects on crumb (Friend *et a*l., 1993; Collar *et al*., 2001).

According to Williams and Phillips (2000), adding hydrocolloids to bakery products may affect processing and product qualities, even though they are present in less than 1% concentrations. An understanding of the thermal characteristics of gelatinisation behaviour and temperature and enthalpy changes of composite flours with added hydrocolloid would be helpful in bakery product development. The thermal characteristics can be analysed with differential scanning calorimetry (DSC) to detect the heat flow associated with the order-disorder transitions in starch, which provide quantitative measurements of gelatinisation (Sabanis *et al*., 2009b). In addition, the inclusion of dietary fibre-containing flour into WF often changes the viscosity pattern of the flour. The pasting properties of the blends are commonly studied using the Rapid Visco-Analyser (RVA) to observe changes in the viscosity of a starch system based on rheological principles (Zaidul *et al*., 2007). The Farinograph is used to measure the dough physical characteristic is popularly applied in determining the wheat dough mixing properties. The two Z-shaped blades of the farinograph mixer rotated at constant speeds and the dough is subjected to mixing at constant temperature. The farinograms generated from flour testing are analyzed to obtain quantitative information on the arrival time, departure time, stability, mixing tolerance index, time to breakdown and water absorption (Mondal and Datta, 2008).

The objectives of the present study are to determine the fibre content of BP and to investigate the effect of hydrocolloids (XG and CMC) on the WF thermal behaviour, pasting and rheological properties in terms of the farinograph of the dough made from WF with added hydrocolloid.

Materials and Methods

Banana pseudostem flour preparation

Banana pseudostems (*Musa acuminata* X *balbisiana* cv. Awak) were collected from local farms in Perak, Malaysia. The BP was processed by manually peeling several layers of the banana pseudostem skin (epidermis) with a sterile knife. The samples were then rinsed with deionized water and cut into small pieces. The pseudostem was boiled for 15 minutes to soften the texture before being soaked in 0.1% w/w sodium metabisulfite solution for 30 min. The pseudostem was then sliced using an electric slicer (Robot coupe, France) before being dried in a ventilated dryer (Afos, Model Mini, No. CK 80520, England) at 60^{o}C for 24 hours. The dried slices of pseudostem were then blended in a blender (Panasonic Model: PB-325, Malaysia) and sieved by passing the material through a 355-µm mesh sieve (No. 42). The BP was kept in an airtight plastic container and stored in a refrigerator prior to use.

Ingredients and formulations

Preliminary evaluations on the chemical composition of WF and BP were conducted to ascertain the moisture, crude protein, crude fat, ash and crude fibre contents of the flours; oven drying (AOAC method 977.11), Kjeldahl's (AOAC method 955.04), Soxhlet (AOAC method 960.39), dry ashing (AOAC method 923.03) and gravimetric methods (AOAC method 991.43), respectively, were used to determine these properties (AOAC, 1995). The chemicals used in this study were of analytical grade.

The samples for the analyses were WF, 10% of WF substituted with BP (10BP) and 10% of WF substituted with BP with the addition of 0.8% (flour weight basis) of XG or CMC (10BPX and 10BPC, respectively). The blends were mixed well and sieved through a 42 mesh sieve for uniform mixing. Xanthan gum (G1253, Sigma brand, USA) was procured from Sigma-Aldrich Sdn. Bhd (Selangor, Malaysia). Carboxymethylcellulose (cat#217274, Calbiochem brand, Germany) was purchased from Merck Sdn. Bhd. (Selangor, Malaysia).

Determination of dough mixing properties

A constant flour weight was conducted on a Brabender Farinograph ®–E (Brabender OHG, Duisburg, Germany) according to AACC method 54-21 (AACC, 2000). Approximately 300 g of WF, 10BP or 10BP with or without the addition of hydrocolloidss (XG or CMC) (corrected to 14% moisture basis) was mixed in a 300-g mixing bowl for 50 min. Parameters such as water absorption, dough development time (DDT), dough stability, mixing tolerance index (MTI) and time to breakdown were recorded.

Differential scanning calorimetry

Thermal properties of the samples were determined using a differential scanning calorimeter (DSC Q 200, TA Instruments, Waters, LLC, New Castle, DE) that was previously calibrated with pure indium as a standard. A sample (approximately 2.0 mg) was placed in Tzero pans, and 10 µL of distilled

water was withdrawn by micro-syringe and placed in a DSC pan and hermetically sealed. The sealed pans were allowed to equilibrate in desiccators for 1 hr before being subjected to analyses. An empty Tzero pan was used as a reference. Pans were heated from 30°C to 150°C at a rate of 2°C/min with a nitrogen gas flow of 50 ml/min. The values for the thermal property parameters, namely onset temperature (To), peak temperature (Tp), conclusion temperature (Tc) and gelatinisation enthalpy (ΔHg), of the samples were obtained directly from the analysis by the TA Instruments Advantage Software Universal Analysis 2000 version 2.6.362.

Pasting Properties Analyses

The pasting properties of the WF blend with BP were assessed using the Rapid Visco-Analyser (Model RVA series 4; Newport Scientific Pty Ltd., Warriewood, Australia). A 3 g sample was dispersed in an aluminium canister containing 25 g of distilled water. The samples were tested according to Standard Profile 1, where the flour-water suspension was held at 50°C for 1 min and then heated to 95°C, held for 10 min, and then cooled to 50°C and held for another 2 min. The starch viscosity parameters measured were pasting temperature, peak viscosity, breakdown viscosity, final viscosity and setback viscosity. The results are expressed as RVU for all of the parameters with the exception of pasting temperature, which is expressed in °C.

Statistical analyses

Statistical analyses were conducted using SPSS 14.0 software (SPSS Inc., Chicago, IL, USA). The results obtained in the present study are represented as the mean values of three individual replicates ± standard deviation (S.D.). Significant differences between mean values were determined by Duncan's multiple range test at a significance level of $P < 0.05$.

Results and Discussion

Chemical Compositions Determination

It is important to know the proximate compositions of the flours used in this study prior to the development of a new formulation of a dietary fibre-rich bakery product. Table 1 showed the composition of WF and BP used in the study. The results indicated that BP is an excellent source of ash (6.75%) and crude fibre (24.33%). However, the protein content of BP was less (2.70%) than that of WF (13.35%). The high content of crude fibre in BP is an indication of its potential application as a high-fibre source added to bakery products to compensate for the deficiency of dietary fibre in the daily diet.

Table 1. Chemical compositions of the WF and BP

[a]Composition (%)	WF	BP
Moisture	12.6	7.84
Protein	13.35	2.70
Fat	0.25	1.11
Ash	0.56	6.75
Crude fibre	0.41	24.33

a All results are reported on the dry weight basis; WF, commercial wheat flour; BP, banana pseudostem flour.

Table 2. Farinograph data of the WF substituted with 10% BP and added hydrocolloids

Sample	WA (%)	Time (min)			MTI (FU)
		Development	Stability	Breakdown	
WF	63.33^{c} ± 0.12	14.97^{b} ± 0.46	30.93^{a} ± 0.15	36.83^{a} ± 0.46	6.67^{c} ± 1.53
10BP	71.30^{b} ± 0.17	14.30^{c} ± 0.36	18.30^{b} ± 0.3	21.50^{b} ± 0.36	19.67^{b} ± 0.58
10BPX	75.13^{a} ± 0.06	16.57a ± 0.21	11.97^{c} ± 0.12	21.63^{b} ± 0.15	25.33^{a} ± 0.58
10BPC	75.10^{a} ± 0.00	13.80^{c} ± 0.17	11.03^{d} ± 0.15	19.83^{c} ± 0.12	19.67^{b} ± 0.58

Mean values (n=3) ± standard deviation followed by the same superscript letters within the same column are not significantly different (p>0.05); WF, commercial wheat flour (control); 10BP, WF substituted with 10% banana pseudostem flour (BP); 10BPX, 10BP with xanthan gum addition; 10BPC, 10BP with carboxymethylcellulose addition; WA, water absorption; MTI, mixing tolerance index; FU, farinograph unit.

Determination of dough mixing properties

The dough mixing properties of the WF, 10BP and the 10BP dough containing hydrocolloids (XG or CMC) are shown in Table 2. Water absorption by WF was significantly different from the 10BP, 10BPX and 10BPC, but there was no significant difference between the doughs with the addition of hydrocolloids. Water absorption increased by BP substitution and with added hydrocolloids. This was consistent with findings from Friend *et al*. (1993), Guarda *et al*. (2004) and Rosell *et al*. (2001) who found that a greater proportion of water is required in the presence of hydrocolloid (cellulose, algal and microbial gums) in wheat and tortilla dough. This was attributed to the hydroxyl groups in both the BP and hydrocolloid structures, which allow more water interactions through hydrogen bonding (Rosell *et al*., 2001). Therefore, gum molecules appear to have greater water binding capacities than gluten (Sim *et al*., 2011).

Dough development time is defined as the difference in the time between the point of the first addition of water and the point immediately before the first detection of dough weakening. The time required for the dough to reach 500 BU of DDT was the shortest in the dough containing CMC (13.80 min), as compared with other samples. However, no significant difference was found between the 10BPC and 10BP (14.3 min) dough. The dough containing XG exhibited the longest DDT (16.57 min).

Dough stability is a measure of the time needed for the curve to stay at or above 500 BU. It gives an

Table 3. Gelatinisation parameters of the WF substituted with 10% BP and added hydrocolloids

Samples	To (°C)	Tp (°C)	Tc (°C)	ΔHg (J/g)
WF	$55.28^{b} \pm 0.63$	$61.62^{b} \pm 0.21$	$68.70^{a} \pm 0.79$	$5.66^{a} \pm 0.07$
10BP	$56.33^{ab} \pm 0.87$	$62.54^{a} \pm 0.36$	$68.39^{a} \pm 0.62$	$4.65^{b} \pm 0.70$
10BPX	$56.38^{ab} \pm 0.18$	$62.27^{a} \pm 0.05$	$68.83^{a} \pm 0.43$	$4.63^{b} \pm 0.18$
10BPC	$56.56^{a} \pm 0.55$	$62.61^{a} \pm 0.40$	$69.36^{a} \pm 0.78$	$4.52^{b} \pm 0.07$

Mean values (n=3) ± standard deviation followed by the same superscript letters within the same column are not significantly different (p>0.05); WF, commercial wheat flour (control); 10BP, WF substituted with 10% banana pseudostem flour (BP); 10BPX, 10BP with xanthan gum addition; 10BPC, 10BP with carboxymethylcellulose addition; To, onset temperature; Tp, peak temperature; Tc, conclusion temperature; ΔHg, gelatinisation enthalpy.

indication of the dough strength, with higher values suggesting stronger dough. According to Mohamed *et al*. (2006), most commercial bread flours have a stability value of up to 10 min. In this study, 10BP showed less stability than the WF dough, and the addition of hydrocolloids in the wheat dough reduced the stability. Samples of 10BPX and 10BPC displayed similar stability values due to the presence of hydrocolloids. Similar reduction in stability was observed by Sabanis and Tzia (2009a) and Sim *et al*., (2011) in their studies on the viscoelasticity of the composite flours and the influence of hydrocolloid additions to wheat dough. This may be due to the weakening of the dough by gluten dilution, as the WF was substituted with non-glutinous flour (Sabanis and Tzia, 2009a), which resulted in less time on the 500 BU line.

The mixing tolerance index is the difference in Farinograph Units between the top of the curve and the top of the curve measured 5 min after the peak is reached (Mohamed *et al*., 2006). The greater the MTI value, the greater is the weakening area. The results indicated that the dough prepared with 10BP, 10BPX and 10BPC had significantly greater weakening areas than the control dough. This may be due to the amount of dietary fibre contained in the BP (Table 1) diluting the gluten protein during mixing, which may have made the dough weak and inextensible. The 10BPX dough was the weakest of the samples evaluated, including the WF dough. According to Mohamed *et al*. (2006), the MTI values influence the bread baking quality. Therefore, 10BPX would be the sample with the lowest baking quality.

The decrease in breakdown time indicated a poor stability of the dough at a 10% level of BP substitution. The 10BP demonstrated similar breakdown time to the 10BPX dough. The results indicate that both the dough are more stable than the 10BPC dough, which required less time to breakdown. The strongest dough was the one containing only WF, which may be due to the higher protein content in the WF delaying gluten formation, thus increasing the mixing time (Mohamed *et al*., 2006). However, the dilution of protein in the sample substituted with10% BP resulted in reduced breakdown time.

Differential scanning calorimetry

The To, Tp, Tc and ΔHg values are displayed in Table 3. As a general trend, the substitution of BP in the blend increased the To and Tp and reduced the ΔHg. The thermal properties of the flour blends in water indicated that the gelatinisation temperature of WF in water (61.62 °C) was lower than that found for the 10BP, 10BPX and 10BPC blends in water (62.27-62.61°C).

The increase in Tp in the blends may be attributed to the presence of BP. Dietary fibre, which is a highly water-binding macromolecule, competes with starch for water absorption, thereby limiting the available water for starch granules to completely swell, consequently raising the Tp for the transition to a solid-like structure (Sabanis *et al*., 2009b; Xue and Ngadi, 2009). In addition, according to Kobylanski *et al*. (2004), non-starch polysaccharides have been contributed to interactions between the starch of WF and the hydroxyl groups of the hydrocolloids. The interactions between starch and hydrocolloids or BP in the system produced a more stable structure and required a higher temperature for disorganisation. Furthermore, XG and CMC are both water-soluble polymers and increase the viscosity of the blends, resulting in reduced heat transfer rates and a shift in Tp toward higher temperatures (Xue and Ngadi, 2009).

The interactions between starch and hydrocolloids promoted a delay in the starch gelatinisation, causing a slight increase in the To (Rojas *et al*., 1999). A similar increasing trend in the Tp of a WF-water mixture upon addition of hydrocolloids or fibre ingredients was previously observed by Rojas *et al*. (1999), Sabanis *et al*. (2009b), Xue and Ngadi (2009). However, the addition of hydrocolloids into the mixture containing WF and BP did not significantly influence the Tp, Tc or ΔHg.

According to the ANOVA results, the total ΔHg of the sample with the substitution of 10% BP for WF and the samples with the addition of either XG or CMC exhibited significantly lower values than the WF alone. The ΔHg of the WF-water mixture was found to be 5.66 J/g, and the lowest ΔHg changes were obtained for the mixture containing BP and BP with the addition of XG or CMC (4.65, 4.63 and 4.52 J/g, respectively) (Table 3). The mixture of hydrocolloids and the WF starch increased the starch gelatinisation temperature but decreased the total enthalpy of gelatinisation of the blends during the heating process. According to Gimeno *et al*. (2004), the interaction between the hydrocolloids and starch retained more water molecules, causing increased mobility during heating, thereby increasing the kinetic energy and

Table 4. Pasting profile of the WF substituted with 10% BP and added hydrocolloids

Parameter	WF	10BP	10BPX	10BPC
PT (°C)	66.38^{a} ± 0.40	66.67^{a} ± 0.40	66.20^{a} ± 0.05	67.23^{a} ± 0.98
PV (RVU)	198.72^{b} ± 1.47	189.14^{c} ± 0.46	213.67^{a} ± 0.47	189.50^{c} ± 0.72
Trough (RVU)	101.92^{c} ± 0.80	98.81^{d} ± 0.39	119.17^{a} ± 0.51	108.83^{b} ± 0.79
BD (RVU)	96.80^{a} ± 0.71	90.33^{c} ± 0.80	94.50^{b} ± 0.71	80.67^{d} ± 1.12
FV (RVU)	202.58^{a} ± 2.32	189.05^{d} ± 1.11	196.75^{b} ± 0.80	192.61^{c} ± 0.31
Setback (RVU)	100.67^{a} ± 2.05	90.25^{b} ± 0.74	77.58^{d} ± 1.13	83.78^{c} ± 0.55

Mean values (n=3) ± standard deviation followed by the same superscript letters within the same row are not significantly different (p>0.05); WF, commercial wheat flour (control); 10BP, WF substituted with 10% banana pseudostem flour (BP); 10BPX, 10BP with xanthan gum addition; 10BPC, 10BP with carboxymethylcellulose addition; PT, pasting temperature; PV, peak viscosity; BD, breakdown; FV, final viscosity; RVU, rapid viscosity unit.

decreasing the enthalpy value. The reduction in ΔHg suggests that fibre interacts synergistically with starch to promote the formation of a more stable structure. Rojas *et al*. (1999) also reported a decrease in the ΔHg of a flour-water mixture upon the addition of various types of hydrocolloids (guar gum, pectin, alginate, xanthan gum and HPMC).

Pasting properties Analyses

Table 4 displays the pasting properties of a WF suspension with or without the addition of hydrocolloids. The pasting temperature is an indication of the minimum temperature required to cook the flour (Kaur and Singh, 2005). The pasting temperature of the sample with the addition of XG had the lowest pasting temperature (66.20°C), and the 10BPC paste exhibited the highest pasting temperature. However, no significant difference was found between the 10% BP substitution and WF samples. These results are in accordance with those reported by Sim *et al*. (2009), who found that the addition of CMC, an ionic gum, to WF caused delayed swelling of the starch granule. This may be attributed to the fact that the CMC was adhered to the starch granules, and the net negative charge on the surface prohibited the water molecules from reaching the starch granules; a relatively higher temperature would therefore be needed to swell the starch granules.

During the heating cycle, a sharper rise in peak viscosity of the paste with the addition of XG (213.67 RVU) than the sample with 10% BP substitution and the sample with the addition of CMC (189.14 and 189.50 RVU, respectively). Peak viscosity indicates the maximum swelling capacity of starch granules. This indicated that in the presence of XG, starch granules can swell very rapidly when reaching beyond the gelatinisation temperature, resulting in an increased viscosity that was not observed with the addition of CMC. The earlier detection of increased viscosity may be caused by the thickening of XG rather than the swelling of the starch granules. According to Christianson *et al*. (1981), the early onset of initial viscosity is attributed to the detection of the first stage of swelling and is dependent on media viscosity rather than the swelling of the starch granules. The WF demonstrated greater peak viscosity than the sample substituted with BP and the sample with CMC. This may have resulted from other components of the BP and CMC, such as fibre, lipids and ash, competing with the starch granules in the WF for water absorption, thereby obstructing the swelling of the starch granules (Nimsung *et al*., 2007). In contrast to the WF and 10BPX samples, the 10BP and 10BPC samples revealed a lower peak viscosity (189.14 and 189.50 RVU, respectively). This may be attributed to the shearing effect from the stirrer during stirring, which may have decreased the paste viscosity of the 10BP and 10BPC samples.

With continuous heating of the paste, the starch granules rupture, resulting in a reduction in viscosity. Breakdown is a parameter that measures the ease with which the swollen granules can be disintegrated (Kaur and Singh, 2005). Compared with the WF, blends with the substituted BP and the BP with added XG and CMC demonstrated stable curves with little breakdown after heating at 95°C for 10 min. The lowest breakdown was observed in the 10BPC (80.67 RVU), indicating its paste stability. The lower breakdown value of the 10BPC, 10BP (90.33 RVU) and 10BPX (94.50 RVU), as compared with the WF (96.80 RVU), may be due to the restricted swelling of the starch granules, which increased the tendency of the hydrophilic chain of the BP fibre to bind with the hydrogen bonds of the water, causing a decrease in available water for the starch granules.

An increase in the pasting viscosity (189.05-202.58 RVU) was found in each mixture and in the pure WF. When the temperature was cooled to 50 °C, gel formation occurred in all of the samples. This may be attributed to the formation of a large number of intermolecular hydrogen bonds (Leelavathi *et al*., 1987). The lowest value of final viscosity was from 10BP, which indicated that this sample has a reduced ability to form a viscous paste compared with the other samples. Both samples containing CMC and XG also indicated a lower final viscosity than the WF.

Kaur and Singh (2005) stated that a limitation of this research is the parameter used for the measurement of the retro-gradation tendency, or syneresis, of flours upon cooling the cooked flour pastes. The 10BP and 10BP with the addition of XG or CMC samples demonstrated a reduced setback during cooling. The WF was found to be highly retrograded, which may be explained by the effect of amylose and amylopectin contents. The BP starch has less amylose and amylopectin than commercial wheat flour starch. According to Nimsung *et al*. (2007),

starch with low levels of amylose could undergo a reduced retro-gradation process than the starch with high levels of amylose. However, further research on the amylose content of BP is essential for providing additional information.

Conclusion

Farinograph results indicated that the existence of fibre from BP increased the water absorption of the composite doughs. In addition, dough with the substitution of 10% BP had weak and inextensible dough during mixing. Thus, these dough preparations indicated reduction in stability and breakdown values compared with those for the WF dough. The sample with the addition of XG had the longest DDT among the samples. The composite flour sample and the samples with added hydrocolloids did not change the Tc of the mixture, increased the To and Tp and decreased the ΔHg of the sample. In terms of pasting profile, no significant differences were found in the pasting temperatures of all of the flour mixtures. The addition of XG into a mixture significantly increased the peak viscosity and trough compared with the WF. However, the 10BP, 10BPX and 10BPC samples significantly decreased the breakdown, final viscosity and setback values compared with the WF suspension. This fundamental analyses are important to applied in the bakery industrial such as bread, cookies, cake, biscuit and as well as muffin.

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