

Physicochemical, pasting and gel textural properties of wheat-ripe Cavendish banana composite flours

¹Ng, K. F., ²Abbas, F. M. A., ¹Tan, T. C. and ^{1*}Azhar, M. E.

¹Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 USM Penang, Malaysia

²Environmental Technology Division, School of Industrial Technology, Universiti Sains Malaysia, 11800 USM Penang, Malaysia

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Abstract

Proximate composition, pH and amylose content of ripe Cavendish banana flour (RBF) prepared in this study were compared with all-purpose wheat flour (WF). RBF was found to be significantly ($P < 0.05$) higher in total carbohydrates and minerals content, while significantly ($P < 0.05$) lower in protein and fat contents compared with those of WF. Wheat-ripe banana composite flours (W-RBF) prepared by partial substitution of WF with RBF were assessed for swelling power, solubility, pasting properties and gel textural properties. Granular swelling of RBF occurred at a higher temperature compared to that of WF, suggesting that more energy and water were required to cook WF-RBF as the presence of soluble carbohydrates would compete for water and this would eventually delay starch hydration and granular expansion during cooking. Higher substitution with RBF led to higher soluble carbohydrates content, and increase in solubility index of WF-RBF. Partial substitution with RBF also resulted in significant ($P < 0.05$) decrease in pasting properties. A higher substitution of WF with RBF could reduce starch gelatinisation during cooking and retrogradation owing to the reduction of available starch in WF-RBF. All WF-RBF gels were significantly ($P < 0.05$) firmer and less sticky compared to WF gels.

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Introduction

Banana is one of the world's leading food crops and they are grown abundantly in both tropical and subtropical countries. Bananas can be categorised into two groups, namely cooking bananas (plantain) and dessert bananas. Dessert bananas are usually consumed in its raw form when it is ripe because of its convenience, ease to eat, sweet taste and aroma as well as its high nutritional value and easy digestibility (Sharrock and Lustray, 2000; Okezie *et al.*, 2003). Banana fruit is rich in minerals (potassium, magnesium and phosphorus), dietary fibre, and various antioxidants, such as vitamin A, vitamin C, vitamin E, and β -carotene (Kanazawa and Sakakibara, 2000).

The qualities of the fresh banana decrease drastically after harvesting as a result of deterioration in fruit's colour, flavour and texture. In order to increase its shelf life and reduce the loss, ripe bananas can be processed into various products such as banana puree, banana juice, beverages, jam and jelly (Mohapatra *et al.*, 2011). An innovative approach on the utilisation of banana is by drying the fruits and transforming them into banana flour. Banana flour production is gaining popularity, especially in banana producing countries in Africa (Happi Emaga

et al., 2008). Banana flour has been incorporated into various products such as flakes (Ruales *et al.*, 1990), high-fibre bread (Juarez-Garcia *et al.*, 2006), slowly digestible cookies (Aparicio-Saguilán *et al.*, 2007), mayonnaise (Izidoro *et al.*, 2007), pasta (Ovando-Martinez *et al.*, 2009) and yellow alkaline noodles (Saifullah *et al.*, 2009).

While many studies have been conducted to investigate the physicochemical and functionalities of unripe banana flour (Nimsung *et al.*, 2007), only a handful of studies were conducted on banana flour prepared from ripe fruits. Study done by Okezie *et al.* (2003) has evaluated the effect of addition of ripe banana flour to maize 'extract' on selected physicochemical properties. Flakes made of ripe banana pulp and full-fat soya flour (Ruales *et al.*, 1990) as well as yellow alkaline noodles made of ripe banana pulp and peel flour (Saifullah *et al.*, 2009) has been developed. As far as we are concerned, studies on ripe banana-wheat composite flour were scanty.

Ripe banana flour (RBF) is rich in soluble carbohydrates due to the conversion of starch into soluble carbohydrate during fruit ripening. Hence, RBF has relatively low water retention capacity and viscosity as compared to unripe banana flour, making them an ideal choice as a food thickener or an ingredient in infant formula food (Zakpaa *et*

*Corresponding author.

Email: azhar@usm.my

Tel: +604 6532268; Fax: +604 6573678

al., 2010). RBF has been applied in weaning food, specialty bakery products and extruded products when fortified with other protein-rich flours (Mohapatra *et al.*, 2011). Breads prepared by partial substitution of wheat flour with RBF were of equal quality as the control, but with lower carbohydrates content, and higher potassium and fibre contents (Mohamed *et al.*, 2010). These studies suggest that RBF has potential to serve as a natural ingredient to enhance nutritional properties, taste and aroma in various food products.

In order to promote the use of RBF, better understanding on the effect of partial incorporation of RBF into the food matrix is important. Wheat flour (WF) is one of the most widely used staple food ingredient, hence the objective of this study was to evaluate the effect of partial substitution of WF with RBF on physicochemical, pasting and gel textural properties of the wheat-ripe banana composite flour (WF-RBF).

Materials and Methods

Materials

Fresh ripe (stage 5 of ripening: yellow with green tip) Cavendish (*Musa paradisiaca* L, cv cavendshii) bananas were purchased from a local market in Penang Island, Malaysia. A total of 171 combs of banana (2,036 bananas) were used in this study. Wheat flour (WF) was purchased from Prestasi Flour Mill (Selangor, Malaysia). All chemicals (Sigma-Aldrich, St. Louis, USA) used in this study were of analytical grade.

Preparation of ripe banana flour (RBF)

RBF was prepared according to procedures as described by Abbas *et al.* (2009b) and Ovando-Martinez *et al.* (2009) with some modifications. The fruits were peeled and cut into slices of approximately 1 cm thick and immediately rinsed in 0.5% (w/v) citric acid solution. The fruit slices were then placed on trays and dried at 60°C in a hot-air dryer (Kimah Industrial Supplies, Model 3021, Penang, Malaysia) for 18 h. The dried fruit slices were ground in a heavy-duty blender (Waring, Connecticut, USA) and passed through 60-mesh screens to obtain RBF. Flour was stored in airtight containers at 4°C prior to analysis.

pH measurement

The pH of RBF and WF was measured using InLab 421 Electrode attached with Delta 320 pH meter (Mettler Toledo, Schwerzenbach, Switzerland). Flour dispersion (8%, w/v) was stirred for 5 min, allowed to stand for 30 min, filtered and the pH of filtrate was then measured (Suntharalingam and Ravindran, 1993).

Proximate composition

Proximate analysis for both WF and RBF was performed in triplicate following AOAC (1995) procedures and included the following: moisture by air oven (Method 935.29), crude protein by Kjeldahl nitrogen (Method 920.152), crude fat by Soxhlet extraction (Method 922.06) and ash by direct analysis (Method 940.26). The percentage of crude protein was estimated by multiplying the total nitrogen content by a factor of 6.25 (AOAC, 1995). Total carbohydrates were calculated by subtracting the total percent values of other measurements from 100. Proximate analyses were expressed as grams per 100 g of flour.

Amylose content

Amylose content of RBF and WF was determined according to the method as described by Hoover and Ratnayake (2001). Flour sample (20 mg, dry weight basis) was dissolved in 8 mL of 90% (v/v) dimethylsulfoxide (DMSO). The contents were mixed vigorously for 20 min and then incubated in water bath (Memmert, WB22, Schwabach, Germany) at 85°C for 15 min with intermittent shaking. Then, the contents were cooled to room temperature and diluted with distilled water to 25 mL in a volumetric flask. The diluted solution (1.0 mL) was aliquoted to a 50 mL volumetric flask and mixed with 40 mL of distilled water. A 5 mL of I₂/KI solution (0.0025 M of I₂ and 0.0065 M of KI) was added into the volumetric flask and then adjusted to a final volume of 50 mL. Then final contents were allowed to stand for 15 min at room temperature prior to determine the absorbance at 600 nm on a spectrophotometer (Shimadzu, UV-1650 PC, Nakagyo-ku, Japan).

Preparation of blended samples

WF was dry-blended with RBF in ratios of 100:0 (WF:RBF), 80:20, 60:40, 40:60, 20:80 and 0:100. Mixing was carried out on weight basis. All blended samples were stored in airtight containers at 4°C until further analysis. All analyses were performed in triplicate. Sample definitions and descriptions for wheat-ripe banana composite flours (WF-RBF) are: 80W:20B: 80% (w/w) of WF mixed with 20% (w/w) of RBF; 60W:40B: 60% (w/w) of WF mixed with 40% (w/w) of RBF; 40W:60B: 40% (w/w) of WF mixed with 60% (w/w) of RBF; 20W:80B: 20% (w/w) of WF mixed with 80% (w/w) of RBF.

Swelling power and solubility

Swelling power and solubility at temperature interval of 10°C, i.e. from 55 to 95°C, were determined according to the method as described by Leach *et al.*

(1959) with some modifications. Blended samples (0.5 g, dry weight basis) were suspended in 25 mL distilled water. The suspension was equilibrated at 25°C for 5 min prior to the incubation in a water bath for 30 min. The samples were cooled in iced water bath for 1 min and equilibrated for 5 min at 25°C before being centrifuged at $1,465 \times g$ for 15 min (Kubota, Kubota 5100, Tokyo, Japan). The supernatant was drawn off by suction. A 5 mL of the supernatant was evaporated (Esco, OFA-54-8, Singapore) at 105°C for 4 h to constant weight. Percentage solubility and swelling power were calculated using Eq. 1 and Eq. 2, respectively:

$$\text{Sol (\%)} = (W_2/W_1) \times 100 \quad (\text{Eq. 1})$$

$$\text{SP (g/g)} = [W_3/(W_1 \times (100 - \text{Sol}))] \times 100 \quad (\text{Eq. 2})$$

where, Sol is the solubility of the flour sample (in %), SP is the swelling power of the flour sample (in g/g) W_1 is the weight of flour sample (in g), W_2 is the dried weight of supernatant (g) and W_3 is the weight of sediment paste (in g).

Pasting properties

Pasting properties were determined using a Rapid Visco Analyser (Newport Scientific, Model RVA series 4, Warriewood, Australia). Standard profile STD1 supplied with the instrument was used with 3.5 g of blended samples (corrected to 14% moisture content) with 25 g of distilled water. Samples were pasted according to a programmed heating and cooling cycle. The dispersions were heated from 50 to 95°C with constant stirring at 2.67 Hz and were held at 95°C for 2.5 min (breakdown). Then the block temperature was cooled to 50°C and held for 2 min. The total cycle was 13 min. Parameters including the pasting temperature (temperature at the onset of rise in viscosity), peak viscosity, trough (minimum viscosity at 95°C), breakdown (peak – trough viscosity), final viscosity (viscosity at 50°C), and setback (final viscosity – trough viscosity) were determined from the pasting curve.

Textural properties

Gels preparation

Flour slurry (40%, w/v) was prepared by mixing 400 g of blended sample into 1 L of distilled water. Preliminary studies indicated that the gels prepared at this concentration were able to yield free-standing gels. The slurry was preheated at 70°C for 10 min to form pourable paste. The paste was then poured into syringes (volume: 20 mL; inner diameter: 19 mm) and cooked in a steamer at 100°C for 20 min. A thin

layer of cooking oil was dropped on the surface of the samples in each syringe to prevent excessive water evaporation. All the samples were cooled to room temperature (25°C) for 2 h. The gels were un moulded and cut into 20 mm in length for texture analysis.

Texture profile analysis (TPA)

TPA was carried out according to the method as described by Kaur *et al.* (2009) using a texture analyser (Stable Micro Systems, TA-TX2, Surrey, UK). The TPA was attached with a 5 kg load cell. A 75 mm diameter compression platen was used to compress a cylindrical sample at a constant speed of 1 mm s^{-1} . The deformation level was set at 75% strain of the original sample height. The bottom plate and the top of the gels were covered with a thin layer of paraffin oil to allow sample expansion in order to avoid the barrel effect during compression.

Compression was repeated twice to generate force versus time curve. The textural parameters of hardness, adhesiveness, springiness, cohesiveness, and chewiness were determined. At least ten measurements were recorded for each type of gel and the experiment was repeated three times. The average values of the triplicate experiments were reported.

Statistical analysis

Significant differences for multiple comparisons were determined by one-way analysis of variance (ANOVA) followed by Duncan test by SPSS statistical package version 14.0 (SPSS, Chicago, Illinois, USA). The p value less than 0.05 were considered as statistically significant.

Results and Discussions

pH, proximate composition and amylose content

The average values of pH of RBF was significantly ($P < 0.05$) lower compared to those of WF (Table 1). The pH values of RBF and WF obtained in this study is in agreement with previously reported data (Abbas *et al.*, 2009a; Victor *et al.*, 2013). A lower pH could be attributed to the presence of organic acids, such as malic acid, in ripe banana fruits (Wyman and Palmer, 1964).

RBF and WF also differed in chemical compositions (moisture, crude protein, crude fat, total carbohydrates, and ash) (Table 1). Proximate composition of WF in this study was in agreement with the values reported by Kashlan *et al.* (1991) and Chiang *et al.* (2013). In addition, proximate composition of RBF was comparable with the findings reported by Suntharalingham and Ravindran (1993), Juarez-Garcia *et al.* (2006) and Abbas *et al.* (2009b).

Table 1. pH¹, amylose content¹ and proximate composition¹ of ripe banana flour and wheat flour.

Sample ²	pH	Amylose (%)	Proximate composition (g/100 g of flour)				
			Moisture	Crude Protein	Crude Fat	Carbohydrate	Ash
RBF	4.55 ± 0.01 ^b	N.D.	7.78 ± 0.09 ^b	4.99 ± 0.24 ^b	0.28 ± 0.05 ^b	82.98 ± 0.25 ^a	3.98 ± 0.06 ^b
WF	5.79 ± 0.17 ^a	17.47 ± 0.6	12.22 ± 0.02 ^a	11.61 ± 0.20 ^a	1.22 ± 0.06 ^a	74.32 ± 0.21 ^b	0.63 ± 0.01 ^b

Notes: N.D. = Not detected.

¹Comparison within the columns was shown in the table with the data written as mean ± standard deviation (n = 3). Means followed by the different superscript letter (a-b) are statistically significant at the 5% level.

²RBF = ripe banana flour; WF = wheat flour.

Moisture, crude protein and crude fat contents of RBF were significantly ($P < 0.05$) lower than those of WF. Differences in the moisture content could be due to the difference in the processing method used to prepare the flour. As reported by El-Porai *et al.* (2013), wheat underwent different processing method yielded wheat flour with different moisture content. Banana flour with low moisture content was documented by Suntharalingham and Ravindran (1993), Juarez-Garcia *et al.* (2006) and Abbas *et al.* (2009b). Significantly ($P < 0.05$) higher protein content in WF is expected due to the presence of gluten proteins (Kuktaite *et al.*, 2004; Chiang *et al.*, 2006). Low content of protein and fat in RBF was inline with the values reported by Abbas *et al.* (2009b).

However, total carbohydrates and ash contents of RBF were significantly ($P < 0.05$) higher than those of WF. Significantly ($P < 0.05$) higher total carbohydrates in RBF are expected since ripe bananas are known to contain high level of sugar, a result of conversion from starch during ripening process (Adão and Glória, 2005; Rodríguez-Ambriz *et al.*, 2008; Fils-Lycaon *et al.*, 2011). Bananas are known to be rich in minerals, such as phosphorus, potassium, calcium and magnesium (Lii *et al.*, 1982; Abbas *et al.*, 2009b). Hence, presence of these minerals at high levels contributed to the significantly ($P < 0.05$) higher ash content in RBF. Low content of ash in WF was comparable with the values reported by Kashlan *et al.* (1991) and Chiang *et al.* (2006).

Amylose content in WF was recorded to be 17.5%. Amount of amylose present in WF depends on the type of wheat used and this can be as low as 0-3% for WF made from waxy wheat to as high as 30-37% for WF made from high-amylose wheat (Van Hung *et al.*, 2006). On contrary, amylose was not detected in RBF. The absence of amylose in RBF is anticipated since starch content in unripe banana decreased to very low level during fruit ripening (Adão and Glória, 2005; Happi Emaga *et al.*, 2007). Lii *et al.* (1982) has reported that starch content in unripe banana (61.7%) could decrease to as low as 2.6% when the fruit is fully ripe.

Swelling power and solubility

Starch is insoluble in cold water, but when heated

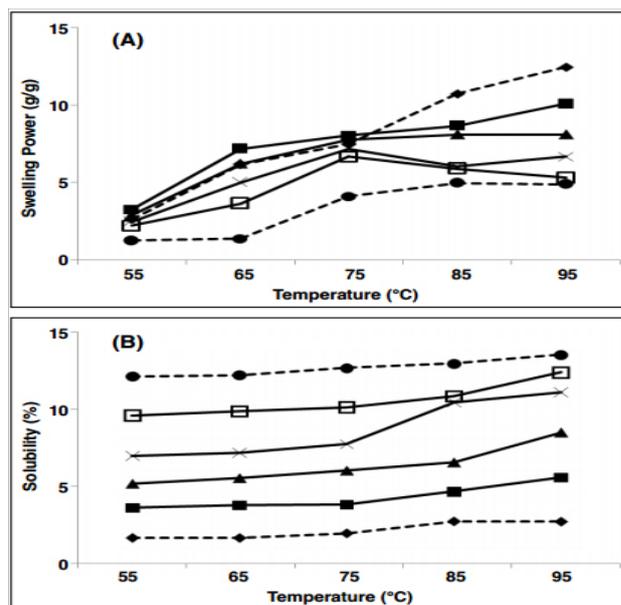


Figure 1. Swelling power (A) and water solubility index patterns (B) of wheat flour (WF) (dotted line with \diamond), ripe banana flour (RBF) (dotted line with \bullet) and wheat-ripe banana composite flours; 80W:20B (solid line with \blacksquare), 60W:40B (solid line with \blacktriangle), 40W:60B (solid line with \times), and 20W:80B (solid line with \square), as a function of temperature.

water diffuses through the walls of the starch granules. This leads to the increase in hydrogen bonding between water molecules and hydroxyl groups of starch molecules leading to disruption of crystalline structures of starch molecules, and ultimately resulted to granular swelling (Srichuwong *et al.*, 2005). According to Whisler and BeMiller (1997), amylose molecules diffuse out from the swollen starch granules concurrently. Swelling ability and solubility of starch granules play an important role in contributing to the pasting and rheological behaviour in most starchy products (Srichuwong *et al.*, 2005).

The swelling power and solubility patterns of WF, RBF and WF-RBF are illustrated in Figure 1. Both swelling power and solubility index were temperature dependent. All samples exhibited very little uptake of water at temperature below 65°C, hence their swelling power were also low at temperature below 65°C. The granular swelling of RBF began at ~75°C, whereas the swelling of WF and WF-RBF occurred at lower temperature (~65°C). This could be attributed to the conversion of starch to sugars during ripening proses of banana fruit resulting to low starch and high soluble carbohydrates contents in RBF (Lii *et al.*, 1982; Fils-Lycaon *et al.*, 2011). Presence of soluble carbohydrates, such as sugars and dietary fibres, in RBF could compete with starch granules for water and hence hindered the swelling of starch granules. Delay in granular swelling of RBF and WF-RBF was noticeable when compared

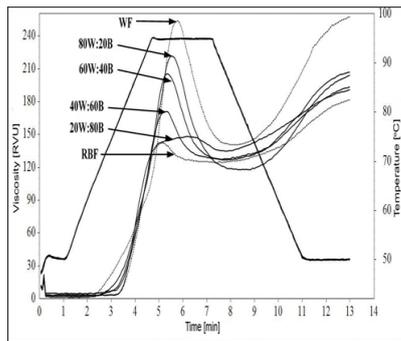


Figure 2. Typical RVA pasting curves of wheat flour (WF), ripe banana flour (RBF) and wheat-ripe banana composite flours.

to those of WF (Figure 1). The swelling power of WF-RBF was in the descending order of 80W:20B > 60W:40B > 40W:60B > 20W:80B. This trend is expected as starch was the major constituent (ca. 70-75%) in WF (Van Hung *et al.*, 2006) and its presence was relatively lower in RBF (Lii *et al.*, 1982).

Since RBF was rich in soluble carbohydrates (Fils-Lycaon *et al.*, 2011), it is expected to exhibit the highest solubility in comparison with WF (Figure 1), which consists mainly of starch (Van Hung *et al.*, 2006). The solubility values of WF-RBF were in-between RBF and WF. Higher portion of RBF substitution yielded higher solubility since higher portion of RBF led to higher soluble carbohydrates content. High solubility plays an important role in homogenising food ingredients and ease in mixing as non-homogenised mixture of ingredients could cause negative effect on the textural and sensory properties of the final product.

Pasting properties

When starch suspension was heated followed by cooling, a series of physical changes in the starch suspension takes place and this can be assessed using a Rapid Visco Analyser (RVA). Typical RVA pasting curves for RBF, WF, and WF-RBF are shown in Figure 2. In general, pasting properties, including PV, BV, final viscosity (FV), and setback viscosity (SV), of WF-RBF decreased with the increase level of RBF substitution during heating and cooling cycles in the RVA test (Table 2). These observations could be attributed to the high amount of soluble carbohydrates in RBF and also the diluting effect of the starch content in the WF-RBF.

As the temperature of starch suspension increased, starch granules absorbed large amount of water and this induced granular swelling. The swollen starch granules occupied more space in the system. Hence, the flow of water was restricted by the loss of free water and this eventually led to rapid increase in viscosity over a range of temperatures (Srichuwong

Table 2. Pasting properties¹ of wheat flour, ripe banana flour and wheat-ripe banana composite flours

Sample ²	PV [RVU]	TV [RVU]	BV [RVU]	FV [RVU]	SV [RVU]	PT [°C]
WF	250.7 ± 3.0 ^a	138.7 ± 2.0 ^a	111.9 ± 1.7 ^a	255.0 ± 2.4 ^a	116.3 ± 0.6 ^a	67.4 ± 0.5 ^d
80W:20B	223.5 ± 1.6 ^b	118.0 ± 0.8 ^b	105.5 ± 1.1 ^b	204.5 ± 0.5 ^b	86.5 ± 1.0 ^b	73.5 ± 0.8 ^e
60W:40B	206.0 ± 0.7 ^c	127.4 ± 0.8 ^b	78.6 ± 0.5 ^c	208.2 ± 1.3 ^b	80.8 ± 0.6 ^c	77.2 ± 0.4 ^b
40W:60B	172.6 ± 1.5 ^d	128.3 ± 1.1 ^b	44.3 ± 1.3 ^d	195.0 ± 1.9 ^c	66.8 ± 0.8 ^d	77.7 ± 0.5 ^{ab}
20W:80B	136.3 ± 5.7 ^f	118.6 ± 4.9 ^c	17.6 ± 1.9 ^e	175.0 ± 5.7 ^d	56.4 ± 0.8 ^e	78.5 ± 0.5 ^a
RBF	147.8 ± 1.2 ^e	135.6 ± 0.9 ^a	12.3 ± 1.5 ^f	190.5 ± 0.4 ^c	54.9 ± 1.0 ^f	78.5 ± 0.5 ^a

Notes: PV - peak viscosity; TV - trough viscosity; BV - breakdown viscosity; FV - final viscosity; SV - setback viscosity; PT - pasting temperature.

¹Comparison within the columns was shown in the table with the data written as mean ± standard deviation (n = 3). Means followed by the different superscript letter (a-f) are statistically significant at the 5% level.

²WF = wheat flour; RBF = ripe banana flour, W:B = ratio of wheat flour to ripe banana flour.

et al., 2005). Viscosity continues to increase with temperature until a certain point, marked as peak viscosity (PV). Starch granules were disrupted as the starch suspension was subjected to a period of constant high temperature (at 95°C) and mechanical shear stress. As a result, starch granules ruptured and more soluble amylose leached out into the system as reflected by the breakdown in viscosity to a holding strength or trough. The rate of the breakdown is dependent on temperature, shear stress applied to the system, and the nature of the starch tested (Newport Scientific, 1998). As the mixture was cooled, starch molecules re-associated to form gel network and this leads to the increased in viscosity.

PV reflects the ability of starch granules to absorb water and swell during cooking (Sandhu *et al.*, 2007). PV recorded in this study ranged from 136.3 to 250.7 Rapid Viscoanalyser units (RVU), with 20W:80B having the lowest PV, whilst the highest PV was recorded from WF (Table 2). PV decreased significantly ($P < 0.05$) with increase in RBF substitution. Hence, the PV of WF-RBF descended in the order; 80W:20B > 60W:40B > 40W:60B > 20W:80B. Similar trend is reported by Okiezie *et al.* (2003), where PV of maize extract flour decreased from 1,080 B.U. (Brabender units) to 330 B.U. with the substitution of maize extract flour with RBF at the level of 50%.

The ability of paste to resist breakdown during cooling is indicated by trough viscosity (TV) (Ikegwu *et al.*, 2010). As indicated in Table 2, TV of RBF and WF was similar ($P > 0.05$), but was significantly ($P < 0.05$) higher than all WF-RBF. Breakdown viscosity (BV) indicates the susceptibility of cooked starch granules to disintegration (Lee *et al.*, 1995). RBF exhibited the lowest BV (12.3 RVU), whereas WF exhibited the highest (111.9 RVU). BV decreased significantly ($P < 0.05$) with increase in RBF substitution. BV of WF decreased more than 84% when WF was substituted with 80% RBF (17.6 RVU). Increase in RBF substitution could have hindered the nature of starch granules hydration and swelling as they were embedded in the starch-sugar matrix. These restrictions due to the presence of soluble

carbohydrate caused less amylose molecules leached out into the matrix during cooking. Ultimately this could result in reduced retrogradation of amylose molecules (Sharma *et al.*, 2009).

Final viscosity (FV) represents the particular quality of the starch, reflecting the stability of the cooked paste and the ability to form a viscous paste or gel after cooling (Ikegwu *et al.*, 2010), while setback viscosity (SV) represents the syneresis of starch upon cooling of the cooked starch paste (Sandhu and Singh, 2007). Both FV and SV values of WF were significantly ($P < 0.05$) higher than RBF. Therefore confirming the expected characteristics of WF to have higher tendency for retrogradation as compared to those of RBF. As a result, cooked WF possessed the potential to form gel, whilst cooked RBF could only form paste upon cooling. Even though FV and SV of WF-RBF were significantly ($P < 0.05$) lower than those of WF, these values were higher than those of RBF. These findings suggest that a firm gel-liked product could be developed using RBF by providing sufficient amount of starch, which in this case incorporating RBF with WF, or other amylose-rich flour.

Pasting temperature (PT) indicates the minimum temperature required in cooking the sample (Kaur *et al.*, 2009). Owing to high sugar and low starch contents in RBF, PT of RBF was significantly ($P < 0.05$) higher than that of WF. PT of WF-RBF increased significantly ($P < 0.05$) with increasing RBF substitution. The PT of WF-RBF was in the descending order of 80W:20B > 60W:40B > 40W:60B > 20W:80B. High amount of soluble-carbohydrate in RBF caused changes in hydrodynamic volume and mobility (translational and rotational) of starch suspension (Sharma *et al.*, 2009). The soluble carbohydrates competed with starch for available water, thus a higher energy was required for gelatinisation. These findings were in agreement with the swelling power of the blended flours as reported earlier (Figure 1a). Findings on the delay in starch gelatinisation in this study provide useful information for development of products with flour composites, since the cooking time of the product is influenced by the composite flour ratios (Wada *et al.*, 1979).

Gel textural properties

From TPA curves, typical textural parameters were generated to indicate textural properties of the WF and WF-RBF gels studied (Table 3). On the contrary, a sagging phenomenon was noted in RBF gels. "Gels" formed were not self-standing, thus no textural properties were obtained for RBF gels.

WF gel had a hardness value of 40.65 N. Low

level of RBF substitution WF-RBF (80W:20B and 60W:40B) gels were significantly ($P < 0.05$) harder than WF gel. Rigidity of starch gel is highly dependent on retrogradation of gelatinised starch granules, syneresis of water and crystallisation of amylopectin (Miles *et al.*, 1985). Therefore, presence of certain level of soluble carbohydrates from RBF in blended flour with relatively high starch content could enhanced starch gel retrogradation that would gave rise to harder gels (Maxwell and Zobel, 1978; Chang and Liu, 1991). However, the hardness of gels would decrease progressively with increasing RBF substitution, particularly when RBF substitution level is more than 60%. As the level of RBF substitution increased, starch content in composite flour gel decreased hence reducing the amount of gelatinised starch granules undergoing retrogradation. Therefore, the hardness of 20W:80B gel was significantly ($P < 0.05$) lower than those of WF gel and was the lowest among all the free-standing gels tested.

Adhesiveness is the energy required to overcome the attractive forces between the surface of the food and the surface of the other materials with which the food comes in contact (Szczeniak, 2002). WF gel possessed the highest adhesiveness value. It was noted that a significantly ($P < 0.05$) lower adhesiveness value of WF-RBF gels when compared to WF gels. Substitution of WF with RBF yielded less sticky gels.

Springiness relates to the rate at which a product physically springs back to its original condition after the deforming force is removed (Szczeniak, 2002). All WF-RBF possessed similar ($P > 0.05$) springiness in comparison to WF, suggesting that partial substitution of WF with RBF had very little influence on the overall wheat starch gel's "rubbery" feeling in the mouth.

Cohesiveness is the extent to which a material can be deformed before it ruptures (Szczeniak, 2002). WF gel exhibited the highest cohesiveness value among all of the samples. The cohesiveness of composite flours gel was significantly ($P < 0.05$) lower than WF gel when it was substituted with more than 40% of RBF in the formulation. In general, gradual decrease in the adhesiveness and cohesiveness of WF-RBF gels was noted with an increase level of RBF substitution, suggesting the occurrence of dilution effect of starch content in WF-RBF.

Chewiness was defined as the energy required to masticate a solid food to a state for swallowing (Szczeniak, 2002). As indicated on Table 3, low level of RBF substitution in WF had little effect ($P > 0.05$) on the chewiness of the gels. However, significant ($P < 0.05$) decrease in chewiness of the

Table 3. Textural properties¹ of wheat flour, ripe banana flour and wheat-ripe banana composite flours gels

Sample ²	Hardness (N)	Adhesiveness (N mm)	Springiness	Cohesiveness	Chewiness (N)
WF	40.65 ± 2.38 ^a	255.52 ± 83.53 ^a	0.28 ± 0.04 ^a	0.33 ± 0.03 ^a	3.85 ± 1.03 ^a
80W:20B	47.01 ± 0.41 ^a	189.15 ± 37.68 ^{ab}	0.29 ± 0.01 ^a	0.31 ± 0.01 ^a	4.18 ± 0.08 ^a
60W:40B	46.57 ± 1.44 ^a	141.89 ± 38.64 ^b	0.26 ± 0.01 ^a	0.27 ± 0.02 ^b	3.40 ± 0.15 ^{ab}
40W:60B	41.34 ± 1.36 ^b	121.25 ± 39.11 ^b	0.27 ± 0.01 ^a	0.24 ± 0.01 ^c	2.78 ± 0.07 ^{bc}
20W:80B	37.50 ± 0.58 ^c	99.94 ± 17.78 ^b	0.25 ± 0.02 ^a	0.22 ± 0.01 ^c	2.15 ± 0.29 ^c
RBF ³	N.M.	N.M.	N.M.	N.M.	N.M.

Notes: N.M. = Not measurable

¹Comparison within the columns was shown in the table with the data written as mean ± standard deviation (n = 3). Means followed by the different superscript letter (a-c) are statistically significant at the 5% level.

²WF = wheat flour; RBF = ripe banana flour; W:B = ratio of wheat flour to ripe banana flour.

³No free-standing gels were able to be formed. Hence, no measurements for textural properties were recorded

gels were recorded when the substitution of RBF in WF reached at least 60% (w/w). Hence, at high level of RBF substitution, the gels tend to get softer.

Conclusion

Partial substitution of WF with RBF caused changes in physicochemical, pasting and gel textural properties of composite flours due to the introduction of high-soluble carbohydrate RBF into the WF and the diluting effect of starch in WF. The outcome from this study suggested that the threshold substitution limit of RBF in WF was ~40% (w/w), with minimal effect on the pasting and textural properties while at the same time enhancing the nutritional values of the products. As RBF substitution level exits above 40% (w/w), there would be insufficient level of gelatinised starch in the formulation and this could affect the overall structure of the food products being developed.

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