International Food Research Journal 29(5): 1101 - 1109 (October 2022)
Journal homepage: *http://www.ifrj.upm.edu.my*

Nutritional and functional characterisation of flour from six plantain (*Musa* spp.) cultivars grown in Benin

[1]*Honfo, F. G., [1]Togbe, E. C., [2]Dekker, M., [1]Akissoe, N. and [1]Ahohuendo, B. C.

[1]*Faculté des Sciences Agronomiques, Université, d'Abomey-Calavi, BP 2819 Jericho Cotonou, Benin*
[2]*Food Quality and Design, Wageningen University, PO Box 8129, 6700 EV Wageningen, the Netherlands*

Article history

Received:
27 March 2020
Received in revised form:
13 December 2021
Accepted:
20 February 2022

Keywords

plantain,
vitamin C,
swelling power,
β-carotene,
viscosity

Abstract

Plantain flour is a promising functional ingredient of various domains in the food industry. The present work investigated the functional attributes and proximate composition of flours derived from six plantain cultivars from Benin, and evaluated their nutritional composition. Among the cultivars, proximate composition of the flours varied in moisture, ash, protein, and fibre ranging from 4.59 - 6.85, 2.01 - 2.56, 2.54 - 3.47, and 0.95 - 1.37% (dry basis), respectively. Significantly higher β-carotene contents (± 9 µg) were found in flours from Orishele and Pelipita cultivars, whereas flours from Aloga 2M and Kpahissi cultivars yielded the highest content of vitamin C (9.64 µg). Flour from Kpahissi cultivar exhibited higher water and oil absorption capacity (161.29 and 81.29%, respectively) than the other flours. In addition, higher viscosity, emulsion, and foaming capacities were recorded in flour from Kpahissi cultivar. Flours from different plantain cultivars differed in their physicochemical and functional properties, and could, therefore, be used in various food domains. In that respect, Kpahissi, Orishele, and Aloga 2M flours could be more suitable in the formulation of particular composite flour for specific uses having good functional parameters such as water and oil absorption, viscosity, emulsion, and foaming capacities.

DOI
https://doi.org/10.47836/ifrj.29.5.12

Introduction

Banana and plantain are important perennial crops cultivated in tropical and sub-tropical regions worldwide (Swennen and Vuylsteke, 2001). These crops belong to the genus *Musa* of the family Musaceae, and majority of their existing varieties are derived from two wild species: *M. acuminata* and *M. balbisiana* (Salunke, 1984). In sub-Saharan Africa, the consumption of banana and plantain covers at least 25% of the energy requirement of 70 million people (FAOSTAT, 2017). In 2017, the production of plantain and banana in West Africa was estimated at nearly 39 million tons, with an overall mean growth rate of 1.7% per annum, due to an increase in cultivated areas combined with an increase in yields (FAOSTAT, 2017). For the growing human populations, plantain represents a staple crop as it plays an important role in food and nutritional security, while providing means for income diversification, and tools for poverty reduction. On the nutritional side, plantain is rich in carbohydrates, dietary fibres, β-carotene, vitamins C and B, as well as minerals such as calcium and iron (Ngoh Newilah, 2005). Plantain alone provides between 9 and 35% of the total amount of calories in the diets of more than 14 million people in sub-Saharan Africa (Ngoh Newilah, 2005). Mature unripe plantain pulp is very rich in starch (14 - 23%, wet basis), and considered as a promising source of starch for the food industry (da Mota *et al.*, 2000). For other uses, plantain is often processed into flour after being dried as chips. Drying is the common method or technique used to extend the shelf life of agricultural products, and to reduce the transport cost through a reduced mass to be transported (Artharn *et al*, 2009). With the increased production and use of plantain flour, new economic strategies are now being considered, such as its use as functional ingredients in various food domains. Plantain flour is a good substitute for wheat flour for gluten-intolerant persons, to whom wheat flour causes irritation in the digestive systems (Aziz *et al.*, 2014). It can, therefore, be used in the preparation of breads, biscuits, and other bakery products. However, the level of utilisation of plantain flour in the food industry is primarily governed/conditioned by the

*Corresponding author.
Email: fernandehonfo@gmail.com

knowledge of its physicochemical and functional properties. According to Chandra and Samsher (2013), functional properties of a food product are those characteristics that determine the behaviour of nutrients of such product during processing, storage, and cooking as they affect the quality and acceptability of the end-products. Although some data have been published on the functional, physicochemical, and pasting characteristics of plantain (Fagbemi, 1999; da Mota *et al*., 2000; Onwuka and Onwuka, 2005; Mepba *et al*., 2007), most of these articles focused on flour from only one variety of plantain, and, therefore, did not cover the variability among cultivars.

In Benin, the annual production of plantain is around 19,000 tons (Chabi *et al*., 2018). This production occurs mainly in the southern and central regions of Benin (Chabi *et al*., 2018), where this crop plays a significant role in the local economy. About 14 local and hybrid cultivars are produced and sold at various stages of maturity (Gandonou *et al*., 2012; Chabi *et al*., 2018). Cultivars such as Aloga, Aloga 2M, Gnivlan, and Kpahissi accounted for more than 80% of the total production, followed by Orishele and Pelipita (Chabi *et al*., 2018; Kpenavoun Chogou *et al*., 2019). Most of these cultivars are easily commercialised due to their characteristics, including the size of the fingers, colour, and firmness of the pulp, that are highly preferred by consumers (Kpenavoun Chogou *et al*., 2019). In Benin, the processing of plantain into flour remains scarce due to the lack of information among plantain processors on the possibility of using plantain flours as a substitute to wheat flour in many products. As a consequence, no data on flours derived from plantain cultivated in Benin is available in the literature. In addition, most studies on plantain in Benin are just limited to the determination of some macronutrients and information on functional parameters, while micronutrients such as β-carotene and vitamin C composition are often missing. However, such information is important for the nutritional quality improvement of products derived from different formulations of banana, plantain, and wheat flours.

The present study aimed at investigating the macro- and micronutrients composition, and the functional properties of plantain flours derived from six cultivars commercially grown in Benin. The outcomes will provide useful information in the selection of the best cultivars, whose flours could be incorporated in different combinations with other flours for various food uses.

Materials and methods

Processing

Six plantain cultivars commonly produced in Benin, namely Aloga, Aloga 2M, Gnivlan, Kpahissi, Orishele, and Pelipita were selected for the study due to their availability on the markets, and their high demand by consumers. Two bunches of each cultivar were randomly harvested at the commercial stage (mature and unripe), in one plantain plantation in the southern Benin in 2019. Flours were produced spontaneously from the pulp from each cultivar after washing, peeling, slicing (2 - 3 mm of thickness), immersing in water containing lemon juice (1 - 2%) to prevent enzymatic browning (Gbadamosi and Oladeji, 2013), and then oven-drying at 55°C for 5 h, followed by milling, sieving, and packaging. Samples were stored at 4°C until further analyses.

Determination of physicochemical parameters of plantain flours

The colour of the plantain flours was analysed using a Hunter colorimeter (Hunter Associates Laboratory Inc., Reston, VA, USA) on the basis of L*, a*, and b* values. Moisture, ash, fat, fibre, and protein (N × 6.25) contents were assessed by using the standard methods of analysis described by AOAC (2002). Carbohydrate content was determined by difference through the following formula: (100 – [%protein + %lipid + %fibre + %Moisture + %ash]).

β-carotene was extracted by the method developed by Sadler *et al.* (1990), coupled with that of Fish *et al*. (2002). This method is based on hexane-acetone-ethanol extraction and HPLC analysis using a reversed phase YMC 30 column (250 × 4.6 mm; S-5), with a gradient of methanol:methyl tert-butyl ether eluent at flow rate of 1.05 mL/min.

Vitamin C (ascorbic acid) extraction was performed using the method adapted from Hernández *et al.* (2006). Samples (equivalent to 0.05 g dry matter) were mixed with 3.5 mL of metaphosphoric acid (MPA) and tert-butylhydroquinone (THBQ) solution (3% MPA, 1 mM THBQ in Milli-Q water) by using an Ultra Turrax. After 5 min at 3,000 rpm and 4°C, the supernatant was collected in a new tube. The pellet was re-extracted twice with 3.5 mL of the MPA and THBQ solution, and after centrifugation, the supernatants of each sample were collected in the same tube. To determine the total of vitamin C, 15 µL of tris-2-carboxyethyl phosphine solution (1 M in Milli-Q water) was added to 1.485 mL of the prepared extract as described earlier. After incubation in the dark at room temperature for 20 min, the samples were analysed by HPLC (Varian Polaris column; C18, 4.6 × 150 mm). With a flow rate of 1 mL/min, and an injection volume of 20 µL, elution was performed by a gradient of phosphoric acid (purity ≥ 85 g/100 g; Merck Millipore) at 0.2 g/100 g in Milli-Q water. The amount of vitamin C was expressed as ascorbic acid equivalents in mg/100 g dry weight contents.

All the analyses were conducted in triplicate.

Determination of functional parameters of plantain flours

Swelling power (SP) at 80°C, and water absorption capacity (WAC) at ambient temperature were determined following the method described by Beuchat (1977). Oil absorption capacity (OAC) was determined using the method of Beuchat (1977). Emulsion capacity (EC) was determined using the method described by Yasumatsu *et al.* (1972). Foam capacity (FC) was determined using a slight modification of the method described by Narayana and Narsinga (1982). For that, 1 g of the sample was added into 50 mL distilled water at 30 ± 2°C in a graduated cylinder. The suspension was mixed and shaken for 5 min to foam. The volume of foam at 30 s after whipping was expressed as FC. Apparent (bulk) density was determined by the method of Jones *et al*. (2000). Apparent viscosity was measured by dissolving appropriate sample in distilled water (2, 6, and 10%). The mixture was mechanically stirred for 2 h at room temperature, and the viscosity was measured with a viscometer (Anton Paar, 501) at 100 rpm for 5 min. Apparent viscosity was then calculated as the mean of the different measures recorded for each sample. Gelation capacity (GC) was determined following the method described by Sathe *et al*. (1982). In test tubes, 5 mL solutions of flours and distilled water were prepared at 4, 6, 8, 19, 12, 12, 14, 16, 18, and 20% concentrations. The mixtures were heated for 1 h in boiling water, followed by rapid cooling under cold running water. The tubes were further cooled at 4°C for 2 h. The least gelation concentration (LGC) was taken when the sample in the inverted test tube did not fall down or slip.

Statistical analyses

All results were expressed as mean values of three separate determinations ± standard error of the mean. Comparison of means among plantain cultivars' parameters was performed using a one-way analysis of variance (ANOVA) followed by Student-Newman-Keuls test ($p < 0.05$). Statistical analyses were run using SPSS software (IBM 22).

Results and discussion

Nutrient composition of plantain flours

Plantain flours were characterised by their moisture (4.59 - 6.85%), ash (2.01 - 2.56%), fat (0.34 - 0.76%), protein (2.54 - 3.47%) and fibre (0.95 - 1.37%) contents on dry basis, as presented in Table 1. The moisture contents in plantain flours were globally lower than the standard moisture content for wheat flour (15.5%) (Codex, 2019a) and maize flour (13.5%) (Codex, 2019b). High moisture content usually subjects food items to increased microbial spoilage, quick deterioration, and short shelf life. So, the plantain flours tested in our study should, fortunately, be resistant to microbial spoilage and should have a longer shelf life than wheat and maize

Table 1. Proximate composition of flours from different plantain cultivars.

Cultivar	Moisture (%)	Ash (%)	Fat (%)	Protein (%)	Fibre (%)	Carbohydrate (%)
Aloga	6.17 ± 0.06^b	2.01 ± 0.01^c	0.65 ± 0.05^b	2.99 ± 0.05^b	1.28 ± 0.02^b	88.19 ± 0.32^b
Aloga 2M	4.80 ± 0.02^e	2.02 ± 0.07^c	0.76 ± 0.02^a	3.47 ± 0.11^a	1.36 ± 0.03^a	88.95 ± 0.22^a
Gnivlan	4.86 ± 0.02^d	2.56 ± 0.01^a	0.53 ± 0.02^c	3.06 ± 0.06^b	1.15 ± 0.02^c	88.99 ± 0.12^a
Kpahissi	5.35 ± 0.02^c	2.23 ± 0.12^b	0.34 ± 0.02^d	2.92 ± 0.11^b	1.28 ± 0.03^b	89.16 ± 0.18^a
Orishele	4.59 ± 0.04^f	2.02 ± 0.12^c	0.61 ± 0.03^b	2.54 ± 0.08^c	1.37 ± 0.02^a	90.23 ± 0.98^a
Pelipita	6.85 ± 0.03^a	2.24 ± 0.01^b	0.67 ± 0.02^b	2.66 ± 0.09^c	0.95 ± 0.01^d	87.57 ± 0.21^b

Data are mean ± standard error of mean (SEM). Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

flours. However, some differences were observed in the nutritional composition of these flours. Significantly higher values of fat and protein were found in the flour from Aloga 2M cultivar, while low values of these components were found in the flours from Kpahissi and Orishele cultivars. The mean values of protein, lipid, fibre, and ash contents reported herein are in line with those reported earlier for plantain flours (da Mota, 2000; Kaur and Singh, 2005; Rodriguez-Ambriz *et al*., 2008), but were lower than those observed by Mepba *et al*. (2007). Moreover, the moisture, ash, and fibre contents reported herein are similar to those recorded by Fagbemi (1999) in flour from blanched plantain, and by Yomeni *et al*. (2004) in some plantain cultivars in Cameroon.

With regards to β-carotene (provitamin A) and vitamin C contents, significant variations were found among plantain flours. Higher values of β-carotene were observed in flours from Orishele and Pelipita cultivars, while higher values of vitamin C were detected in flours from Aloga 2M and Kpahissi cultivars (Figure 1). Apart from the value recorded in Kpahissi flour, β-carotene contents of flours from the other cultivars were higher than those recorded in some hybrid plantains flours (4.79 µg/100 g) (Adeniji *et al*., 2006).

Flour colours were characterised by the lightness (L*), redness (a*), and yellowness (b*). L* value was significantly affected by plantain cultivar, ranging from 75.72 (Pelipita) to 84.03 (Orichele) (Table 2).

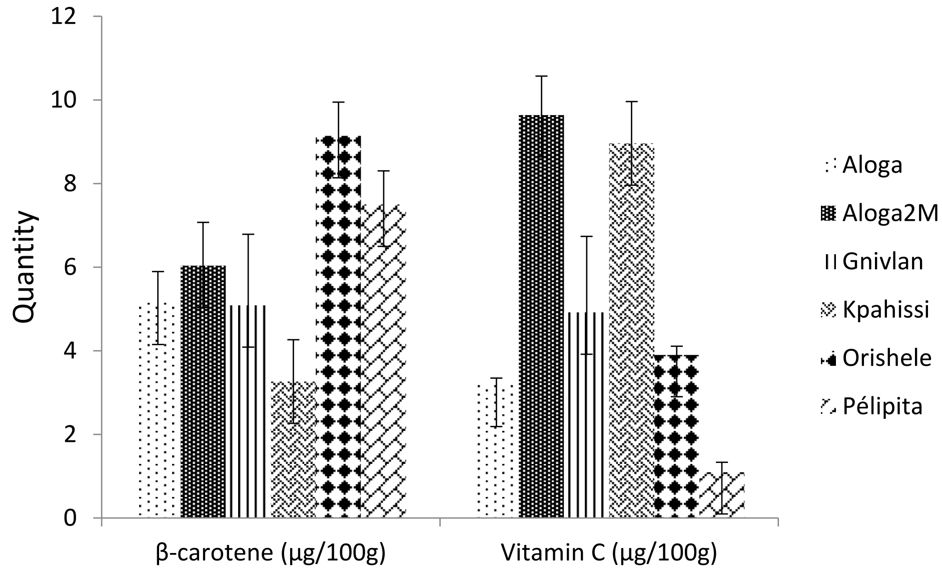

Figure 1. Mean values of β-carotene and vitamin C of flours from different plantain cultivars.

Table 2. Colour characteristics of flours from different plantain cultivars.

Cultivar	L*	a*	b*	ΔE
Aloga	77.88 ± 0.10[b]	-0.72 ± 0.02[c]	9.81 ± 0.14[b]	27.21 ± 0.01[b]
Aloga 2M	80.25 ± 0.03[a]	-1.02 ± 0.01[d]	11.23 ± 0.00[a]	24.67 ± 0.02[b]
Gnivlan	76.41 ± 0.06[b]	-0.34 ± 0.01[b]	10.32 ± 0.01[b]	27.90 ± 0.01[b]
Kpahissi	79.14 ± 0.06[a]	-1.37 ± 0.00[e]	7.96 ± 0.00[c]	27.48 ± 0.23[b]
Orishele	84.03 ± 0.05[a]	-1.20 ± 0.01[d]	12.27 ± 0.01[a]	21.86 ± 0.01[b]
Pelipita	75.72 ± 0.04[b]	0.17 ± 0.01[a]	11.71 ± 0.01[a]	40.96 ± 23.12[a]

Data are mean ± standard error of mean (SEM). Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$).

Similarly, a* value varied significantly among plantain cultivars, and ranged from -1.37 (Kpahissi) to 0.17 (Pelipita). Negative values of a* were found for all flour samples apart from the flour from Pelipita cultivar. The value of b* varied significantly among cultivars, and ranged from 7.96 (Kpahissi) to 12.27 (Orishele). Yellow and red colours of fruits and legumes are generally linked to their β-carotene contents; thus, higher values of b* and a* in flours from Pelipita and Orishele cultivars might indicate a high content of β-carotene as compared to other cultivars. The values of ΔE that indicate the total colour difference of flours ranged from 21.86 - 40.96. Pelipita flour had the highest value of ΔE, thus indicating a high colour difference of the flour derived from this cultivar. The differences observed in colour characteristics of plantain flours could be attributed to specific characteristics of each cultivar coupled with the agro-climatic variabilities.

Functional characteristics of plantain flours

The swelling power (SP) at 80°C differed significantly among flours from plantain cultivars, ranging from 3.49% (Aloga) to 4.58% (Orishele) (Table 3). The water absorption capacity (WAC) at ambient temperature also differed significantly among flours from plantain cultivars, with the highest values observed in flours from Kpahissi and Orishele cultivars (Table 3). SP and WAC are linked to the capacity of flour to absorb water under various conditions: a high WAC enables the processor to add more water to the flour during food preparation, and favours its use as a soup thickener. Both parameters depend on particle sizes, cultivar types, and processing methods (Dendegh *et al*., 2019). However, according to Hodge and Osman (1976), flours with high SP and WAC have more hydrophilic constituents such as polysaccharides. Similarly, Ihekoronye and Ngoddy (1985) stated that higher SP and WAC values are often associated with higher carbohydrate contents, especially starch contents in the plantain flour, whose complex molecule will require more water during hydrolysis. This assertion was evidenced with the high content of carbohydrates in the flour from Orishele cultivar assessed in the present work. On the culinary side, flours from both Kpahissi and Orishele cultivars seem to be more suitable for bakery products with regards to their capability to absorb more water than flours from the other cultivars assessed. The values of WAC and SP reported herein are similar to those obtained by Fagbemi (1999), Mepba *et al*. (2007), Ayo-Omogie *et al*. (2010), and Arinola *et al*. (2016) for plantain flours.

The oil absorption capacity (OAC) of flours differed significantly among cultivars (p = 0.029), and varied from 68.85% (Aloga) to 81.29% (Kpahissi) (Table 3). Values reported herein are lower than those obtained by Awoyale *et al*. (2016) in plantain flours stored in different conditions, and by Chandra *et al*. (2015) in composite flours. According to Kinsella (1976), the OAC of flours is an important characteristic as it improves the mouth feel and retains the flavour. Therefore, the relatively high values of oil absorption capacities of flours from Kpahissi, Orishele, and Aloga 2M cultivars suggest that flavour retention might be high, and that they might be useful in food preparations that involve oil mixing like in bakery products where oil is an important ingredient.

Table 3. Functional properties of flours from different plantain cultivars.

Cultivar	SP (%)	WAC (%)	OAC (%)	FC (%)	EC (%)	BD (%)
Aloga	3.49 ± 0.08^b	128.47 ± 0.31^c	68.85 ± 0.41^b	12.41 ± 0.19^b	9.10 ± 0.22^c	0.77 ± 0.09^a
Aloga 2M	3.56 ± 0.05^b	122.33 ± 0.37^c	71.88 ± 0.23^b	13.44 ± 0.21^a	9.77 ± 0.16^b	0.80 ± 0.10^a
Gnivlan	3.71 ± 0.08^b	126.40 ± 0.42^c	70.36 ± 0.45^b	11.26 ± 0.13^c	8.85 ± 0.21^c	0.68 ± 0.11^a
Kpahissi	4.03 ± 0.06^a	161.29 ± 0.33^a	81.29 ± 0.32^a	14.02 ± 0.14^a	15.10 ± 0.36^a	0.71 ± 0.06^a
Orishele	4.58 ± 0.06^a	147.34 ± 0.51^b	76.51 ± 0.68^b	12.26 ± 0.21^b	9.97 ± 0.32^b	0.76 ± 0.04^a
Pelipita	3.83 ± 0.08^b	116.48 ± 0.31^c	69.38 ± 0.48^b	9.49 ± 0.25^d	5.67 ± 0.31^d	0.77 ± 0.02^a

Data are mean ± standard error of mean (SEM). Means followed by different lowercase letters in the same column are significantly different ($p < 0.05$). SP: swelling power, WAC: water absorption capacity, OAC: oil absorption capacity, FC: foaming capacity, EC: emulsion capacity, and BD: bulk density.

The foam capacity (FC) of flours differed significantly among cultivars. The highest value was observed with Kpahissi flour (14%) followed by that of Aloga 2M, while the lowest value (9.49%) was noticed in Pelipita flour (Table 3). Similar values were found in wheat flour (Chandra *et al.*, 2015), while higher values were detected in composite flours (Adeleke and Odedeji, 2010; Chandra *et al*., 2015). High FC is essential in food processing, and often correlates with protein contents (Chandra and Samsher, 2013). In the present study, this correlation was not significant ($r = 0.342$, $p = 0.560$); this could be explained by the low value of proteins in the different flours investigated. Chandra *et al.* (2015) revealed that the mixture of many flours may improve FC.

A significantly higher emulsion capacity (EC) was observed in flour from Kpahissi cultivar (15.10%) as compared to those from other cultivars (Table 3). This relatively high value is comparable to those found in wheat flour by Adeleke and Odedeji (2010), thus suggesting that in composite flour, wheat flour might increase the EC. However, this assumption remains to be investigated for a better formulation of flour composed of plantain and wheat. EC values around 9% was observed in the other flours, except for that of Pelipita cultivar (5.67%). Elsewhere, Chandra *et al*. (2015) reported that EC and OAC values increased with decreasing proportions of wheat flour in composite flour. In addition, high EC and OAC values are beneficial in baking products such as cakes and biscuits that require emulsion and reaming properties (Onwuka and Onwuka, 2005).

The bulk density (BD) of flours is defined as the density measured without the influence of any compression. BD ranged from 0.68 - 0.80% (Table 3). No significant differences were observed among cultivars; however, higher values were found in flours from Aloga 2M, Aloga, and Pelipita cultivars, whereas the lowest value was recorded in flour from Gnivlan cultivar. Similar values of BD have been previously reported for wheat flours (Mepba *et al*., 2007; Adeleke and Odedeji 2010; Islam *et al*., 2012). Dendegh *et al*. (2019) observed that BD depends on particle size and initial moisture contents of the flour. In addition, Joshi *et al*. (2015) stated that BD is influenced by lipid and moisture contents. This assumption is consistent with the positive and significant correlation observed between BD and moisture content ($r = 0.761$, $p = 0.031$) reported herein. A high BD of flours suggests their suitable use in food preparations, while a low BD is desired in the formulation of baby foods where high nutrient density is required (Mepba *et al.*, 2007).

Apparent viscosity values increased from 2 - 10% concentration of flour, irrespective of plantain cultivars (Figure 2). At 6% concentration, flour from Kpahissi cultivar yielded the highest value of apparent viscosity, while flour from Gnivlan cultivar yielded the highest value at 10% concentration. Apparent viscosity is often dependent on the starch component, and Kpahissi as well as Orishele flours exhibited high value of carbohydrates. However, higher apparent viscosities were observed by Fagbemi (1999) in blanched plantain flours.

The least (minimum) gelation concentration is defined as the lowest protein concentration at which gel remains in the inverted tube, and this is used as the index of gelation capacity (Dendegh *et al*., 2019). For this parameter, Pelipita flour formed a gel at a concentration of 8%, lower than those of the other cultivars (Table 4). The same trend was observed with the total gel concentration which was at 16% with flour from Pelipita cultivar, and at 18% with the other flours. Similar values of least gelation concentration were detected in composite flours by Chandra *et al*. (2015). The lower the least gelation concentration, the better is the gelating ability of the protein ingredient (Akintayo *et al*., 1999). However, according to Singh (2001), the gelation capacity of flours is generally influenced by a physical competition for water between protein gelation and starch gelatinisation. Therefore, variations in the gel-forming capacity of the flours, and in other functional characteristics could be attributed to the variation in constituents such as protein and fat; thus suggesting that interactions between such components have a significant role in the functional properties of plantain flours (Cristina *et al*., 2004).

Conclusion

Considering the nutritional characteristics such as protein, fibre, vitamin C, and β-carotene of the plantain cultivars tested in the present work, the best plantain cultivars for making flours were Aloga 2M, Gnivlan, and Aloga. With regards to the values of

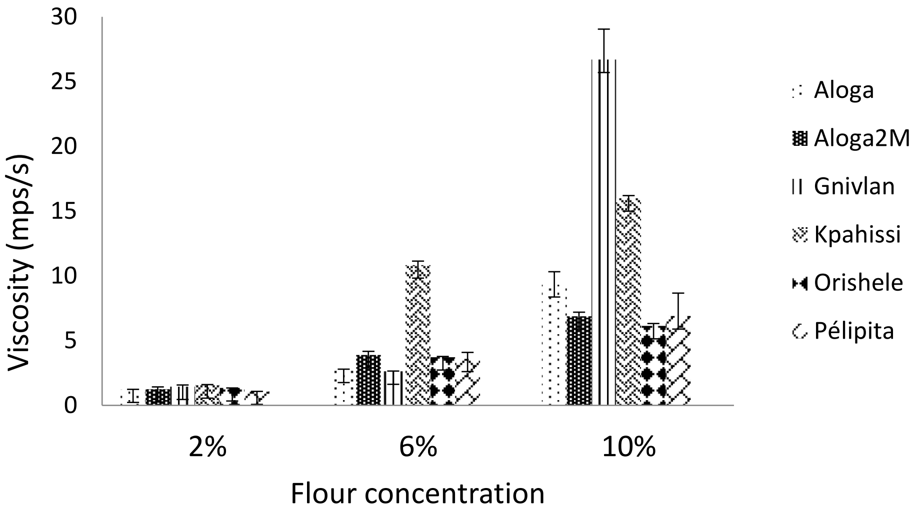

Figure 2. Apparent viscosity of flours from different plantain cultivars (mps/s).

Table 4. Gelation concentration of flours from different plantain cultivars.

Concentration (%)	Cultivar					
	Aloga	Aloga 2 Main	Gnivlan	Kpahissi	Orishele	Pelipita
6	-	-	-	-	-	-
8	-	-	-	-	-	Gel
10	Gel	Gel	Gel	Gel	Gel	Gel
12	Gel	Gel	Gel	Gel	Gel	Firm gel
14	Firm gel	Firm gel	Firm gel	Firm gel	Gel	Firm gel
16	Firm gel	Firm gel	Firm gel	Firm gel	Firm gel	Very firm gel
18	Very firm gel	Very firm gel	Very firm gel	Very firm gel	Very firm gel	Very firm gel
20	Very firm gel	Very firm gel	Very firm gel	Very firm gel	Very firm gel	Very firm gel

- : no gel observed.

apparent viscosity, emulsion, and foaming, Kpahissi flour was the most suitable in composite flours for food formulations. Further, Kpahissi, Orishele, and Aloga 2M flours could serve as ingredients in gluten-free food formulations.

Acknowledgements

The present study was carried out as part of the project “Avlanto-Benin” funded by Food & Business Applied Research Fund (ARF). Grateful appreciation is extended to the Food Quality Design Group (FQD) of Wageningen University for their invaluable assistance in the vitamin C, β-carotene, and viscosity analyses.

References

Adeleke, R. O. and Odedeji, J. O. 2010. Functional properties of wheat and sweet potato flour blends. Pakistan Journal of Nutrition 9: 535-538.

Adeniji, T. A., Sanni, L. O., Barimalaa, I. S. and Hart, A. D. 2006. Determination of micronutrients and colour variability among new plantain and banana hybrids flour. World Journal of Chemistry 1: 23-27.

Akintayo, E. T., Oshodi, A. A. and Esuoso, K. O. 1999. Effect of NaCl, ionic strength and pH on the foaming and gelation of pigeon pea (*Cajanus cajan*) protein concentrates. Food Chemistry 66: 51-56.

Arinola, S. O., Ogunbusola, E. M. and Adebayo, S. F. 2016. Effect of drying methods on the chemical, pasting and functional properties of unripe plantain (*Musa paradisiaca*) flour. British Journal of Applied Science and Technology 14: 1-7.

Artharn, A. Prodpran, T. and Benjakul, S. 2009. Round scad protein-based film: Storage stability and its effectiveness for shelf-life extension of dried fish powder. Food Science and Technology 42: 1238-1244.

Association of Official Analytical Chemists (AOAC). 2002. Official methods of analysis of AOAC International.16th ed. United States: AOAC.

Awoyale, W., Maziya-Dixon, B., Alamu, O. E. and Menkir, A. 2016. Effect of packaging materials and storage conditions on the degradation of xanthophylls in yellow-maize ogi powder. Journal of Nutrition and Food Research 4(8): 522-527.

Ayo-Omogie, N. H., Adeyemi, A. I. and Otunola, T. E. 2010. Effect of ripening on some physicochemical properties of cooking banana (*Musa ABB* Cardaba) pulp and flour. International Journal of Food Science and Technology 45: 2605-2611.

Aziz, I., Lewis, N. R., Hadjivassiliou, M., Winfield, S. N., Rugg, N., Kelsall, A., ... and Sanders, D. S. 2014. A UK study assessing the population prevalence of self-reported gluten sensitivity and referral characteristics to secondary care. European Journal of Gastroenterology Hepatology 26: 33-39.

Beuchat, L. R. 1977. Functional and electrophoretic characteristics of succinylated peanut flour protein. Journal of Agricultural and Food Chemistry 25: 258-261.

Chabi, C. M., Dassou, G. A., Dossou-Aminon, I., Ogouchoro, J., Omondi Aman, B. and Dansi, A. 2018. Banana and plantain production systems in Benin: Ethnobotanical investigation, varietal diversity, pests, and implications for better production. Journal of Ethnobiology and Ethnomedicine 14: 1884-1902.

Chandra S., Singh, S. and Kumari, D. 2015. Evaluation of functional properties of composite flours and sensorial attributes of composite flour biscuits. Journal of Food Science and Technology 52: 3681-3688.

Chandra, S. and Samsher, S. 2013. Assessment of functional properties of different flours. African Journal of Agricultural Research 38: 4849-4852.

Codex. 2019a. Codex Standard 152-1985 - standard for wheat flour. Rome: Food and Agriculture Organization (FAO).

Codex. 2019b. Codex Standard 155-1985 - standard for degermed maize (corn) meal and maize (corn) grits. Rome: Food and Agriculture Organization (FAO).

Cristina, M., Monte, G., Elsa, R. and Giugliani, J. 2004. Recommendations for the complementary feeding of the breastfed child. Journal of Pediatrics 80: 131-141.

da Mota, V. R., Lajolo, M. F., Ciacco, C., Beatriz, R. and Cordenunsi, B. R. 2000. Composition and functional properties of banana flour from different varieties. Starch 52: 63-68.

Dendegh, T. A., Ukeyima, M. and Dendegh, R. A. 2019. Proximate composition, functional and sensory properties of pearl millet, soy flour and baobab fruit pulp composite flour as a complementary food. Asian Food Science Journal 8: 1-11.

Fagbemi, N. T. 1999. Effect of blanching and ripening on functional properties of plantain (*Musa aab*) flour. Plant Foods for Human Nutrition 54: 261-269.

FAOSTAT. 2017. Plantain banana production. Rome: Food and Agriculture Organization (FAO).

Fish, W. W., Perkins-Veazie, P. and Collins, J. K. 2002. A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. Journal of Food Complementary Analysis 15: 309-317.

Gandonou, G., Ahanhanzo, C., Agbangla, C., Agbidinoukoun, A., Doussoh, A., Cacai, G. and Dossoukpevi, R. 2012. *In vitro* micro-propagation of the local variety "Aloga" of plantain (*Musa x paradisiaca* L.) in Benin. International Journal of Biology and Chemistry Sciences 6: 1102-1111.

Gbadamosi, S. O. and Oladeji, B. S. 2013. Comparative studies of the functional and physico-chemical properties of isolated cassava, cocoyam and breadfruit starches. International Food Research Journal 20(5): 2273-2277.

Hernández, Y., Lobo, M. G. and González, M. 2006. Determination of vitamin C in tropical fruits: A comparative evaluation of methods. Food Chemistry 96: 654-664.

Hodge, J. C. and Osman, E. M. 1976. Carbohydrates. In Fennema, R. O. (ed). Principles of Food Science, Part I - Food Chemistry, p. 97-200. New York: Marcel Dekker.

Ihekoronye, A. I. and Ngoddy, P. O. 1985. Integrated food science and technology for the tropics. 1st ed. London: Macmillan Publishers Ltd.

Islam, M. Z., Taneya, M. L., Shams-Ud-Din, M., Syduzzaman, M. and Hoque, M. M. 2012. Physicochemical and functional properties of brown rice (*Oryza sativa*) and wheat (*Triticum aestivum)* flour and quality of composite biscuit made thereof. Agriculturists 10: 20-28.

Jones, D., Chinnaswamy, R., Tan, Y. and Hanna, M. 2000. Physiochemical properties of ready-to-eat breakfast cereals. Cereal Foods World 45: 164-168.

Joshi, A. U., Liu, C. and Sathe, S. K. 2015. Functional properties of select seed flours. LWT - Food Science and Technology 60: 325-331.

Kaur, M. and Singh, N. 2005. Studies on functional, thermal and pasting properties of flours from different chickpea (*Cicer arietinum* L.) cultivars. Food Chemistry 91: 403-411.

Kinsella, J. E. 1976. Functional properties of proteins in foods: A survey. Critical Review in Food Science and Nutrition 7: 219-232.

Kpenavoun Chogou, S., Abokini, E., Togbe, E., Ahohouendo, A., Odjo, C., Egounlety Biokou, A. G., ... and Ahohuendo, C. B. 2019. Reference study of the Avlanto-Benin Project - investigation report. Cotonou, Benin.

Mepba, D. H., Eboh, L. and Nwaojigwa, S. U. 2007. Chemical composition, functional and baking properties of wheat-plantain composite flours. African Journal of Food Agriculture and Nutrition Development 7: 1-22.

Narayana, K. and Narsinga, R. M. S. 1982. Functional properties of raw and heat processed winged bean (*Psophocarpus tetragonolobus*) flour. Journal of Food Science 42: 534-538.

Ngoh Newilah, G. 2005. Food use, physicochemical and biochemical characterization of the fruits of some cultivars and hybrids of bananas and plantains produced in Cameroon. Cameroon: Université de Yaoundé, PhD thesis.

Onwuka, G. I. and Onwuka, N. D. 2005. The effects of ripening on the functional properties of plantain and plantain based cake. International Journal of Food Properties 8: 347-353.

Rodriguez-Ambriz, S. L., Islas-Hernández, J. J., Agama-Acevedo, E., Tovar, J. and Bello-Perez, L. A. 2008. Characterization of a fibre-rich powder prepared by liquefaction of unripe banana flour. Food Chemistry 107: 1515-1521.

Sadler, G., Davis, J. and Dezman, D. 1990. Rapid extraction of lycopene and β-carotene from reconstituted tomato paste and pink grapefruit homogenates. Journal of Food Science 55: 1460-1461.

Salunke, D. K. 1984. Banana and plantain. In Salunke, D. K. and Desai, B. B. (eds). Postharvest Biotechnology of Fruits, p. 43-57. Boca Raton: CRC Press.

Sathe, S. K., Desphande, S. S. and Salunkhe, O. K. 1982. Functional properties of winged bean (*Psophocarpus tetragonolobus*) proteins. Journal of Food Science 47: 491-495.

Singh, U. 2001. Functional properties of grain legume flours. Journal of Food Science and Technology 38: 191-199.

Swennen, R. and Vuylsteke, D. 2001. Bananier. In Raekemaekers, R. H. (ed). Agriculture en Afrique Tropicale, p. 611-637. Bruxelles: DGCI.

Valmajor, R., Anno, A., Malina, V. R., Singh, R. H. and Ndubizu, T. O. C. 1976. Plantain production system. Parasidiaca 1: 7-11.

Yasumatsu, K., Sawada, K., Maritaka, S., Toda, J., Wada, T. and Ishi, K. 1972. Whipping and emulsifying properties of soy bean products. Agriculture Biology and Chemistry 36: 719-727.

Yomeni, M. O., Njoukam, J. and Tchango Tchango, J. 2004. Influence of the stage of ripeness of plantains and some cooking bananas on the sensory and physicochemical characteristics of processed products. Journal of the Science of Food and Agriculture 84: 1069-1077.