PHYSICOCHEMICAL CHARACTERIZATION OF 3 CULTIVATED IVORIAN PLANTAIN COMMONLY USED FOR MAKING LOCAL DISHES SUCH *FOUTOU* AND *FOUFOU*

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ABSTRACT

Plantain is an important food crops consumed by several people worldwide. In many countries, semi ripe plantain are often used for traditional dishes. Chemical composition ((ash, protein, fat, total sugars, resistant starch (RS), total starch (TS), carotenoids, polyphenols) as well as color parameters and cooking quality of the most cultivated and consumed plantain in Côte d'Ivoire : Corne 1, French 2 and Orishele at stage 5 of ripening (more yellow than green) were determined. Their gelatinization properties were also analyzed. Corne 1 variety contained the most ash, phosphorus, magnesium and sodium and the least amount of protein. Its pulp recorded the highest a* value (signifying a more intense red color), it absorbed the least water during cooking and had high enthalpy of gelatinization. Orishele variety contained the most total sugars, iron and potassium. The color of its pulp is the most saturated and recorded the highest b* value (corresponding to a more pronounced yellow color) and its temperature of gelatinization is the highest. French 2 variety contains the most total polyphenols, calcium, total starch, and resistant starch. Its pulp is the lightest (high L* value). However, all varieties have similar levels of total carotenoids and have the same yellow-orange color. This study provides physicochemical properties for different plantain varieties useful to improve their processing and assess to their nutritional value.

Keywords : Plantain, ripening, composition, cooking parameters, gelatinization properties,

RESUME

***CARACTERISATION PHYSICOCHIMIQUE DE 3 PLANTAINS IVOIRIENS CULTIVES, COURAMMENT UTILISES POUR LA PREPARATION DE PLATS LOCAUX TELS QUE LE* FOUTOU *ET LE* FOUFOU**

La banane plantain est une denrée alimentaire importante, consommée par plusieurs peuples à travers le monde. Dans de nombreux pays, les bananes plantain moyennement mûres sont souvent utilisées pour les préparations de plats traditionnels. La composition chimique (cendres, protéines, graisses, sucres totaux, amidon résistant (RS), amidon total (TS), caroténoïdes, polyphénols) ainsi que les paramètres de couleur et de qualité de cuisson des bananes plantain les plus cultivées et consommées en Côte d'Ivoire : Corne 1, French 2 et Orishele au stade 5 de mûrissement (plus jaune que vert) ont été déterminés. Leurs propriétés de gélatinisation ont également été analysées. La variété Corne 1 contenait le plus de cendres, phosphore, magnésium et sodium et le moins de protéines. Sa pulpe présentait la plus forte valeur de a (signifiant une couleur rouge plus intense), elle a absorbé le moins d'eau au cours de la cuisson et avait l'enthalpie de gélatinisation (Δ H) la plus* *élevée. La variété Orishele contenait le plus de sucres totaux, fer et potassium. La couleur de sa pulpe était la plus saturée et présentait la plus forte valeur de b* (correspondant à une couleur jaune plus prononcée) et sa température de gélatinisation était la plus élevée. La variété French 2 renfermait le plus de polyphénols totaux, calcium, amidon total et amidon résistant. Sa pulpe était la plus claire (valeur de L* élevée). Cependant, toutes les variétés avaient des teneurs en caroténoïdes totaux similaires et la même couleur jaune-orange. Cette étude fournit les propriétés physicochimiques de différentes variétés de plantains utiles pour améliorer leur traitement et estimer leur valeur nutritionnelle.*

Mots clés : *Plantain, mûrissement, composition, paramètres de cuisson, propriétés de gélatinisation*

INTRODUCTION

Plantain plays an important role in the economy and food security of many worldwide wet tropical regions (FAO, 1988). In Côte d'Ivoire, the annual production of plantain was estimated at about 1,35 Mt in 2010 (Lescot, 2010) and plantain consumption reaches about 120 kg / inhabitant / year. Plantain is the third basic foodstuff after yams and cassava (Ducroquet, 2002) and it is the main staple food in producing regions.

More than 150 subgroups of plantain are cultivated in Central and West Africa (Lescot, 2010) and they are classified in four types according to the type of bunch: French, French Horn, False Horn, and True Horn (Tezenas du Montcel *et al.,* 1983). A wide range of plantain varieties is grown in Côte d'Ivoire. Local varieties such as Afoto or Corne 1 (False Horn), Ameléthia (French Horn), Kpatrégnon (True Horn), and Agnrin or French 2 (French) are among the most consumed varieties. Horn-type plantain represents 90 % of plantain production (Agbo *et al.,*1996) and Corne 1 is the most cultivated. French varieties have high production yields but consumers prefer Horn varieties for their large fingers.

Plantain fruits are usually consumed unripe, semiripe and ripe after cooking in diverse forms like *foutou* and *foufou*. *Foutou* is a sticky paste obtained after cooking and pounding in a mortar of peeled banana fingers and cassava roots, whereas *foufou* is a plastic paste obtained by cooking and crushing in a mortar peeled plantain fingers in addition to palm oil. These dough-like foods are frequently consumed by Ivorian and other African people in worldwide.

Plantain variety and degree of ripeness are important factors for the acceptability of processed products by consumers (Dzomeku *et al.,* 2006). A preliminary survey conducted in 2015 by the authors on inhabitants of Abidjan (Côte d'Ivoire) indicated that both Horn and French varieties were preferred for *foutou* making, whereas Horn varieties were judged more suitable for *foufou* making (data not shown). Also, semiripe plantain at stage 5, i.e. more yellow than green (Emaga *et al.,* 2007), is the most used degree of ripeness for these dishes. Browning is observed in many plants during ripening, handling, storage, and post-harvest processing and affects the nutritional quality and sensory properties of food products due to color and flavor changes (Martinez and Whitaker, 1995), thereby reducing the consumer acceptability. Food color is a quality and acceptance criterion for consumers. The main sources of food browning during processing are chemical discoloration caused by copper, iron, manganese, traces of heavy metals, natural pigments (chlorophylls, carotenoids, anthocyanins, etc.), as well as reactions like the Maillard reaction, which corresponds to the condensation of reducing sugars with amino acid groups occurring at high temperatures (Utomo *et al.,* 2008), the caramelization of sugars and the enzymatic oxidation of phenols into brownish compounds (Manzocco *et al.,* 2000).

Several researches were published on physicochemical, biochemical properties and nutritional values of many unripe plantain varieties (Eggleston *et al.*, 1992; Coulibaly *et al.,* 2007; Gibert *et al.*, 2009), but little information is available on the characterization of the semiripe plantain.

The purpose of this study is to determine the physicochemical properties of plantain varieties Corne 1, French 2 and Orishele to carry out actions needed to process them and predict the quality of the final product. Moreover, this study may add to our understanding of properties of semiripe plantain.

MATERIAL AND METHODS

VARIETIES AND FRUIT SAMPLES

Corne 1 (False Horn), French 2 (French), and Orishele (False Horn) plantain varieties were grown in a farm located in Azaguié (Côte d'Ivoire, 5°37'40''N, 4°5'12''W) at 50 km east of Abidjan. They were all harvested at a stage of maximal maturity, i.e. when at least one ripe fruit appeared on the bunch (Mitra, 1995) in June. Starting from the flowering date, this harvesting stage corresponded to 80 days for the Corne 1 and French 2 varieties and 70 days for the Orishele variety. Three bunches by variety were harvested and carried to the laboratory, where fruit samples were collected from the second hand from the proximal end of the bunch, following the recommendation of Baiyeri and Oritz (2000). The fruits were then placed on wooden pallets, sprayed with a solution containing 20 % ethylene glycol (Sigma-Aldrich, Steinheim, Germany) and 80 % water (Goonatilake, 2008) and covered with a black tarpaulin for artificial ripening to stage 5, more yellow than green. This stage is obtained two days after spraying of the solution. Cooking quality and color parameters were determined using fresh pulp.

FLOUR PREPARATION

Thin slices (2 cm thickness) of fresh plantain pulps were dried in a ventilated oven (Memmert, Schwabach, Germany) at 40 °C for 48 h. Dried slices were ground at 12000 rpm in an ultracentrifugal mill ZM 200 (Retsch, Haan, Germany) equipped with a sieve with 1 mm trapezoid holes. Then, flours were stored at 4 ° in polyethylene containers for compositional, thermal and structural properties determination.

COLORIMETRIC ANALYSIS AND COOKING QUALITY PARAMETERS DETERMINATION

Color measurement of fresh pulp of each variety were determined with a spectrophotometer Datacolor Microflash 4,0 (Datacolor International, Switzerland) using the L* a* b* colour system. L* represents the sample luminosity, varying from black (0) to white (100) ; a* represents the color varying from green (-) to red (+) ; the value for b* represents the color varying from blue (-) to yellow (+). The pulps were cut into slices of 2 cm thick and immediately placed into petri dishes (60 mm diameter and 15 mm height) and the cover was placed on their top. The light source was placed above the covered petri dish before carrying out the measure. The values of chroma (C*) and hue angle (h*) for each sample were also calculated using the following formulas (Flores-Silva *et al.,* 2015) :

$$h^* = \arctan (b^*/a^*)$$

$$C^* = \sqrt{a^2 + b^2}$$

Cooking was performed as described by Kouadio *et al.* (2011). The fresh pulps were cut into small pieces of 10 mm. 30 g of these pieces were weighed per sample and cooked in 500 ml boiling water for 20 min. The cooked pieces were collected in a 1 mm mesh sieve, immersed 10 times in cold water, and allowed to stand for 2 min. The last drops under the sieve were removed with a blotting paper. For dry matter determination, 30 g of the fresh pulp were weighted. Cooked and fresh pieces were dried at 70 °C for 15 h and then at 103 °C for 3 h in a vacuum oven (Heraeus, Hanau, Germany). Cooking quality parameters, i.e.dry matter (DM), water absorbed during cooking (WA), soluble dry matter during cooking (SDM) and water absorption capacity (WAC), were calculated per 100 g of raw matter on wet basis.

BIOCHEMICAL CHARACTERIZATION

Moisture, ash and crude fat contents of flour samples were determined by standard methods developed by the Association of Official Analytical Chemists (AOAC, 1990).

Total protein content was determined through the quantification of total nitrogen by Kjeldahl method. The conversion coefficient of banana nitrogen content into total proteins was 5,32 (Gibert *et al.,* 2009).

Total sugar content was determined by the phenol-sulfuric acid method (Dubois *et al.*, 1956). Sugars concentration was estimated at 540 nm using a UV/visible spectrophotometer (Milton Roy Spectrophotonic, USA), and a glucose (1 g/L) standard curve.

Total starch (TS) content was measured using K-TSTA 04/09 kit Megazyme (Libios, Pontcharra-sur-Turdine, France), according to « E determination » for samples containing resistant starch, D-glucose, and/or malto-dextrins. Flour (≈ 100 mg ± 0.5 mg dried basis (db)) was dispersed in a centrifuge tube containing 5 mL of 80 % (v / v) ethanol. The tubes were incubated for 5 min at 80 - 85 °C and homogenized on a vortex. Ethanol solution (5 ml) was added to each tube. Tubes were centrifuged at 1500 g for 10 min and, the supernatants were discarded. The operation was carried out twice. A magnetized bar and 2 ml of KOH (2 M) were added to each tube. Tubes were placed in an ice-water bath and stirred for 20 min with a magnetic stirrer. 8 ml of sodium acetate buffer (1.2 M, pH 3.8), 0.1 ml of α-amylase, and 0,1 ml of amyloglucosidase were added to each tube, tubes were homogenized on a magnetic stirrer, and incubated in a water bath at 50 °C for 30 min. They were then centrifuged at 1500 g for 15 min and the supernatants recovered. Supernatant (0.1 ml) was transferred to a tube and glucose oxidase-peroxidasereagent (goPod, 3 ml) was added. The mixture was incubated at 50 °C for 20 min and the absorbance was measured at a wavelength of 510 nm. The total starch content was determined by multiplying the glucose content by 0.9 (glucose to starch conversion factor).

Resistant starch (RS) was determined with K-RSTAR 09/14 kit Megazyme (Libios). Flour (≈100 ± 0,5 mgdb) was incubated with 10 ml HCl-KCl buffer (pH 1.5) and 200 µl pepsin solution (100 mg /ml HCl-KCl buffer) at 40 °C for 1 h with constant shaking. Subsequently, sample was incubated with pancreatic α-amylase (10 mg/ml sodium maleate buffer ; pH 6.0) containing amyloglucosidase (3.300 U) for 16 h at 37 °C with constant shaking. After hydrolysis, sample was washed thrice with ethanol. The separated pellet from super-natant was further digested with KOH (2M), and then incubated with amyloglucosidase. Glucose released was measured like described previously for starch determination by using a goPodreagent, and applying the factor of 0.9.

Total polyphenols were extracted from a total of 1.0 g of flour with methanol-water (80 : 20 v/v, 50 ml g^{-1} sample) acidified with HCl (2N, 0.1 % p/v), 120 min at room temperature (20 ± 2 °C) under constant stirring. After centrifugation (15 min, 20 °C, 1800 g) supernatants were pooled and used to determine extractable polyphenols by the Folin-Ciocalteu procedure (Singleton *et al.,* 1999). The results were expressed as gallic acid equivalents (mg GAE/g dry matter).

Total carotenoids were spectrophotometrically quantified using the method described by Rodriguez-Amaya (1999). A total of 5.0 g (db) of flour was homogenized with 50.0 ml acetone, and 150.0 mg magnesium carbonate for 10 min, then the mixture was filtered with whatman no 1 filter paper through a buchner funnel. This was repeated until the residue was devoid of color. The acetone extract was transferred in a separatory funnel containing 40.0 ml of petroleum ether, and approximately 300 ml of distilled water was added lettingto avoid formation of an emulsion. The two phases were allowed to separate and the lower, aqueous phase was discarded. The whole setup was washed 3 - 4 times with distilled water to remove residual acetone. The petroleum ether phase was collected in a volumetric flask, making the solution pass through a small funnel containing anhydrous sodium sulfate (≈15 g) to remove residual water. The volume was made up to 25 ml with petroleum ether and the absorbance read at 450 nm.The total carotenoid content was calculated from the following equation (de Carvalho *et al.,* 2012) :

$$Total\ carotenoids(\mu g/g) = \frac{A \times V \times 10^4}{A_{1cm}^{1\%} \times M}$$

A : absorbance of extract, V : volume of extract (25 ml), $A_{1cm}^{1\%}$: extinction coefficient of ß-carotene in petroleum ether (2 592 $l.mol^{-1}.cm^{-1}$), M : sample weight (g).

Minerals (potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and phosphorus (P), iron (Fe)) of plantain flour samples were determined with Scanning Electron Microscope/ Energy Dispersion Spectrometry (SEM/EDS), variable pressure DC/AR (SEM FEG Zeiss Supra 40 VP), is equipped with an X-ray detector (Oxford Instruments) connected to a micro analyzer platform EDS (Inca Cool Dry, without liquid nitrogen) as described by Fofie *et al.* (2016). A total of 2.0 g of sample was incinerated, then 10.0 mg of ash are homogeneously spread with double-sided adhesive carbon onto a primed pad and attached to the object holder of SEM/EDS. The whole was introduced into the SEM chamber for microanalysis-RX (EDS).

GELATINIZATION PROPERTIES

Thermal properties of the raw ripe plantain flours were measured using a differential scanning calorimeter, DSC 204 F1 (Netzch, Phoenix, USA) previously calibrated with indium. The gelatinization temperature was evaluated as indicated by Hernández-Jaimes *et al.* (2013) with slight modifications. A total of 6.0 mg (db) of flour was weighed in an aluminium pan and deionised water (12.0 µl) was added. The pans were hermetically sealed, equilibrated in a desiccator for 1 hr then, the mixture was heated in the DSC cell from 30 to 100° C applying a heating rate of 10° C min˙1. An empty pan was used as reference. The onset (T_o), peak (T_p), and end (T_e) gelatinization temperatures, as well as the enthalpy of gelatinization (ΔH expressed in J g˙1), were determined by the Proteus thermal analysis software (Netzch GmbH & Co., Selb, Germany).

STATISTICAL ANALYSIS

The software used for statistical evaluation was Statistica V.8.05 (Stat Soft Inc., Tulsa, Oklahoma). Data were analysed by one-way ANOVA and means values were separated by Turkey's test at p d $\leq$0.05. Experiments were conducted in triplicates and reported values correspond to means ± standard deviations.

Person correlation and principal component analysis (PCA) was performed to determine the relationships between biochemical composition, cooking, and color parameters, and gelatinization properties of plantain varieties with XLSTAT 2017.1 software (Addinsoft, Paris, France).

RESULTS

COLOR PARAMETERS

Color parameters of fresh pulps of semiripe plantains were presented in Table 1. Significant differences ($p < 0.05$) were observed between varieties. Pulps of plantain varieties were rather light as denoted by elevated L* values comprised between 70.5 and 75.5. Relatively high positive values of b* ranging from 37.8 to 42.8 confirmed that the pulps of investigated plantain varieties were yellowish. The a* values were found in the range from 8.8 to 13.3, indicating that plantain pulps were slightly more red than green. Maximal L*, a*, and b* values were obtained for French 2, Corne 1, and Orishele varieties respectively. The value of C* was comprised between 38.7 and 44.8. The color of the Orishele pulp was the most saturated, whereas that of French 2 was the least saturated. The value of h* was found in the ranges of 70.9 (Corne 1) - 77.3 (French 2), indicating that predominant color of pulps of three semiripe plantain studied was yellow-orange.

Table 1 : Colour attributes and cooking quality parameters (g/100 g on wet basis) of raw semiripe plantains

Attributs de couleur et paramètres de qualité de cuisson (g / 100 g sur une base humide) de plantains crus et moyennement mûrs

Samples	Orishele	Corne 1	French 2
L*	70.5^c± 0.8	72.5^b± 0.4	75.5^a± 0.5
a*	10.6^b ± 0.2	13.3^a ± 0.4	8.6^c ± 0.2
b*	42.8^a ± 0.4	37.8^b ± 0.6	38.4^b ± 0.8
C*	44.0^a ± 0.4	40.8^b ± 0.9	38.7^c ± 0.9
Hue	76.0^b ± 0.5	70.9^c ± 0.3	77.3^a ± 0.3
Dry matter (DM)	40.3 ± 0.0^b	38.8^c ± 0.1	42.5^a ± 0.2
Water absorbed (WA)	52.2 ± 0.9^a	41.8^c ± 1.1	48.9^b ± 1.2
Soluble dry matter (SDM)	1.4 ± 0.0^a	1.1^a ± 0.0	1.5^a ± 0.4
Water absorption capacity (WAC)	87.4 ± 1.5^a	68.3^b ± 1.9	85.1^a ± 2.4

Mean values followed by the same letters in the same column are not significantly different at p d $\leq$ 0.05

COOKING QUALITY PARAMETERS

Cooking quality parameters of fresh pulps are presented in Table 1. Plantains Orishele, Corne 1 and French 2 were significantly different ($p< 0.05$) in terms of dry matter. Dry matter of plantains varied from 38.8 (Corne 1) to 42.8 g/100 g (French 2) on wet basis (wb). Corne 1 exhibited significant difference in pulp water absorption capacity, and water absorbed (WA) from other varieties, but no significant difference was found between Orishele and French 2. Water absorption capacity (WAC), and water absorbed (WA) were ranged from 68.3 to 87.4 g/100 g wb, and 41.8 to 52.2 g/100 g wb respectively. No significant difference ($p > 0.05$) was found between plantain varieties for soluble dry matter (SDM).

CHEMICAL COMPOSITION

Chemical compositions of the pulp of Orishele, Corne1 and French 2 at stage 5 of ripening are shown in Table 2. Some significant differences between plantain varieties were observed ($p < 0.05$). The ash content of the three varieties of plantain varied from 2.30 to 2.20 g/100 g db. The highest ash content of Corne 1 (2.30 g/100 g db) should subsequently confirm by mineral analysis. No significant difference is observed between Orishele and French 2 regarding ash content. Proteins values varied from 5.53 to 5.73 g/100 g db. The lowest proteins content was observed in Corne 1. No significant difference is observed between Orishele and French 2 for proteins content. Lipids contents were low and the average was 1.00 g/100 g on dry basis. Polyphenols content varied from 844.4 to 1044.3 (EAG mg/kg db). Corne1 had the lowest but French 2 contained the highest polyphenols. Total sugars varied from 7.7g/100 g to 10.7 g/100 db. French 2 had the lowest and Corne 1 had the highest sugars content. TS, and RS values varied from 64.0 to 66.4 g/100 g db and 15.0 to 18.4 g/100 g db, respectively. French 2 had the highest RS value, and Corne 1 had the lowest TS content. Not significant difference was observed between plantain flour for carotenoids content.

Table 2 : Chemical composition of plantains on dry basis

Composition chimique des plantains sur une base sèche

Samples	Orishele	Corne 1	French 2
Ash (g / 100 g)	$2.22^{b} \pm 0.02$	$2.30^{a} \pm 0.04$	2.20 ± 0.01^{b}
Proteins (g / 100 g)	$5.73^{a} \pm 0.01$	$5.53^{b} \pm 0.03$	5.71 ± 0.02^{a}
Fat (g / 100 g)	$1.01^{a} \pm 0.03$	$1.03^{a} \pm 0.07$	$0.97^{a} \pm 0.01^{a}$
Total sugar(g / 100 g)	$10.1^{a} \pm 0.0$	$8.1^{b} \pm 0.1$	$7.7^{c} \pm 0.1^{c}$
TS(g / 100 g)	$64.02^{c} \pm 0.11$	$65.94^{b} \pm 0.35$	$66.45^{a} \pm 0.18$
RS(g / 100 g)	$16.0^{b} \pm 0.3$	$15.0^{c} \pm 0.3$	$18.4^{a} \pm 0.2^{a}$
Total polyphenols (EAG mg/kg)	$977.7^{ab} \pm 0.8$	$844.4^{b} \pm 0.4$	$1044.3^{a} \pm 0.4^{a}$
Total Carotenoid (µg/g)	$5.89^{a} \pm 0.1$	$5.96^{a} \pm 0.1$	$5.96^{a} \pm 0.1^{a}$

TS : total starch, RS : resistant starch. Values followed by the same letters in the same column are not significantly different at $p \leq 0.05$.

Table 3 presents the mineral content of plantain flours. There were significant differences between all samples in mineral. Corne 1 had significantly higher phosphorus (137.5 mg/100 gdb), magnesium (108.7 g/100 g db) and sodium (16.0 mg/100 g db) contents than other plantain varieties. However, Corne 1 had the lowest potassium content. All varieties had high phosphorus contents varying from 108.4 to 137.5 mg/100 g db. Orishele had the highest potassium (1444.4 mg/100 g db) but the lowest phosphorus (108.4 mg/100 g) contents. French 2 flour exhibited the highest calcium (7.08 mg/100 g db), but the lowest magnesium (88.7 mg/100 g db) and sodium (4.9 mg/100 g db) contents.

Table 3 : Mineral content of plantains (mg/100 g on dry basis)

Teneur en minéraux des plantains (mg / 100 g sur une base sèche)

Samples	Phosphorus	Potassium	Magnesium	Calcium	Sodium	Iron
Orishele	$108.38^{c} \pm 1.09$	$1\,444.4^{a} \pm 1.1$	$93.68^{b} \pm 0.04$	$4.60^{b} \pm 1.21$	$11.78^{b} \pm 0.85$	$2.98^{a} \pm 0.03$
Corne 1	$137.50^{a} \pm 1.57$	$1\,284.7^{c} \pm 2.3$	$108.73^{a} \pm 1.21$	$6.19^{ab} \pm 1.33$	$16.02^{a} \pm 0.48$	$1.52^{b} \pm 0.25$
French 2	$132.93^{b} \pm 1.59$	$1\,386.6^{b} \pm 1.9$	$88.73^{c} \pm 0.09$	$7.08^{a} \pm 0.12$	$4.92^{c} \pm 0.12$	$1.43^{b} \pm 0.47$

Mean values followed by the same letters in the same column are not significantly different at p d $\leq$ 0.05.

GELATINIZATION PROPERTIES

Thermal properties of raw ripe plantain flour samples are displayed in Table 4. The Corne 1 variety presented the lowest values for T_o (74.5°C) and T_p (80.0°C), while the Orishele variety exhibited the highest T_o (75.8°C) and T_p (81.1°C) values. Both the varieties had the same T_e. The ÄH values ranged from 5.26 to 7.50 (J/g). Corne 1 had the highest ÄH value, but difference was not observed between Orishele, and French 2 varieties.

Table 4 : Gelatinization properties of plantains

Propriétés de gélatinisation des plantains

Samples	Thernal properties			
	T_o (°C)	T_p (°C)	T_e (°C)	ΔH (J/g)
Orishele	$75.8^{a} \pm 0.6$	$81.1^{a} \pm 0.0$	$86.8^{a} \pm 0.0$	$5.26^{b} \pm 0.30$
Corne 1	$74.5^{b} \pm 0.5$	$80.0^{b} \pm 0.3$	$85.7^{a} \pm 0.4$	$7.50^{a} \pm 0.40$
French 2	$75.3^{ab} \pm 0.1$	$80.6^{ab} \pm 0.4$	$86.1^{a} \pm 1.0$	$5.90^{b} \pm 0.42$

T_o, onset temperature ; T_p, peak temperature ; T_e, end temperature ; ΔH, enthalpy of gelatinization. Mean values followed by the same letters in the same column are not significantly different at p d $\leq$ 0.05

PEARSON CORRELATION COEFFICIENTS

Pearson correlation coefficients between biochemical composition (protein, fat, total sugar, starch, resistant starch), cooking parameter (water absorbed (WA)), and gelatinization properties (peak temperature (Tp), enthalpy (ΔH)) is presented in Table 5. Results showed that water absorbed was strongly positively correlated ($r = 0.95$, $p < 0.05$) to protein content. Also, Tp was very positively correlated to protein content ($r = 0.79$, $p < 0.05$), and total sugars ($r = 0.68$, $p < 0.05$). Enthalpy of gelatinization (ΔH) was strongly negatively related to protein content ($r = -0.91$, $p < 0.05$), and positively with water absorbed (WA) during cooking ($r = 0.91$, $p < 0.05$). Inter-correlations between biochemical parameters indicated that total sugars content was strongly negatively correlated ($r = -0.99$, $p < 0.05$) to total starch content, and very negatively correlated ($r = -0.80$, $p < 0.05$) to resistant starch content. Resistant starch was also very positively related ($r = 0.82$, $p < 0.05$) to total starch content.

Table 5 : Pearson correlation coefficients between protein, lipid, total sugars, total starch, resistant starch, peak gelatinization temperature Tp, enthalpy of gelatinization (ΔH), and water absorbed (WA) during cooking ($p < 0.05$).

Coefficients de corrélation de Pearson entre protéines, lipides, sucres totaux, amidon total, amidon résistant, température de pic de gélatinisation Tp, enthalpie de gélatinisation (ΔH) et quantité d'eau absorbée (WA) pendant la cuisson (p < 0.05)

	Proteins	Fat	Total_sug	Starch	Resist_starch	WAC	Tp	ΔH
Proteins	1	-0.533	0.453	-0.425	0.142	0.950	0.795	-0.907
Fat	-0.533	1	-0.513	0.578	0.258	-0.484	-0.565	0.593
Total_sug	0.453	-0.513	1	-0.989	-0.805	0.618	0.678	-0.638
Starch	-0.425	0.578	-0.989	1	0.821	-0.589	-0.674	0.601
Resist_starch	0.142	0.258	-0.805	0.821	1	-0.065	-0.296	0.118
WAC	0.95	-0.484	0.618	-0.589	-0.065	1	0.840	-0.907
Tp	0.795	-0.565	0.678	-0.674	-0.296	0.840	1	-0.884
ΔH	-0.907	0.593	-0.638	0.601	0.118	-0.907	-0.884	1

PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal component analysis (PCA) performed on physicochemical, and thermal characteristics of plantain varieties is illustrated in Figure 1. The first two components explained 86.56 % of the total variance. Component 1 (CP1) explained the majority (49.60 %) of the variance, whereas component 2 (CP2) explained 36.90 % of the variance.

CP1 was positively related to cooking parameters (DM, SDM, WAC, and WA), gelatinization temperature (T_o, T_p, and T_e), hue angle, total polyphenols, proteins, potassium (K), and iron (Fe) These parameters were opposed on CP1 to ash, fat, magnesium (Mg), sodium (Na), enthalpy of gelatinization (ΔH), and a*. This illustrates on the one hand that, variety which absorbed much water during cooking had high soluble dry matter, proteins and potassium, high gelatinization temperature values, but low lipids, ash, phosphorus and magnesium content, enthalpy of gelatinization, and on the other hand that, variety which had high value of a* (fairly red) had low total polyphenol content.

CP2 was positively related to total starch (TS), resistant starch (RS), calcium (Ca) and L*. These parameters were opposed on CP2 to dry matter (DM), total sugars, sodium (Na), iron (Fe), and 1045/1022, color parameters C*, and b*. This means that variety which had high dry matter content, contained high total starch, resistant starch, and calcium and low ordered structure of starch, amorphous proportion in starch ordered structure, total sugars, sodium and iron. Also, variety with high values of total sugars, color parameters C*, and b* corresponds to a darker sample (i.e. a lower L* value).

The projection of plantain varieties on the components CP1 and CP2 showed that Corne 1 variety was characterized by high ash, magnesium, phosphorus, and sodium contents, and high enthalpy of gelatinization. Its pulp was reddish (high a* value). Orishele variety was characterized by high water absorption capacity and high water absorbed during cooking due to its high protein content. It also contained high total sugars, potassium (K), iron (Fe), and gelatinization temperature. The Orishele pulp was the most yellow (high b* value) and its color was the most saturated (high C* value). The French 2 variety was characterized by high total starch, resistant starch, and calcium (Ca) content. Its pulp had also high hue angle, and L* (lighter) values.

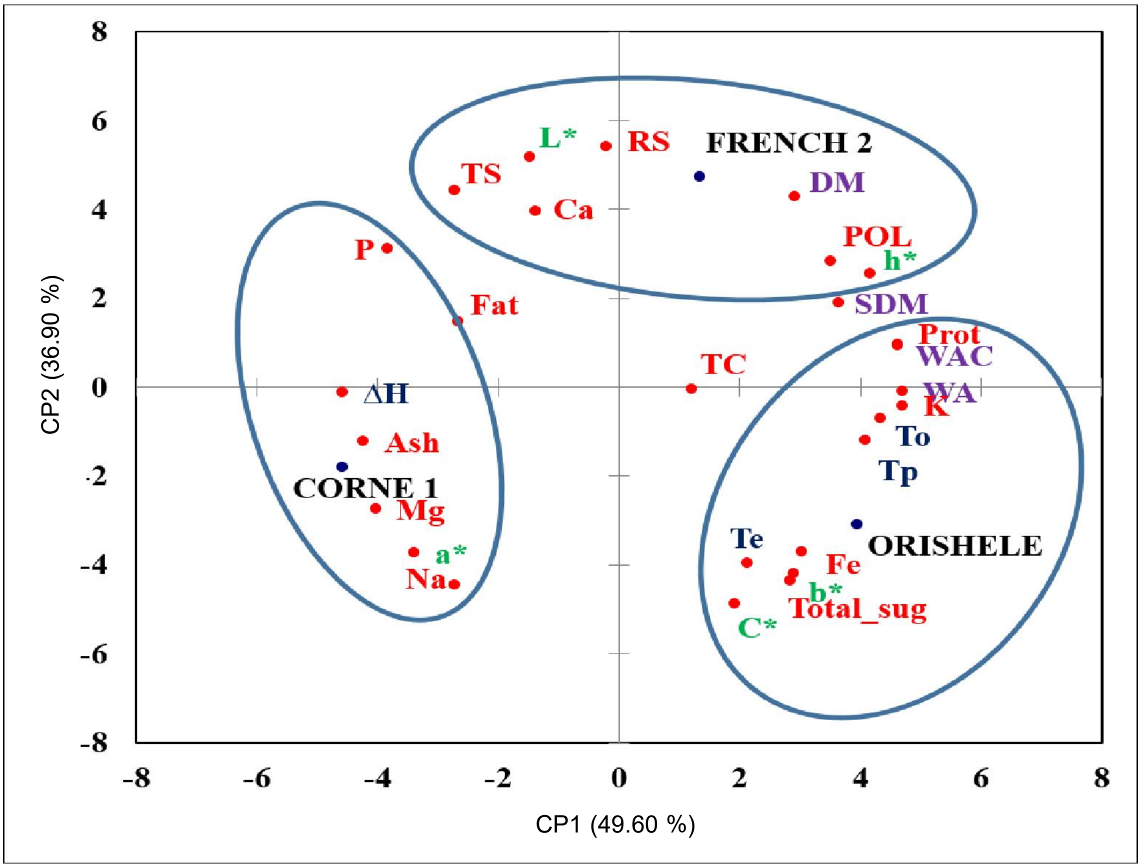

Figure 1 : Principal component analysis (PCA) of cooking, and color parameters, biochemical composition, and gelatinization properties of plantains

Analyse en composantes principales (ACP) des paramètres de la cuisson et de couleur, de la composition biochimique, et des propriétés de gélatinisation des plantains

Dry matter (DM), soluble dry matter (SDM), water absorption capacity (WAC), water absorbed (WA), ash (Ash), proteins (Prot), fat (Fat), total sugar (Total_sug), total starch (TS), resistant starch (RS), total carotenoids (TC), total polyphenols (POL), potassium (K), phosphorus (P), magnesium (Mg), sodium (Na), calcium (Ca), onset gelatinization temperature (T_0), peak gelatinization temperature (T_p), endset gelatinization temperature (T_e), enthalpy of gelatinization (ΔH), , balance green-magneta (a*), balance blue-yellow (b*), brightness (L*), chromacity (C*), hue angle (h*)

DISCUSSION

The values of L* (70.5 - 74.7) and b* (37.8 - 42.7) obtained for fresh pulps of Orishele, Corne 1, and French 2 varieties were higher than L * (62.22 - 68.35) and b * (25.49 - 30.02) values reported by Falade and Oyeyinka (2014) for fresh pulp of Agbagba and Obino l'Ewai varieties at different ripening stages. However, their values of a* (9.04 - 11.06) were quite close to those obtained in this work (8.5 - 13.3). The variation in color between the varieties of plantain would be due to their differences in colored pigment contents. Principal component analysis revealed that the more plantain contains polyphenols, the lower its value of a*. A similar trend was observed by Yodmanee *et al*. (2011) for pigmented rice. Polyphenols induce enzymatic browning reactions. Polyphenoloxidase catalyzed the oxidation of dopamine (abundant phenol in plantain), which causes the browning of fresh or processed products. Browning of plantain adversely affects consumer's acceptability. Moreover, the variation in b* among plantain varieties is related to their sugar and protein content because of their role in non-enzymatic browning (Jamin and Flores, 1998).

The cooking test carried out on the various varieties of plantain studied showed that Orishele and French 2 varieties absorbed the same quantity of water, which was greater than that absorbed by the Corne 1 variety during cooking. A significant positive correlation was observed between the amount of water absorbed and the protein content ($r = 0.95$, $p < 0.05$). Protein and carbohydrate levels would improve the water absorption capacity of food systems due to their hydrophilic constituents with polar or charged side chains (Hodge and Osman, 1976).

Proteins content of different plantain varieties studied (5.6 g / 100 g db) were comparable to that obtained by Odenigbo *et al.* (2013a) for plantain grown in Nigeria at similar stage of ripening (5.0 g / 100 g db). Protein contents of plantain at stage 5 of ripening were higher than those of green plantain (stage 1 and 2) ranging from 2.3 to 3.4 g / 100 g db (Gibert *et al.,* 2009; Eleazu et al., 2011 ; Annor et al., 2016) This confirms the results of Giami and Dismas (1994), and Ayo-Omogi *et al*. (2010) who observed an increase in the protein content of banana during ripening. According to Tressel *et al*. (1975), this increasing would be due to the possible conversion of enzymes and / or protein synthesis during ripening.

Fat contents of different plantain varieties studied (1 g / 100 g DM) was low, but almost twice as high as that reported by Assemand *et al.* (2012) and Odenigbo *et al.* (2013a) for plantain at similar ripening stage. These weak contents indicate that plantain is a very poor lipids fruit.

Total sugars (8.6 g / 100 g db) and total starch (55.9 g / 100 g db) contents of plantain varieties studied were respectively higher and lower than those reported by Gibert *et al*. (2009) for green plantain (stage 1) : 1.5 g / 100 g db and 81.2 g / 100 g db respectively. This is consistent with the fact that total sugars increase during ripening due to the enzymatic hydrolysis of the starch into sugars (Sakyi-Dawson *et al*., 2008). Thus, a very significant negative correlation was found between sugars and total starch contents ($r = -0.99$, $p < 0.05$). At this stage of ripening, the fruits of plantain would have a rather sweet taste.

Resistant starch contents of plantain varieties studied ranged from 15.0 to 18.4 g / 100 g db were higher than those obtained by Odenigbo *et al*. (2013b) for plantain and cooking bananas at similar ripening stage (4.6 - 13.9 g / 100 g db). A strong significant positive correlation was observed between the contents of resistant starch and total starches ($r = 0.82$, $p < 0.05$). This is consistent with the results of Miao et al. (2013).

The high values of polyphenols may be attributed to the degree of ripening of plantain. N'goh *et al.* (2005) reported that polyphenols content increases during ripening. This result indicates a predisposition to browning of semiripe plantain for the three studied varieties. The sensitivity to enzymatic browning of the studied varieties can be assumed to decrease in the following order: French 2 > Orishele > Corne 1.

The carotenoid values of the samples were very close and higher than those obtained by Adegunwa *et al.* (2012) who found 4.29 µg/g on dry basis for semiripe plantain. Carotenoids are also responsible, with phenolic compounds, for variations in color between plants.

The ash content obtained in this study is close to that reported by Assemand *et al.* (2012). All plantain varieties studied had high potassium, magnesium and phosphorus higher than values reported by Assemand *et al.* (2012) for plantain at similar ripening stage (stage 5) and by Coulibaly *et al.* (2007) for unripe plantain. Calcium content obtained by these authors were higher than those of plantain studied. These differences may be due to soil composition and the influence of environmental factors during plant development (Hardisson *et al*., 2001). Ripening would also result in changes in mineral composition (Emaga *et al*., 2007; Baiyeri *et al.,* 2011). Potassium is the most abundant mineral in the pulp of three plantain varieties studied, followed by phosphorus, magnesium, calcium and finally sodium. A similar trend was reported by Adeniji *et al.* (2007).

Gelatinization (onset (T_0), peak (T_p), endset (T_e) temperatures, and enthalpy (ÄH) of plantain studied were respectively higher and lower than the values obtained by Pelissari *et al*. (2012). These differences would be a consequence of the degradation of the starch during pulp ripening. The differences in gelatinization peak temperatures between the varieties would be due to the combined effect of other constituent components. Positive correlations were found between Tp and protein content ($r = 0.79$, $p < 0.05$) and total sugars ($r = 0.68$, $p < 0.05$). Zaidul *et al.* (2008) noted that the presence of suspended proteins provides a protective effect which prevents the entry of water into the starch granules. The sugars could also be attached to the amorphous portion of the starch, which creates bonds between the starch chains and thus delays the gelatinization (Spies and Hoseney, 1982). The enthalpy of gelatinization represents the amount of energy needed to break the molecular interactions within the starch granules during gelatinization (Pelissari *et al.*, 2012).

On the nutritional and technological and in relation to the principal component analysis, the plantain varieties studied have different characteristics. Orishele variety is characterized by the highest levels of iron and potassium. Potassium is involved in muscle formation, carbohydrate metabolism, protein synthesis, hormone secretion, heart regulation and acid-base balance. With sodium and chloride, which are characteristic of the extracellular fluid, potassium determines osmolarity and plays a major role in the distribution of fluids both inside and outside the cell and thus in maintaining the cell volume (Navarro and Vaquero, 2003). Iron participates in a wide variety of metabolic processes, including the synthesis of deoxyribonucleic acid (DNA), the formation of hemoglobin, and the transport of electrons and oxygen (Abbaspour *et al.* 2014). Moreover, the most saturated orange-yellow color of Orishele is required for foods like foutou and foufou.

Corne 1 variety contained the most magnesium, phosphorus and sodium. The importance of magnesium in the human body has been reported by Glasdam *et al.* (2015). Magnesium is used to regulate blood glucose levels, help in the production of energy and proteins, and in the prevention of high blood pressure, heart disease and diabetes. Inorganic phosphate (Pi) plays an essential role in skeletal development, mineral metabolism and various cellular functions involving intermediate metabolisms and energy transfer mechanisms. It is an essential component of bone mineralization, phospholipids in membranes, nucleotides that provide energy and serve as components of DNA and RNA, and phosphorylated intermediates in cell signaling (Takeda *et al.,* 2004). Sodium helps control blood pressure and regulates the function of muscles and nerves.

French 2 variety had the highest levels of resistant starch, total polyphenols and calcium (Ca). Resistant starch has hypoglycemic effects (Han *et al.*, 2003) and cholesterol-lowering (Han *et al.*, 2003 ; Martinez-Flores *et al.*, 2004). It would increase the absorption of calcium and iron (Jenkins *et al.*,1998 ; Jenkins and Kendall, 2000) and lipid oxidation (Higgins *et al.*, 2004). French 2 variety would therefore be a beneficial food for the gastrointestinal tract. It is evident that polyphenols are natural antioxidants which contribute to the reduction of low density lipoprotein levels in the blood, thus reducing certain cancers and cardiovascular diseases. Calcium is involved in bone formation, vascular contraction, vasodilation, muscle function, nerve transmission, intracellular signaling and hormonal secretion (Beto, 2015). Also, because of its high content of polyphenols, French 2 was the most susceptible for enzymatic browning during processing and storage.

Orishele and French 2 varieties absorbed the most water during cooking, which would have an influence on the texture of their products. Indeed, in the presence of excess water and at high temperatures, a high water absorption capacity of the starch leads to the destruction of many granules, which would reduce its viscosity and thus its elasticity. These varieties would therefore be suitable to produce foufou because of the texture of this paste which is plastic (without elasticity). French 2 variety could be proposed, especially to diabetics, for the preparation of the foufou.

The relatively high total carotenoid contents of the plantain varieties studied make them valuable for health. Carotenoids are antioxidants that offer various health benefits, such as reducing the risk of cardiovascular disease, cancer and degenerative diseases (Eleazu *et al.*, 2012). Also, carotenoid pigments such as provitamin A are associated with good human vision. The pigment accumulates in the retina and helps prevent its degeneration and aging (Krinsky and Johnson, 2005).

Low levels of certain nutrients do not allow plantain to cover the needs of the organism on its own. However, it should be emphasized that the consumption of plantain in foutou and foufou is always accompanied by a sauce rich in proteins and minerals.

CONCLUSION

The study of biochemical composition and physicochemical properties revealed many significant differences ($p<0.05$) between plantain varieties.

Corne 1 variety had the highest value of a *, the highest ash, phosphorus, magnesium and sodium ; the lowest protein content ; the lowest water absorption capacity during cooking, and the highest value of enthalpy of gelatinization. Orishele variety had the highest levels of total sugars, and potassium, as well as the highest values of b *, C * and peak gelatinization temperature. French 2 variety had the highest levels of total polyphenols, total and resistant starch, calcium, and L *value. However, all varieties have the same total carotenoid contents and have the same yellow-orange color.

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