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Effect of Ripening on Physicochemical Composition of Plantain Cultivars and *Musa* Hybrids Grown in Cameroon

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ABSTRACT

Fruits from 11 local plantain cultivars and four plantain hybrids were evaluated for some physicochemical changes during ripening. At harvest, peel thickness and fruit grade as well as fruit length varied considerably according to *Musa* type, but the local plantain cultivar *Biya 2* exhibited the highest values (4.20 mm, 5.93 cm and 43.60 cm, respectively). During post harvest maturation of the fruits, pulp to peel ratio, total soluble extracts and total titratable acidity of the pulps increased significantly while firmness, pH and dry matter content of the pulps decreased considerably and sometimes significantly. All the parameters investigated varied significantly according to plantain cultivars and hybrids. Coupled with pulp colour, fruit grade and length as well as sensorial and nutritional qualities are important elements that enable processors to obtain high quality products and breeder's decisions during the creation and selection of new plantain hybrids.

Keywords: plantains, postharvest, physicochemical properties, ripening

INTRODUCTION

Bananas and plantains are members of the *Musaceae* family and provide a dessert fruit (banana) or a starch staple food (plantain) to millions of people in the world. They rank amongst citrus, pome fruit and grapes as major international trading commodities (Turner 1997). Most cultivars of the edible plantains are triploid (genomic group AAB) and are derived from *M. acuminata* (A) and *M. balbisiana* (B), genomes of *Musa acuminata* and *M. balbisiana* (Simmonds and Shepherd 1955). In Cameroon, plantain production in 2009 was estimated at 1.4 million tonnes (FAO 2011). Plantains are cultivated in tropical and subtropical regions around the world and are classified into four main types: French, French horn or Bâtard, False horn and True horn (Tézenas du Monctcel 1985; **Fig. 1**). The African Research Centre on Bananas and Plantains (CARBAP) based in Njombé – Cameroon host the world reference field collection of bananas and plantains, including a unique set of more than 150 plantain cultivars. Most of these accessions are unknown by the world population. However, these varieties are susceptible to pests and diseases, and it is for this reason that *Musa* breeding programs create plantain hybrids that show variable levels of resistance to pests and diseases as well as improved yield.

In Cameroon, plantains are consumed fresh as desserts at ripen stages for some cultivars or processed (into boiled pulps, fried pulps, dried pulps, pounded pulps, etc.) either at green or ripen stages for almost all cultivars. They are generally eaten cooked or boiled green/unripe and eaten as a vegetable, fried when ripe or unripe to make fried-ripe-plantains or chips, baked when ripe or green, mashed, etc. (Ngoh Newilah *et al.* 2005a). The rate at which *Musa* fruits ripen and the changes in composition that occur during ripening are significant in determining how long they remain useful for specific processing methods.

Reviews on the postharvest aspects of *Musa* fruits physiology have become more frequent over the last 40 years. The frequent occurrences reflect the need to describe and evaluate the increasing rate of progress being made in this area. Many studies have being carried out around the world in relation to dessert bananas focusing on their composition during ripening, postharvest biochemistry and physiology, biochemistry of ripening. John and Marchal (1995) re-

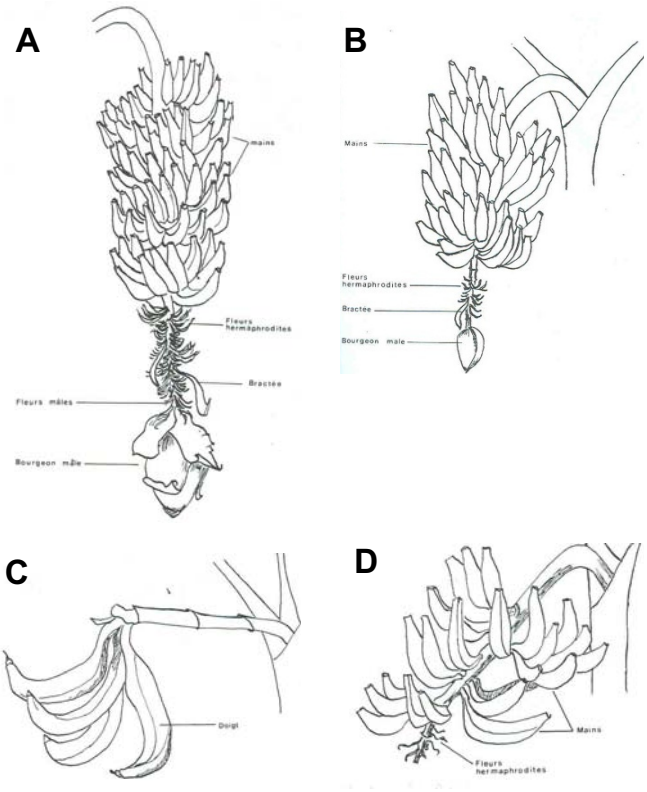

Fig. 1 Some plantain types. (Source: Tezenas du Montcel, 1985). (**A**) "French géant" type; (**B**) "French moyen" type; (**C**) "true horn" type; (**D**) "false horn" type.

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viewed the biochemistry and ripening of bananas and plantains; which dealt with the preclimacteric phase and the environmental factors that affect it, before describing the biochemical changes associated with ripening. In some African countries, studies have been carried out concerning *Musa* physico-chemical evaluation. Burdon *et al.* (1991) reported the rate of plantain ripening and the changes during ripening for three Nigerian plantain cultivars. Onyejegbou and Ayodele (1995) found that the stage of ripeness of the fruits affects the quality of plantain chips. Collin and Dalnic (1991) and Aboua (1991) described changes in plantain cultivars grown in Ivory Coast and Asiedu (1987) studied some plantain varieties in Malawi. These authors observed a significant increase in the pulp to peel ratio during ripening. In Cameroon, Ngalani *et al.* (1998) evaluated changes in major plantain cultivars grown commercially compared with a dessert and a cooking banana. They found that the dry matter contents of the pulp of the analysed plantain cultivars were significantly higher than those of cooking and dessert bananas and that they did not change significantly from stage 1 to stage 7. Recently, Ngoh Newilah *et al*. (2009) evaluated the significant physicochemical changes that occur during postharvest maturation of 14 dessert and cooking banana cultivars. Also, a preliminary study has been carried out in CARBAP related to the effects of early fruit development and ripening on physiological parameters of 3 *Musa* types including a plantain named *French sombre* (Ngoh Newilah *et al.* 2010).

In order to stimulate the food and breeding uses of plantains as well as to complete their agronomic characterisation, the Post Harvest Technology Laboratory of CARBAP (in the framework of its characterisation activities) decided to make available information concerning physicochemical composition during ripening of the largest plantain collection and the new hybrids created by the breeding programme of CARBAP as well as that from FHIA (Fundación Hondureña de Investigación Agrícola) been grown in Cameroon. Thus, this study aimed to evaluate the evolution of some physicochemical parameters of eleven local plantain cultivars and four plantain hybrids during their postharvest maturation (ripening) at ambient temperature.

MATERIALS AND METHODS

Materials

Eleven local plantain cultivars: 'Bâtard' (BTD), 'Big ebanga' (BE), 'Biya 2' (B2), 'Essong' (ESS), 'Elat' (EL), 'French clair' (FC), 'French sombre' (FS), 'Kelong mekintu' (KM), 'Mbouroukou 1' (MBK1), 'Mbouroukou 3' (MBK3), 'Red yade' (RY) and four plantain-hybrids: 'A11' (A11), 'CRBP 39' (C39), 'CRBP 755' (C755), 'FHIA 21' (F21), from different *Musa* genomic groups were considered. The local plantain cultivars chosen are representatives of the various plantain types available at CARBAP – Cameroon, hosting a unique set of more than 150 plantain cultivars.

Sampling

An experimental plot (with a completely randomised block design) was settled in 2003 in CARBAP. The total duration of the experiment was 2 years. It contained 32 cultivars of *Musa*, each variety being represented by 12 plants divided in 2 bands. The follow up of these plants was done based on CARBAP's recommendations (CARBAP 2002).

Plantain bunch was harvested when a ripe fruit appeared on its first hand. In the laboratory, fruits from the second and third hands were randomised, collected and sorted according to external colour of the peel (Dadzie and Orchard 1997) into 4 maturation stages: full green (initial or stage 1), green with yellow points (start ripe or stage 3), yellow with green ends (ripe or stage 5) and entirely yellow with black points (fully ripe or stage 7).

Physicochemical analysis

The pulp firmness was measured using a manual penetrometer (*Cosse* model) on the 2 halves of the fruit according to Dadzie and Orchard (1997) and the results were expressed in kg/cm². Fruit length was determined by measuring the outer curve of individual fruit with a tape from the distal end to the point at the proximal end where the pulp is judged to terminate. Fruit girth or circumference and peel thickness were determined by measuring respectively individual fruit with a tape at the widest midpoint of each fruit and peel with a pair of calliper.

Preparation of pulp aqueous extract

At each ripening stage, 15 g of pulp tissues were collected from the medium part of the fruit and grinded within 2 min in an electric blender with 45 ml distilled water. The pulp juice was obtained after filtration using Whatman No. 1 paper.

Refractive index of pulp juice (RI)

A single drop of the filtrate was placed on the prism of a refractometer (REF 113, Brix range from 0–32% at 20°C) that was finally pointed towards a light source and the percentage of total soluble solids (TSS) is obtained by multiplying the recorded value by three as indicated in the formula (Dadzie and Orchard 1997):

$$\% \text{ TSS (g/l)} = 3IR - 0.8$$

pH and total titratable acidity (TTA)

The pH of the pulp juice was measured with a bench top pH meter (Inolab, pH level 2), while total titratable acidity was ascertained manually by titration with 0.1 N sodium hydroxide until the phenolphthalein indicator just changes pink/red. The temperature of the laboratory ranged from 24 to 25°C during analysis. The results are expressed as milliequivalent per 100 g sample in terms of malic acid, which is the predominant acid present in bananas and plantains (Josylin 1970):

$$C_{ATT} \text{ (mEq/100 g)} = (400/11) \times V_{NaOH\ 0,1N}$$

Peel and pulp dry matter content

Dry matter content was determined by oven drying at 105°C for 24 h of a known quantity of peel or pulp.

Statistical analysis

Three replications on at least five individual samples from different bunches per cultivar were analysed for each parameter. Analysis of variance was performed using the statistical package, SAS version 8.2 for Windows (SAS 2001). The means were compared at $P < 0.05$ using the Student Newman Keul's test.

RESULTS AND DISCUSSION

Fruit girth, length and peel thickness

In Cameroon, fruit girth is an important criterion for householders during selection of plantain cultivars for specific uses. For example, ESS, FC and FS are preferred during processing of *Kondre*, a specific meal of the *Bamiléké* tribe (Ngoh Newilah *et al.* 2005). The girths of these three local plantain cultivars range from 3.77 to 4.09 cm and are lower compared to 5.93 cm exhibited by B2, a "false horn" plantain that also presented highest values related to fruit length and peel thickness of the fifteen accessions analyzed and that represented the various plantain types (**Fig. 1**). However, F21 exhibited the highest values of fruit girth and length as well as peel thickness among the plantain-like hybrids studied (**Table 1**). Based on the fruit girth and length as well as peel thickness, B2 is considered as a good plantain cultivar for chips manufacturing but the bunch contain less number of fruit compared to other local plantain cultivars

Table 1 *Musa* fruit characteristics at harvest.

Musa type	Genome	Fruit girth (cm)	Fruit length (cm)	Peel thickness (mm)
Plantain hybrids				
A11	AA	3.80 ± 0.09 hijk	24.90 ± 0.62 fghi	2.50 ± 0.10 hi
CRBP39	AAAB	3.85 ± 0.11 ghij	23.00 ± 0.74 hij	3.07 ± 0.13 efgh
CRBP755	AAA	3.03 ± 0.08 mn	16.33 ± 0.57 no	2.91 ± 0.10 fgh
FHIA21	AAAB	4.35 ± 0.20 efg	24.00 ± 1.40 ghij	4.00 ± 0.24 ab
Plantain cultivars				
Batard	AAB	4.84 ± 0.11 cd	27.71 ± 0.74 def	3.71 ± 0.13 abcd
Big ebanga	AAB	5.20 ± 0.12 bc	33.33 ± 0.80 b	3.83 ± 0.14 abc
Biya 2	AAB	5.93 ± 0.09 a	43.60 ± 0.62 a	4.20 ± 0.10 a
French clair	AAB	4.04 ± 0.07 fghi	24.80 ± 0.51 fghi	3.03 ± 0.08 efgh
French sombre	AAB	4.09 ± 0.08 efghi	26.16 ± 0.57 defg	3.33 ± 0.10 cdefg
Essong	AAB	3.77 ± 0.10 hijk	27.88 ± 0.66 de	3.27 ± 0.11 cdefg
Elat	AAB	3.64 ± 0.09 ijkl	28.77 ± 0.59 cd	3.04 ± 0.10 efgh
Kelong mekintu	AAB	4.43 ± 0.09 ef	22.10 ± 0.62 ijk	3.30 ± 0.10 cdefg
Mbouroukou 1	AAB	5.40 ± 0.09 b	30.80 ± 0.62 c	4.00 ± 0.10 ab
Mbouroukou 3	AAB	5.52 ± 0.08 b	30.83 ± 0.57 c	3.33 ± 0.10 cdefg
Red yade	AAB	4.19 ± 0.08 efgh	25.75 ± 0.57 efgh	3.25 ± 0.10 cdefg

Means ± standard deviation with the same letters in the same columns are not significantly different P < 0.05 (Student Newman Keul's test)

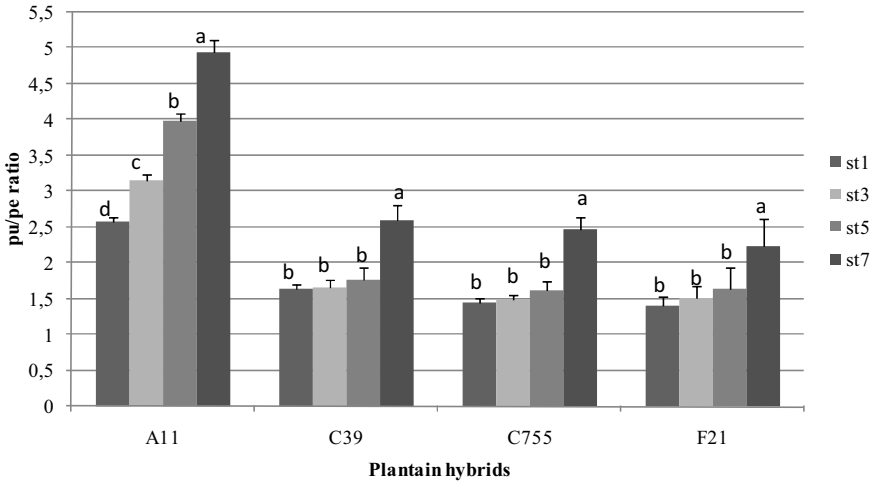

Fig. 2 Changes in pulp to peel ratio during ripening of plantain hybrids. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

and hybrids of this study. The girths of A11, C39 and C755 are respectively closer to the values exhibited by *CRBP60*, FC and RY recognised as their female parents.

The peel thickness is a good criterion that helps to predict the difficulties that may be encountered during *Musa* peeling in processing units. Generally, the greater the peel thickness, the easier will be the peeling process. Thus, the studied plantains cultivars will be more easily peeled compared to the hybrids analysed except F21 that exhibited same peel thickness with B2, although MBK1 presented the highest value.

Concerning the fruit length, B2 still exhibited the highest value (43.6 cm). The plantain cultivars that were analysed were longer than plantain hybrids, except KM (**Table 1**). The longer fruits are preferred by householders and street – restaurant owners because they provide many services thus are economical advantageous. Parameters such as length and fruit girth as well as peel thickness are always influenced by the *Musa* types, the agronomic pathways and trial follow-up. However, the fruit development was highly correlated to these three parameters (fruit girth and length as well as peel thickness) and also significantly influenced by the soil types, the planting period, the climatic changes and hydric stress from shooting to harvest.

Contrary to peel thickness, fruit girth and length measured only at harvest, pulp to peel ratio, pulp firmness, total soluble solids, pH, total titratable acidity and dry matter content were evaluated during ripening. The peel colour changes during post harvest maturation enabled the appreciation of ripening stages.

Pulp to peel ratio

During ripening, pulp to peel ratio of all the analysed varieties increased considerably (**Figs. 2, 3**). No significant differences were observed between plantain hybrids pulp to peel ratio from unripe to ripe stage except A11, meanwhile the differences within plantain pu/pe ratio were sometimes significant between unripe, start ripe and ripe fruit. Generally, the difference between unripe and fully ripe pu/pe ratio of plantain hybrids and cultivars are highly significant. These same trends were observed during investigations on some plantains cultivars grown in Cameroon, Ivory Coast and Nigeria (Aboua 1991; Collin and Dalnic 1991; Burdon *et al.* 1991; Onyejegbou and Ayodele 1995; Ngalani *et al.* 1998). Recently, similar results were observed by Ngoh Newilah *et al.* (2009) on some cooking and dessert bananas produced in Cameroon. Changes in pulp to peel ratio during ripening indicate differential variations in moisture content of the peel and pulp. The increase during post harvest maturation is related to the rapid increase in the sugar concentration in the pulp compared to the peel thus contributing to a differential change in osmotic pressure. Furthermore, the peel loses water both by transpiration to the atmosphere and also to the pulp by osmosis; thereby contributing to an increase in the fresh weight of the pulp as the fruit ripens.

Pulp firmness

At harvest, the pulp firmness of all the analysed samples was above 2 kg/m². MBK1 and BE exhibited the highest values (3.48 and 3.43 kg/m², respectively) compared to the

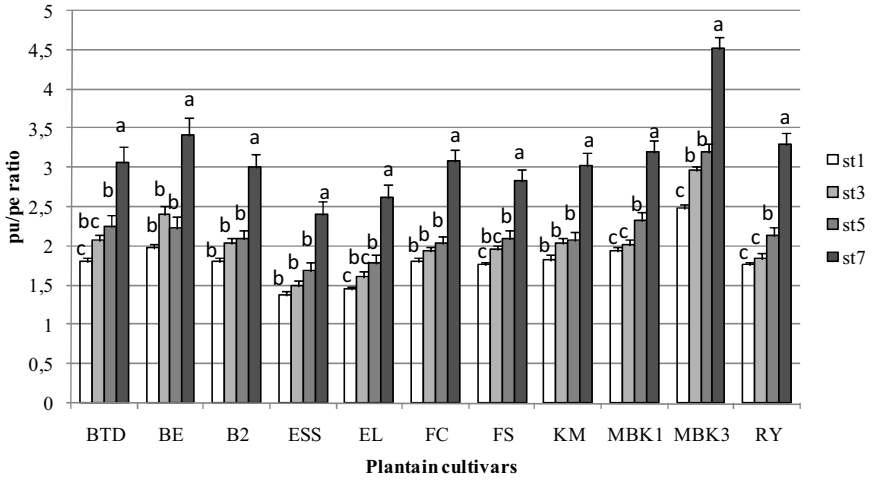

Fig. 3 Changes in pulp to peel ratio during ripening of plantain cultivars. BTD: Bâtard; BE: Big ébanga; B2: Biya 2; ESG: Essong; EL: Elat; FC: French clair; FS: French sombre; KM: Kelong mekintu; MK1: Mbouroukou 1; MK3: Mbouroukou 3; RY: Red yade; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

Table 2 Changes of pulp firmness during post harvest maturation of plantain fruits.

Plantain cultivars	Stage 1 (unripe)	Stage 3 (start ripe)	Stage 5 (ripe)	Stage 7 (fully ripe)
Batard	3.15 ± 0.10 a	2.17 ± 0.11 b	1.48 ± 0.07 c	0.95 ± 0.05 d
Big ebanga	3.43 ± 0.11 a	2.21 ± 0.12 b	1.41 ± 0.07 c	0.85 ± 0.05 d
Biya 2	3.14 ± 0.09 a	2.24 ± 0.09 b	1.38 ± 0.06 c	0.90 ± 0.04 d
Essong	3.00 ± 0.09 a	1.98 ± 0.10 b	1.27 ± 0.06 c	0.66 ± 0.04 d
Elat	3.18 ± 0.08 a	2.08 ± 0.09 b	1.38 ± 0.05 c	0.87 ± 0.04 d
French clair	3.12 ± 0.07 a	2.21 ± 0.08 b	1.15 ± 0.05 c	0.54 ± 0.03 d
French sombre	3.12 ± 0.08 a	2.00 ± 0.08 b	1.24 ± 0.05 c	0.65 ± 0.04 d
Kelong mekintu	2.77 ± 0.09 a	2.08 ± 0.09 b	1.31 ± 0.06 c	0.73 ± 0.04 d
Mbouroukou 1	3.48 ± 0.09 a	2.54 ± 0.09 b	1.50 ± 0.06 c	0.87 ± 0.04 d
Mbouroukou 3	3.06 ± 0.08 a	1.95 ± 0.08 b	1.34 ± 0.05 c	0.72 ± 0.04 d
Redyade	2.54 ± 0.08 a	1.80 ± 0.08 b	1.23 ± 0.05 c	0.57 ± 0.04 d

Means ± standard deviation with different letters in the same line are significantly different $P < 0.05$ (Student Newman Keul's test)

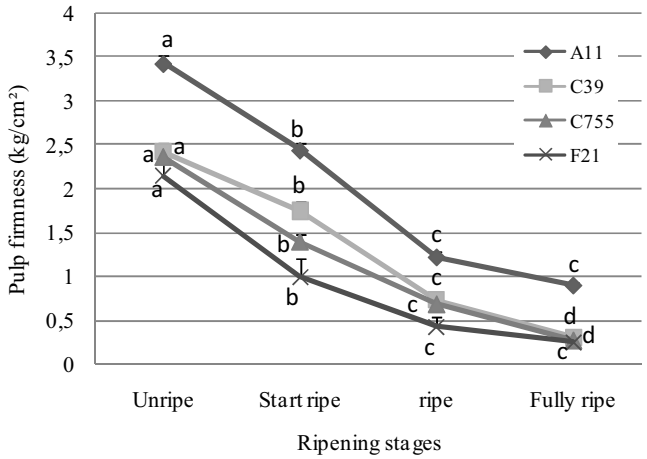

Fig. 4 Pulp firmness changes during ripening of plantain hybrids. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

French type plantains considered as reference plantains by consumers in Cameroon due to their relatively low firmness, their sensorial qualities and their agronomic yield. During post harvest maturation, the pulp firmness of all the studied plantains decreased, F21 exhibited the lowest value (0.25 kg/cm²) when the pulps were fully ripened. At this stage (st7), the pulp firmness of plantain hybrids are less than 0.32 kg/cm² except that of A11 (0.9 kg/cm²); meanwhile plantain cultivars showed higher levels with at least 2.16 times the lowest value (**Fig. 4; Table 2**).

This highly significant loss of firmness was also observed with some *Musa* cultivars grown in Cameroon and Ivory Coast (Aboua 1991; Collin and Dalnic 1991; Burdon *et al.* 1991; Onyejegbou and Ayodele 1995; Ngalani *et al.* 1998). The same trend (loss of firmness) was also reported for some white and red guava varieties during ripening (Bashir and Abou-Goukh 2003). Generally, as ripening progress, pulp firmness decline. It has been associated to three processes: (i) breakdown of starch to form sugar (ii) breakdown of the cell walls or reduction in the middle lamella cohesion due to solubilisation of pectic substances (Palmer 1971; Smith *et al.* 1989) and (iii) movement of water from the peel to the pulp due to osmosis process. At fully ripened stage, dessert banana pulps have lowest firmness compared to other cooking bananas and plantains, which need to be processed before eaten (Ngoh Newilah *et al.* 2005, 2009).

Total soluble solids

The soluble solid content of a fruit is based on soluble compounds such as sugars, acids, vitamin C, amino acid and some pectines. **Figs. 5** and **6** show changes in (TSS) content during ripening of plantain hybrids and cultivars. At harvest, pulp TSS ranged from 1 to 2 g/l with F21 and EL showing highest values 2.8 and 2.03 g/l, respectively. This result confirmed the local assumption indicating that at unripe stage, pulp of EL is the sweetest among all the local plantain varieties in Cameroon. During ripening, TSS of the analysed hybrid and cultivar pulps changed significantly from unripe to fully ripe. **Table 3** shows that from the unripe to start ripe stage, the increasing factor is less than or equal to 5 for both hybrids and plantain cultivars; meanwhile this factor ranges from 5 to 11 and from 6 to 13 for unripe to ripe stage and for unripe to fully ripe stage, respectively. At all ripening stages, most of the plantain cultivars showed higher TSS levels compared to hybrids; even though F21 values were closer to plantains cultivars. The variation trend observed in this study is similar to those obtained on plantain cultivars (*Orishele*, FC, Rose d'Ekona, 2 Hands Planty, BE and BTD*)* grown in Cameroon, Ivory

Table 3 TSS increasing factor during ripening of plantain hybrids and cultivars.

Musa type	Unripe – start ripe	Unripe – ripe	Unripe – fully ripe	Start ripe – ripe	Start ripe – fully ripe	Ripe – fully ripe
Plantain hybrids						
A11	5	11	13	2	3	1
CRBP 39	3	6	10	2	3	2
CRBP 755	3	6	9	2	3	2
FHIA 21	2	5	6	2	3	1
Plantain cultivars						
Batard	5	10	15	2	3	1
Big ebanga	5	9	14	2	3	2
Biya 2	5	9	13	2	3	2
Essong	5	10	15	2	3	1
Elat	4	6	9	2	3	2
French clair	3	6	11	2	3	2
French sombre	4	7	10	2	2	1
Kelong mekintu	5	9	14	2	3	2
Mbouroukou 1	4	8	11	2	3	1
Mbouroukou 3	4	8	12	2	3	1
Red yade	3	6	9	2	3	1

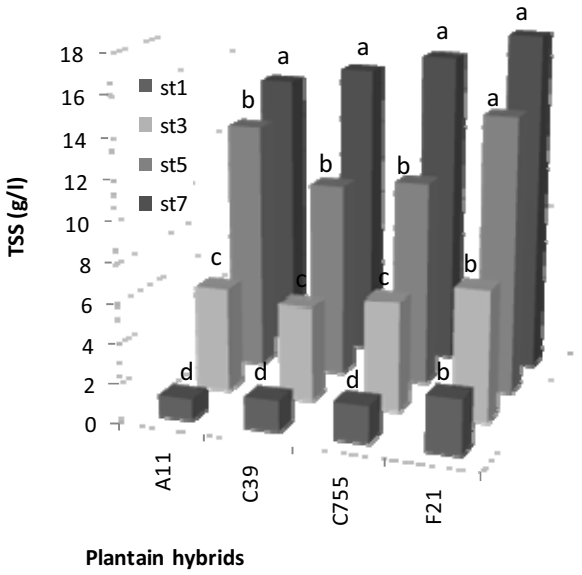

Fig. 5 Changes in total soluble solids during ripening of plantain hybrids. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

Coast and Nigeria (Aboua 1991; Collin and Dalnic 1991; Burdon *et al.* 1991; Onyejegbou and Ayodele 1995; Ngalani *et al.* 1998). The same variation trend (increase) was also observed during ripening of some dessert and cooking bananas grown recently in Cameroon (Ngoh Newilah *et al.* 2009). This increase is highly related to the conversion of starch into sugars in the ripened pulps during post harvest maturation, thus reducing the firmness of the pulps that become richer in TSS. The most striking post harvest chemical change which occurs during post harvest ripening of banana, cooking banana and plantain is the hydrolysis of starch and the accumulation of sugar i.e. sucrose, glucose and fructose (von Loesecke 1950; Palmer 1971) which are responsible for the sweetening of the fruit as it ripens. In dessert banana the breakdown of starch and the synthesis of sugar are usually completed at full ripeness, while in plantain this breakdown is slower and less complete and continues in over ripe and senescent fruits (Marriot *et al.* 1981).

Peel and pulp pH

pH values give a measure of the acidity or alkalinity of a product. At harvest the pH of the *Musa* peels analysed

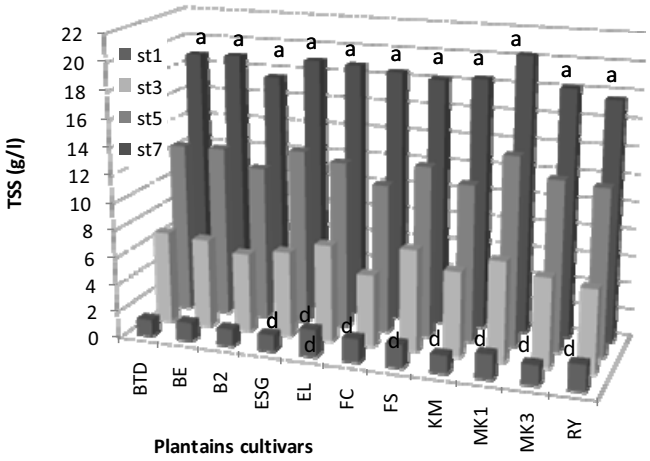

Fig. 6 Changes in total soluble solids during ripening of plantain cultivars. BTD: Bâtard; BE: Big ébanga; B2: Biya 2; ESG: Essong; EL: Elat; FC: French clair; FS: French sombre; KM: Kelong mekintu; MK1: Mbouroukou 1; MK3: Mbouroukou 3; RY: Red yade; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

ranged from 5.36 to 5.86, respectively for F21 and C755 (**Table 4**). During ripening, these values rarely change significantly ($P < 0.05$) although considerable variations (increase) occur in most plantain hybrids from unripe to fully ripe stage. The same trend (very slight increase) was observed with some plantain cultivar peels meanwhile most of them show different trends from unripe – start ripe – ripe – to fully ripe stage i.e. (i) decreasing – decreasing – increasing; (ii) decreasing – increasing – increasing or (iii) increasing – decreasing – increasing. The screening of plantain peels according to their pH parameter is of great importance in Cameroon because of its use as a sauce stabiliser in many regions.

Unlike the peels at harvest, *Musa* pulps analysed show higher pH values closer to 6, *Mbouroukou 3* exhibiting the highest (6.19). During ripening, all the pH levels decrease and fall at approximately 0.7 – 1.3 unit from unripe to start ripe stage; then the pH levels reduce from 1.0 – 1.6 unit when we move from unripe to ripe stage. Finally pH levels reduction is estimated at 1.1 – 1.7 units lost depending on the plantain hybrids or cultivars (**Table 5**). The pH of *Musa* pulps decrease significantly during post harvest maturation although sometimes the differences are not significantly observed from ripe to fully ripe stage. Similar result were obtained on dessert and cooking bananas grown in Cameroon (Ngoh Newilah *et al.* 2009).

Total titratable acidity

Titratable acidity gives a measure of the amount of acid present. Assessment of pH and titratable acidity of bananas and plantains are used primarily to estimate consumption qualities and hidden attributes. **Figs. 7** and **8** show the evolution of (TTA) during post harvest maturation of *Musa* pulps. At harvest TTA levels were more than 300 mEq/100 g and less than 500 mEq/100 g except for F21 (509 mEq/100 g). During ripening, TTA of almost all the hybrids and plantain cultivars analysed increased significantly from unripe to ripe stage; the increasing rate been estimated at 2 to 4 times the initial values. When we moved from ripe to fully stage the variations (decreasing for plantain hybrids and increasing for plantain cultivars) were considerable but not always significantly different. TTA could be considered as a good indicator of fruit ripeness. Acids make an important contribution to the post harvest quality of the fruit, as taste is mainly a balance between the sugar and acid contents.

Table 4 Changes in peel pH during post harvest maturation of *Musa* fruits.

Musa type	Stage 1 (unripe)	Stage 3 (start ripe)	Stage 5 (ripe)	Stage 7 (fully ripe)
Plantain hybrids				
A11	5.72 ± 0.05 cdefg	5.87 ± 0.05 abcde	6.12 ± 0.05 a	6.17 ± 0.05 bc
CRBP39	5.60 ± 0.06 efgh	5.65 ± 0.06 cdefgh	5.46 ± 0.06 hi	5.56 ± 0.06 j
CRBP755	5.86 ± 0.04 bcdef	5.88 ± 0.05 abcde	5.87 ± 0.05 abcde	6.09 ± 0.05 bcd
FHIA21	5.36 ± 0.12 h	5.37 ± 0.12 gh	5.78 ± 0.12 bcdefgh	5.99 ± 0.12 bcdefg
Plantain cultivars				
Batard	5.67 ± 0.06 cdefgh	5.58 ± 0.06 cdefgh	5.53 ± 0.06 ghi	5.55 ± 0.06 j
Big ebanga	5.60 ± 0.06 efgh	5.54 ± 0.07 efgh	5.62 ± 0.07 cdefghi	5.73 ± 0.07 ghij
Biya2	5.63 ± 0.05 defgh	5.55 ± 0.05 defgh	5.48 ± 0.05 hi	5.60 ± 0.05 ij
Essong	5.66 ± 0.05 cdefgh	5.59 ± 0.06 cdefgh	5.50 ± 0.05 ghi	5.63 ± 0.05 hij
Elat	5.53 ± 0.05 gh	5.57 ± 0.05 defgh	5.49 ± 0.05 hi	5.65 ± 0.05 hij
French clair	5.58 ± 0.04 fgh	5.55 ± 0.04 defgh	5.47 ± 0.04 hi	5.66 ± 0.04 hij
French sombre	5.56 ± 0.04 fgh	5.57 ± 0.05 defgh	5.42 ± 0.05 i	5.61 ± 0.05 hij
Kelong mekintu	5.58 ± 0.05 fgh	5.56 ± 0.05 defgh	5.47 ± 0.05 hi	5.60 ± 0.05 ij
Mbouroukou 1	5.60 ± 0.05 efgh	5.55 ± 0.05 defgh	5.41 ± 0.05 i	5.55 ± 0.05 j
Mbouroukou 3	5.60 ± 0.04 efgh	5.57 ± 0.05 defgh	5.59 ± 0.05 defghi	5.78 ± 0.05 efghij
Red yade	5.58 ± 0.04 fgh	5.56 ± 0.05 defgh	5.53 ± 0.05 ghi	5.56 ± 0.05 j

Means ± standard deviation with the same letters in the same colon are not significantly different $P < 0.05$ (Student Newman Keul's test)

Table 5 Changes in pulp pH during post harvest maturation of *Musa* fruits.

Musa type	Stage 1 (unripe)	Stage 3 (start ripe)	Stage 5 (ripe)	Stage 7 (fully ripe)
Plantain-like hybrids				
A11	6.15 ± 0.05 a	5.16 ± 0.06 b	4.66 ± 0.03 c	4.77 ± 0.04 c
CRBP39	5.86 ± 0.06 a	4.96 ± 0.07 b	4.64 ± 0.03 c	4.59 ± 0.05 c
CRBP755	6.11 ± 0.05 a	5.23 ± 0.05 b	4.91 ± 0.02 c	4.89 ± 0.03 c
FHIA21	5.69 ± 0.12 a	4.98 ± 0.14 ab	4.65 ± 0.07 b	4.55 ± 0.09 b
Plantain cultivars				
Batard	6.12 ± 0.06 a	4.83 ± 0.07 b	4.54 ± 0.03 c	4.43 ± 0.05 c
Big ebanga	6.12 ± 0.07 a	4.93 ± 0.08 b	4.61 ± 0.04 c	4.56 ± 0.05 c
Biya2	6.17 ± 0.05 a	4.98 ± 0.06 b	4.62 ± 0.03 c	4.47 ± 0.04 d
Essong	6.13 ± 0.06 a	4.96 ± 0.06 b	4.60 ± 0.03 c	4.52 ± 0.04 c
Elat	5.84 ± 0.05 a	4.94 ± 0.06 b	4.56 ± 0.03 c	4.44 ± 0.04 c
French clair	6.02 ± 0.04 a	5.01 ± 0.05 b	4.64 ± 0.02 c	4.49 ± 0.03 d
French sombre	5.98 ± 0.05 a	4.84 ± 0.05 b	4.55 ± 0.02 c	4.48 ± 0.03 c
Kelong mekintu	5.93 ± 0.05 a	4.88 ± 0.06 b	4.56 ± 0.03 c	4.43 ± 0.04 d
Mbouroukou n°1	6.00 ± 0.05 a	4.93 ± 0.06 b	4.52 ± 0.03 c	4.44 ± 0.04 c
Mbouroukou n°3	6.19 ± 0.05 a	4.98 ± 0.05 b	4.65 ± 0.02 c	4.54 ± 0.03 c
Red yade	5.83 ± 0.05 a	4.97 ± 0.05 b	4.61 ± 0.02 c	4.54 ± 0.03 c

Means ± standard deviation with different letters in the same line are significantly different $P < 0.05$ (Student Newman Keul's test)

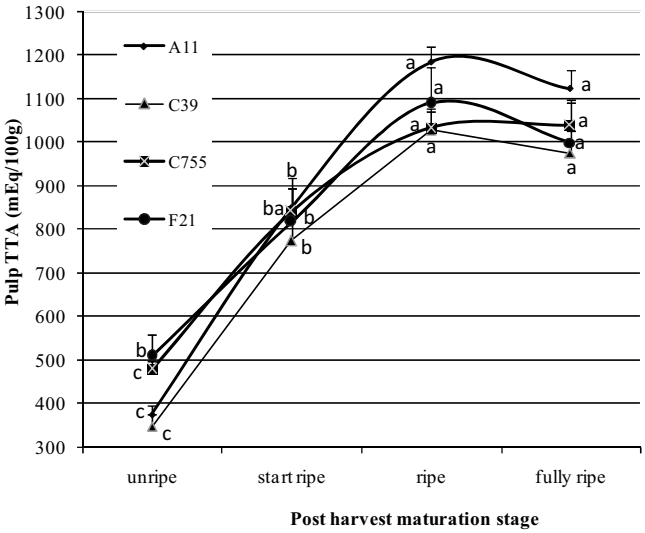

Fig. 7 TTA changes during post harvest maturation of plantain hybrids. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

Pulp and peel dry matter content

At harvest, dry matter contents of the plantain pulps were significantly higher ($P < 0.05$) than those of hybrids, they ranged respectively from 34–39 g/100 g fresh weight (FW) and from 31–34 g/100 g FW. These values are significantly higher and similar compared to those of dessert bananas (20–29 g/100 g FW) and cooking bananas (29–40 g/100 g FW) respectively that were grown in the same agronomic condition in Njombé – Cameroon and studied by Ngoh Newilah *et al*. (2009). Considering the yield criteria during processing which is strongly correlated to the dry matter content (DMC), unripe plantain and cooking banana pulps are more suitable for flour and chips production because of their high dry matter contents.

During maturation, changes occur in pulp DMC. Generally, from unripe to fully ripe maturation stage, dry matter contents of hybrids and plantains decreased considerably from 2 to 4 units. Furthermore, the reduction was mostly significant for all the analyzed *Musa* types except for F21, BTD, B2 and ESS (**Figs. 9, 10**). Usually, from unripe to start ripe stage no significant differences were observed during the reduction of dry matter content levels.

Dry matter content of bananas and plantains are important post harvest quality attributes in the assessment of fruit maturation. At stage 1, peel dry matter contents ranged from 7 to 13 g/100 g FW and plantains (BTD, BE and B2) exhibited the highest values. **Figs. 11** and **12** show that contrarily to pulp, during fruit ripening peel DMC increased significantly up to 19–20 g/100 g for hybrids (A11) and plantains (ESS) from unripe to fully ripe stage. High rate of respiration accompanied by water loss that occurs in banana peel during ripening, particularly at climacteric stage (i) causes a net reduction in the proportion of the pulp dry matter and (ii) enable peel dry matter increase.

Finally, statistical analyses showed high correlations among some analysed parameters (**Table 6**). During fruit ripening, pulp to peel ratio increase while pulp DMC de-

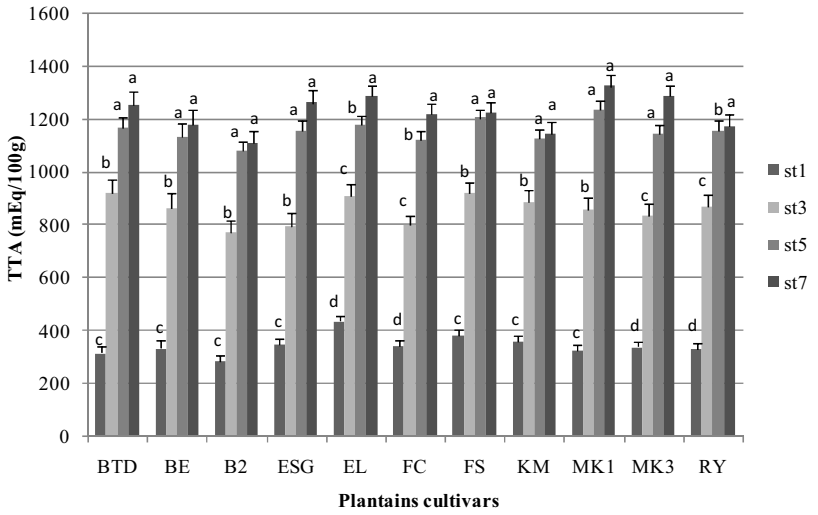

Fig. 8 TTA changes during post harvest maturation of plantain cultivars. BTD: Bâtard; BE: Big ébanga; B2: Biya 2; ESG: Essong; EL: Elat; FC: French clair; FS: French sombre; KM: Kelong mekintu; MK1: Mbouroukou 1; MK3: Mbouroukou 3; RY: Red yade; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

Fig. 9 Changes in dry matter contents during hybrid pulp maturation. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

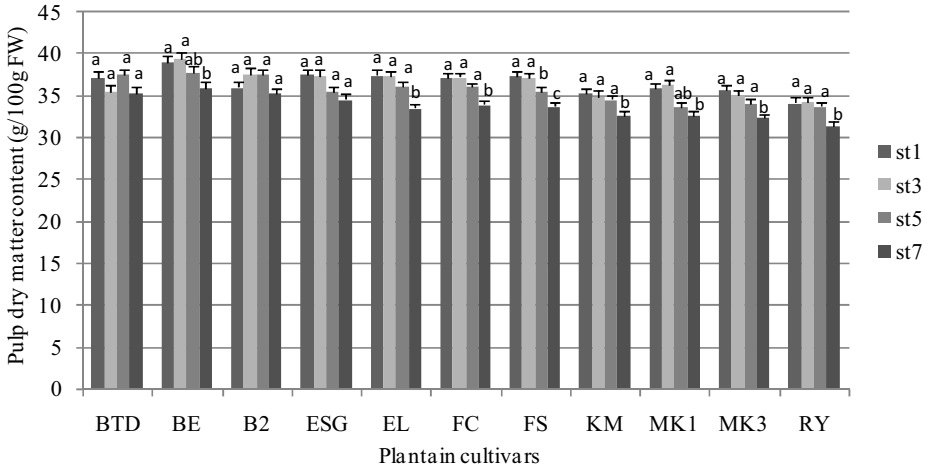

Fig. 10 Changes in dry matter contents during plantain pulp maturation. BTD: Bâtard; BE: Big ébanga; B2: Biya 2; ESG: Essong; EL: Elat; FC: French clair; FS: French sombre; KM: Kelong mekintu; MK1: Mbouroukou 1; MK3: Mbouroukou 3; RY: Red yade; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

crease. The same highly negative correlations were observed between pulp TTA and pulp pH as well as pulp TSS and pulp firmness.

CONCLUSION

Physicochemical characteristics of pulps and peels varied significantly according to *Musa* types (plantain cultivars and hybrids) and ripening stages. During post harvest maturation, most parameters showed significant and exponential increase or decrease between unripe and fully ripe stages, confirming the changes that occur in fruit composition during ripening. Also, hyperbolic increase or decrease were observed between closely ripening stages (unripe – start ripe, start ripe – ripe and ripe – fully ripe). This late trend of modification was sometimes considerable but not always significant.

The parameters investigated are essential and complementary to breeders for the selection of new hybrids with the following characteristics: (i) more or partially resistant

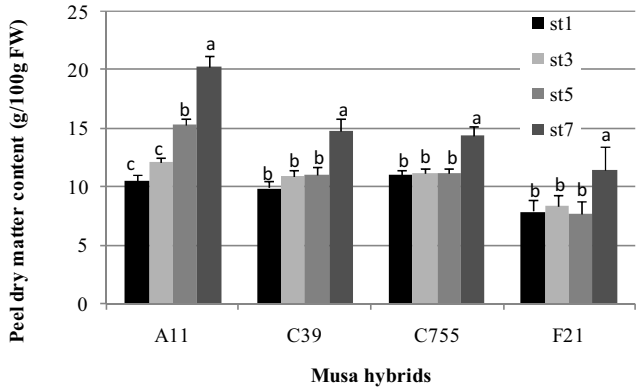

Fig. 11 Changes in peel dry matter content during hybrids post harvest maturation. C39: CRBP 39; C755: CRBP 755; F21: FHIA 21; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

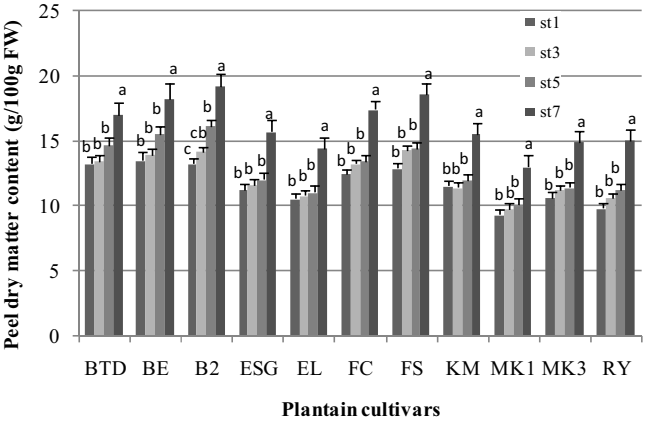

Fig. 12 Changes in peel dry matter content during plantain fruit ripening. BTD: Bâtard; BE: Big ébanga; B2: Biya 2; ESG: Essong; EL: Elat; FC: French clair; FS: French sombre; KM: Kelong mekintu; MK1: Mbouroukou 1; MK3: Mbouroukou 3; RY: Red yade; st1: unripe; st3: start ripe; st5: ripe; st7: fully ripe.

to pest and diseases, (ii) high agronomic performance and (iii) sensorial and nutritive qualities closely similar to local varieties regularly accepted by consumers. Also, the variation trends of investigated criteria during ripening of plantain fruits are very important elements that enable Musa processors to improve the qualities of banana and plantain derived products. Data from this study will be reported to the *Musa Germplasm Information System* of Bioversity International in order to be shared worldwide. Further studies including nutritional aspects, sensorial and microbial analysis as well as effects of processing on the fruit composition will be carried out involving more plantain cultivars and hybrids from CARBAP *Musa* collection.

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Table 6 Some correlation coefficients between *Musa* physicochemical characteristics during ripening.

Musa **Types**	**pu/pe – pu DMC**	**TTA – pu pH**	**TSS – firmness**
Plantain hybrids			
A 11	- 0.524 (0.000)	- 0.939 (0.000)	- 0.960 (0.000)
CRBP39	- 0.676 (0.000)	- 0.861 (0.000)	- 0.937 (0.000)
CRBP755	- 0.719 (0.000)	- 0.843 (0.000)	- 0.941 (0.000)
FHIA21	- 0.610 (0.108)	- 0.967 (0.000)	- 0.931 (0.000)
Plantains cultivars			
Bâtard	- 0.084 (0.667)	- 0.960 (0.000)	- 0.932 (0.000)
Big ébanga	- 0.333 (0.110)	- 0.959 (0.000)	- 0.938 (0.000)
Biya2	- 0.427 (0.006)	- 0.888 (0.000)	- 0.949 (0.000)
Essong	- 0.455 (0.005)	- 0.935 (0.000)	- 0.944 (0.000)
Elat	- 0.603 (0.000)	- 0.902 (0.000)	- 0.927 (0.000)
French clair	- 0.612 (0.000)	- 0.956 (0.000)	- 0.955 (0.000)
French sombre	- 0.551 (0.000)	- 0.966 (0.000)	- 0.965 (0.000)
Kelong mekintu	- 0.404 (0.009)	- 0.906 (0.000)	- 0.953 (0.000)
Mbouroukou 1	- 0.396 (0.011)	- 0.966 (0.000)	- 0.953 (0.000)
Mbouroukou 3	- 0.508 (0.000)	- 0.948 (0.000)	- 0.941 (0.000)
Red yade	- 0.410 (0.003)	- 0.925 (0.000)	- 0.945 (0.000)

Values in parenthesis represent probabilities of the correlation coefficient
pu/pe: pulp to peel ratio; pu DMC: pulp dry matter content; TTA: total titratable acidity; pu pH: pulp pH; TSS: total soluble solids

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