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Abstract

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Characterization of *Musa* sp. Fruits and Plantain Banana Ripening Stages According to Their Physicochemical Attributes

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ABSTRACT: This study aimed at understanding the contribution of the fruit physicochemical parameters to *Musa* sp. diversity and plantain ripening stages. A discriminant analysis was first performed on a collection of 35 *Musa* sp. cultivars, organized in six groups based on the consumption mode (dessert or cooking banana) and the genomic constitution. A principal component analysis reinforced by a logistic regression on plantain cultivars was proposed as an analytical approach to describe the plantain ripening stages. The results of the discriminant analysis showed that edible fraction, peel pH, pulp water content, and pulp total phenolics were among the most contributing attributes for the discrimination of the cultivar groups. With mean values ranging from 65.4 to 247.3 mg of gallic acid equivalents/100 g of fresh weight, the pulp total phenolics strongly differed between interspecific and monospecific cultivars within dessert and nonplantain cooking bananas. The results of the logistic regression revealed that the best models according to fitting parameters involved more than one physicochemical attribute. Interestingly, pulp and peel total phenolic contents contributed in the building up of these models.

KEYWORDS: *Musa sp. fruits, physicochemical analysis, total phenolic compounds, ripening stage, discriminant analysis, principal component analysis, logistic regression*

INTRODUCTION

With a world production of more than 138 million tons in 2010, bananas (*Musa* sp. fruits) are the seventh most important food crop after maize, rice, wheat, potato, soybean, and cassava.[1] Although Asia is the continent of origin of both wild and cultivated *Musa* sp., this crop is now also widely cultivated in Latin America, Caribbean countries, and Africa, where their fruits contribute to food security and socio-economical life. Studies have shown that bananas are good sources of starch, fibers, minerals (potassium, magnesium, phosphorus, manganese), and vitamin B_6 for consumers.[2] Furthermore, bananas are a source of natural dietary antioxidants such as carotenoids and phenolic compounds, which exhibit health-promoting effects including antioxidant, anti-inflammatory, antibacterial, and anticancer activities.[3,4] Our recent study revealed that bananas are good sources of phenolic compounds, hydroxycinnamic acids, particularly ferulic acid-hexoside, and flavonol glycosides e.g. rutin dominating in the plantain pulp and peels, respectively.[5] Information about the nutrient composition of bananas is of major importance for breeders and programs of varietal dissemination.

Edible *Musa* sp. are characterized by a large diversity, which constitutes one of the most interesting property for breeders. Several field collections exhibiting *Musa* sp. diversity are hosted in Latin America, India, Asia, and Africa countries where they are managed for breeding.[6] *Musa* sp. genotypes are generally classified according to the consumption mode of the fruits (dessert or cooking bananas) and the constitution of their genome.[7,8] The wild diploid bananas are characterized by the presence of seeds in their pulps and include two main species *Musa acuminata* Colla (AA) and *Musa balbisiana* Colla (BB), which contributed to the major groups of edible bananas. Intra- and interspecific hybridizations between these wild species in nature gave rise to many seedless cultivars whose reproduction occurs by vegetative multiplication (rationing or suckering). These cultivars are diploids or triploids with different genomic constitutions composed of genome A or genomes A and B. According to molecular and cytological studies, most of the edible cultivars have the genomic constitutions AA, AB, AAA, AAB, or ABB.[9,10] Their peels are mostly green at harvest.

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Table 1. Description of *Musa* sp. Fruits Collected at Harvest[a]

groups based on the consumption mode	genomic constitution[b]	subgroup	name of the accessions	peel color at harvest	groups based on the consumption mode and the genomic constitution
dessert	AAA	Ibota	Yangambi km5	green	D-A
	AAA	Ibota	Khom Bao	green	
	AAA	Red	Figue Rose Naine	red	
	AB	Ney Poovan	Figue Pome Ekona	green	D-AB
	AB	Ney Poovan	Safet Velchi	green	
	ABB	ABB ind.	Rana	green	
nonplantain cooking	AA	AAcv ind.	Kekiau	green	NPC-A
	AA	AAcv ind.	Tomolo	green	
	AAA	Lujugira	Mujuba	green	
	AAB	Laknao	Laknao	green	NPC-AB
	AAB	Maïa Maoli	Iho-U-Maohi	green	
	AAB	ABB ind.	Kupulik	green	
	ABB	Kalapua	Dwarf Kalapua	green	
	ABB	Pelipita	Pelipita.	green	
plantain cooking	AAB	Plantain	Mbeta 1	green	PC-French[c]
	AAB		Red Yade	green	
	AAB		French Rouge 18	green	
	AAB		Ntie	green	
	AAB		Rouge de Loum	green	
	AAB		Banane Tigrée	green with black spots	
	AAB		Kar Ngou	green with chestnut pigments	
	AAB		French Sombre	green	
	AAB		Meki	green	
	AAB		Kelong Mekintu	green	
	AAB	plantain	Mbouroukou no. 1	green yellowish	PC-Horn[c]
	AAB		3/4 Nain	green	
	AAB		Batard	green	
	AAB		76–17	green	
	AAB		Niangafelo	red silver,	
	AAB		Essang	green with chestnut pigments	
	AAB		Soya	green with chestnut pigments	
	AAB		Moto Ebanga	chimeric green white	
	AAB		Ihitisim	green	
new hybrids		secondary triploid hybrids derived from plantain (AAA/AAB	C 292	green	unknown
			F 568	green	

[a]Abbreviations: cv, cultivar; ind, undetermined; D, dessert; NPC, nonplantain cooking; PC, plantain cooking. [b]A, B: genomic constitution of *Musa accuminata* and *Musa balbisiana* respectively. [c]French, Horn: agro-morphological character within plantain cooking indicating respectively the presence or the absence of the male bud at harvest.

Central Africa is considered as a secondary center of plantain (a type of cooking banana) diversity harboring a wide range of unique varieties.[11,12] In general, the presence or absence of the male bud at harvest is used to distinguish the two main types of plantain, namely, the French and the Horn plantains, respectively. There is also a wide diversity in fruit peel colors. Somatic mutations are likely to be responsible for the great morphological diversity observed in plantains.[13] Moreover, the breeders undertake crossings between *Musa* varieties including wild species and cultivars. This leads to the creation of hybrids with improved disease resistance such as CRBP 14, CRBP 39, FHIA 17, and FHIA 21, which contribute to the diversity observed in this group.[14]

Due to the large diversity of bananas, there is still a lack of information on the physicochemical characteristics of fruits of numerous varieties. Most of the studies focused on the export dessert banana "Grand Nain" (AAA). Investigations on plantain are often limited to their pulps. For instance, Gibert et al.[15] investigated the difference between dessert and cooking bananas based on some physicochemical characteristics of the pulp and found that dry matter, edible fraction, pH, total ash, and total sugar can help to differentiate dessert, nonplantain cooking, and plantain cooking bananas. However, more information may emerge if the secondary metabolites as well as the overall physicochemical attributes of the fruit pulp and peel are also taken into account.

Edible *Musa* sp. are also characterized by the ripening process occurring during the storage. During ripening, the fruits undergo physicochemical changes associated with organoleptic and nutritional modifications. These changes have many implications on their uses in food processing. For instance, the quality of plantain banana chips and the functional properties of dessert banana flour vary according to the ripening stage of the raw material.[16−18] In field collections, postharvest characterization of the ripening stages are assessed on dessert and cooking bananas.[19] However, the identification of the fruit ripening stages is currently based on a subjective color scale, which is designated for dessert banana with green peels at harvest.[20] With regard to the large diversity of peel color among plantain cultivars, there is a need to predict the ripening stages of the fruits using quantitative attributes. A study on some physicochemical characteristics of plantain pulp and peel during ripening reported changes in edible fraction, pH, dry matter, and pulp soluble solids.[21] To our best knowledge, no attempt to predict the ripening stage from these postharvest physicochemical characteristics has been reported.

This study proposed multivariate analytical approaches to describe how some postharvest physicochemical characteristics can be used (i) to discriminate groups within the diverse *varieties* of *Musa* sp. and (ii) to predict the ripening stages in plantains.

■ MATERIALS AND METHODS

Plant Material. The starting plant material consisted of 33 *Musa* genotypes from the germplasm collection of the African Research Centre on banana and plantain (CARBAP) in Njombe in the littoral region of Cameroon at 80 m above the sea level (Table 1).[22] This working collection was organized in six cultivar groups based on their consumption mode, genomic constitution and morphological characters. Each of the three consumption groups, which are dessert, nonplantain cooking, and plantain cooking bananas, were divided in two subgroups. For dessert and nonplantain cooking bananas, monospecific varieties were separated from interspecific varieties. The first group contained only the A genome (A group) whereas the other one was made of varieties containing both the A and B genomes (AB group). For the plantains, the two main phenotypic classes (French and Horn) were separated. In addition, two newly created plantain-like hybrids resistant to the black Sigatoka disease were also part of the study and constituted a separated group. Bunches were harvested at CARBAP in 2010 at physiological maturity according to the protocol described by Tchango, Achard and Ngalani.[23] For each genotype, two to three bunches from different plants were used.

At least 15 fruits were collected from the middle hands of each bunch and allowed to ripe at room temperature in cardboard containers. Dessert and plantain banana ripening stages have been defined on the basis of changes in peel colors according to the scale described by Soltani, Alimardani, and Omid.[20] The four ripening stages 1, 3, 5, and 7 assessed correspond to peel color being all green, greener than yellow, yellow with green ends, and yellow with brown speckles, respectively. For each ripening stage, 3 fruits were removed from the cardboard and weighted. Each fruit was cut on the length and across the width into four quarters. Diagonally opposite quarters were put together to form two groups. For each group, samples from the three fruits were pooled. The pulps and peels of one group were separately freeze-dried, ground, and then vacuum sealed in polypropylene plastic bags. The other group was used for the determination of color, edible fraction, peel thickness, total soluble solids, pH, and total ash content. The freeze-dried samples were transported to the laboratory (Louvain-La-Neuve, Belgium) and kept at −20 °C.

Chemicals. Gallic acid and Folin-Ciocalteu reagent (2 N) were purchased from Sigma (St Louis, MO). Pure acetone, glacial acetic acid, and sodium carbonate (purity ≥99.5) were respectively obtained from Prolabo (Fontenay-sous-bois, France), Fisher Scientific (Loughborough, U.K.), and Merck (Darmstadt, Germany).

Physicochemical Analyses. *Banana Peel and Pulp Color.* The color of peel and pulp was assessed at different ripening stages by a hand-held color reader (CR-14, Konica Minolta, Japan) displaying the CIE Yxy chromaticity coordinates. The recorded values were then transformed into C (chroma) and L (lightness) color indexes.[24]

Edible Fraction and Peel Thickness. Two quarters of each fruit were separately weighted, the peel was then separated from the pulp and weighted. Edible fraction (%) was calculated by dividing the pulp weight by the pulp and peel weight. Peel thickness was measured using a caliper, and the result was expressed in millimeters.

Total Soluble Solids and pH. Total soluble solids and pH were determined according to the methods described in the International Network of the Improvement of Banana and Plantain technical guidelines.[19] For each part of the fruit, a mixture of the sample in distilled water (1:3, w: w) was vigorously blended for 2 min. The mixture was filtered using a Whatman no. 1 paper and the refraction index was read using a visual hand-held refractometer. The total soluble solids were expressed in degrees Brix (°Bx). The pH was measured with a benchtop pH meter (Knick, Berlin, Germany).

2.3.4. Water and Total Ash Contents. The fresh samples of pulp and peel were separately analyzed for their water and ash contents according to the norms of AFNOR.[25] Water content was determined by oven drying for 24 h at 105 °C. The content of total ash composed of free minerals and mineral salts was determined by calcinating the dried samples at 550 °C during 24 h. The results were expressed in percentage of the fresh sample.

Total Phenolic Content. For each freeze-dried banana peel and pulp sample, 0.5 g were extracted with 10 mL of acetone/water/acetic acid (50:49:1). The mixture was vortexed for 1 min. and the extraction was carried out in a water bath under agitation at 40 °C for 1 h. The extract was centrifuged at 5000*g* for 20 min at 4 °C. The colorimetric method[26] for total phenolic content determination was then used as a measure of the reducing capacity of the sample.[27] For the calibration curve, 5 concentrations were prepared from a stock solution of gallic acid. The results were expressed in milligrams gallic acid equivalents (GAE)/100 g of fresh weight (FW).

Statistical Analysis. The statistical analysis of the data was performed by the JMP9.0 statistical discovery software from SAS and SAS entreprise guide 4.3.

Discriminant Analysis. A linear discriminant analysis[28] was performed to (i) compare the physicochemical profile of the six cultivar groups, and to (ii) assign each new hybrid fruit to one of the groups. To compare cultivar groups, the software displayed the scatterplot of the *Musa* sp. fruit scores and the loading plot of the physicochemical attributes. The loading plot reflected the relative contribution of physicochemical attributes to the separation of the groups. In order to identify to which cultivar group a new hybrid fruit sample is closest, classification functions were created for each group in the form

$$F = b_1x_1 + b_2x_2 + \dots + b_nx_n + c \qquad (1)$$

Each of the six classification functions were evaluated with the physicochemical attributes (x) of the hybrid fruit sample. This later was assigned to the group whose classification function yielded the highest value.

Logistic Regression. In order to predict the ripening stage of plantain cultivars according to physicochemical attributes, an ordinal logistic regression was performed. The ripening stage was considered as an ordinal response with 4 modalities. For each ripening stage, the software gave the cumulative logit(j), which is the logarithmic function of the ratio between the cumulative probability $P(y \leq j)$ that a plantain sample "y" is at a level less or equal to a given ripening stage "j" with $j = 1, 3, 5$, or 7 and the probability that it is not $(1 - P(y \leq j))$. Its formula as adapted from Gillet, Brosteaux, and Palm[29] is written as follows:

$$\text{Logit}(j) = \ln \frac{P(y \leq j)}{1 - P(y \leq j)} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p \quad (2)$$

In eq 2, β_0 is the constant, each of the $\beta_{(1\rightarrow p)}$ values stands for the coefficients related to each X physicochemical attribute. The model gives the coefficients for the first three ripening stages, the last one being used as the reference in the statistical procedure. The models were evaluated by the R^2 and the corrected Akaike information criterion (AICc), which measures the fit of the model.[30] Twelve plantain genotypes with a green peel color at stage 1 were used to build the models. Only models explaining at least 70% of the variability are presented. Three plantain genotypes (two with three biological replicates and one with two biological replicates) with green peel with chestnut pigments at stage 1 were used to investigate the abilities of the models to predict the ripening stages. To predict the ripening stage of a plantain sample y, the probability $P(y = j)$ for this sample to be at a ripening stage j is estimated for each ripening stage and the sample is considered to be at the ripening stage that has the highest probability. For that, the cumulative probability $P(y \leq j)$ formula is first deduced from eq 2 as follows:

$$P(y \leq j) = \frac{e^{\text{logit}(j)}}{1 + e^{\text{logit}(j)}} \quad (3)$$

Cumulative probabilities are then calculated for ripening stages 1, 3, and 5 and probabilities $P(y = j)$ are deduced as follows:

$$P(y = 1) = P(y \leq 1) \quad (4)$$

$$P(y = 3) = P(y \leq 3) - P(y \leq 1) \quad (5)$$

$$P(y = 5) = P(y \leq 5) - P(y \leq 3) \quad (6)$$

$$P(y = 7) = 1 - P(y \leq 5) \quad (7)$$

■ RESULTS AND DISCUSSION

Physicochemical Composition of Cultivar Groups at Harvest. *General Description.* Tables 2 and 3 present the results of the physicochemical composition of the seven groups of *Musa* sp. fruits. At harvest, the fruits were at the ripening stage 1.

Most of the physicochemical attributes studied varied according to the cultivar groups. Significant differences were observed for pulp color indexes L and C (chroma and lightness), edible fraction, peel thickness, pulp water content, pulp total soluble solids, pulp pH, and pulp total phenolic compounds. As regard the comparison between pulp and peel, the physicochemical attribute values were different except for total soluble solids and pH. The observations about the L index being lower in peel and the water content being higher in peel were also reported in the literature for dessert bananas.[31,32] The data showing that the total phenolic compounds were (1.5 to 2 times) higher in peel than in pulp also matched with a report published on total phenolic compounds in Malaysian bananas.[33]

Among the dessert bananas, the cultivar Yangambi km5 presented the highest content of pulp total phenolic compounds (306.4 mg GAE/100 g FW). The contents obtained for A dessert banana pulps were higher than the contents reported for the dessert banana Pisang Mas (35.9–72.2 mg GAE/100 g FW) by Alothman, Bhat, and Karim.[34] Peel total phenolic compound contents of A dessert bananas (252.1–383.5 mg GAE/100 g FW) were similar to those of the export dessert banana Grand Nain at a ripe stage (2.6–3.1 g GAE/100g dry weight ~260–310 mg/100g FW) reported by González-Montelongo, Gloria Lobo, and González.[35] Surprisingly, the cultivar Pelipita from the AB nonplantain cooking banana group showed the highest pulp total phenolic compound values (319.5 ± 70.4 GAE/100 g FW) within our banana collection. A drastically lower value was reported by Ngoh Newilah et al.[36] for this genotype (46 μg GAE/100 g dry weight ~0.02 mg GAE/100 g FW). This low value might have resulted from the fact that the samples were dried in oven, which might have provoked phenolic compound oxidation. The highest pulp total phenolic compound values of plantains were obtained for the French plantain Niangafelo (198.4 ± 28.9 mg GAE/100 g FW) and the Horn plantain Moto Ebanga (182.1 ± 27.4 mg GAE/100 g FW). These results show that bananas and plantains could be as important sources of phenolic compounds as other vegetables such as potato (3950 μg GAE/g dry weight ~90.85 mg GAE/100 g FW),[37] bitter melon (143.6 ± 8.4 mg GAE/100 g FW), and beetroot (257.2 ± 0.7 mg GAE/100 g FW).[38]

Discriminant Analysis. A linear discriminant analysis was performed to point out the most relevant physicochemical attributes contributing to the differentiation between cultivar groups. Furthermore, this approach was also intended to help allocating each of the two new hybrids to one of the cultivar groups.

Figure 1 presents the scatterplot of the standardized discriminant scores (A) and the corresponding standardized scoring coefficients of the physicochemical attributes or loading plot (B). The 2 first discriminant functions (1 and 2) explain 79.23% of the variation between groups. These 2 first discriminant functions were found to be highly significant ($P < 0.0001$). The matrix generated by the software indicated that the number of samples correctly classified in the groups accounted for 92.6% of the samples involved in this analysis. The scatterplot shows that the dessert banana groups are separated from the cooking banana groups along the function 1 axis. On this axis, peel pH, pulp water content, edible fraction and fruit mass have the higher scoring coefficients in absolute terms, meaning that they were mostly responsible for this differentiation. The two groups of dessert bananas (A and AB) are separated according to function 2 axis, where pulp total phenolic compounds have the highest scoring coefficient. Pulp total phenolic compounds appear therefore to have highly contributed to the differentiation between the dessert bananas containing only the A genome (247.3 ± 76.3 mg/100 g FW) and those containing both A and B genomes (103.7 ± 33.2 mg/100 g FW). The nonplantain cooking bananas also split on the second axis: the A nonplantain cooking group has considerably higher scores on the second axis than the AB nonplantain cooking group. Furthermore, the AB nonplantain cooking group partly overlaps with the French and Horn plantain cooking groups, suggesting close physicochemical characteristics.

The comparison of the loading and the score plots of Figure 1 indicates that dessert bananas had the highest values of peel pH, edible fraction, and pulp water content whereas AB nonplantain cooking bananas and plantain cooking bananas had the lowest values for these attributes. It also appears that AB dessert bananas had the highest edible fraction values and A dessert bananas had the highest pulp water content values. The fact that the pulp water content mean value of the A dessert

Table 2. Physicochemical Characteristics (L and C Indexes, Fruit Mass, Edible Fraction, Peel Thickness, and Water Content) of *Musa* sp. Fruits at Harvest[#]

groups and accession names	peel L index	pulp L index	peel C index	pulp C index	fruit mass (g)	edible fraction (%)	peel thickness (mm)	peel water content (% FW)	pulp water content (% FW)
D-A	**50.1 ± 10.3[a]**	**77.3 ± 2.1[ab]**	**25.9 ± 6[a]**	**28.4 ± 3.9[ab]**	**126.9 ± 50.7[a]**	**68.3 ± 1.8[abc]**	**2.5 ± 0.5[ab]**	**89.6 ± 1[a]**	**74.2 ± 1.1[a]**
Figue Rose Naine	39	75.3	19.0	32.9	184.5	67.7	3.0	88.5	75.5
Khom Bao	59.4 ± 5.2	79.5 ± 1.5	28.5 ± 2.3	26.6 ± 2.4	107.0 ± 16.7	70.3 ± 2.2	2.3 ± 0.3	89.9 ± 0.2	73.9 ± 1.6
Yangambi km5	51.8	77	30.1	25.7	89.0	66.8	2.2	90.3	73.3
D-AB	**52.8 ± 3.8[a]**	**80.3 ± 0.9[a]**	**32.3 ± 1.7[a]**	**24.4 ± 12.5[b]**	**96.6 ± 40[a]**	**76.2 ± 4[a]**	**2.1 ± 0.7[b]**	**89.1 ± 0.3[a]**	**69.7 ± 5.3[ab]**
Figue Pomme Ekona	54.4	80.9	33.6	16.7	76.5	78.1	2.8	88.8	65.5
Safet Velchi	55.5 ± 3.2	80.8 ± 0.7	32.9 ± 2	17.7 ± 0.5	70.7 ± 1.4	78.7 ± 0.6	1.4 ± 0.1	89.4 ± 0.5	68.0 ± 1.4
Rana	48.5	79.3	30.3	38.9	142.7	71.6	2.2	89.0	75.7
NPC-A	**46.8 ± 4.5[a]**	**77.5 ± 3.4[ab]**	**29.4 ± 2.1[a]**	**38.0 ± 3.8[ab]**	**188.3 ± 51.5[a]**	**70.6 ± 3.7[ab]**	**2.5 ± 0.3[ab]**	**88.9 ± 1.1[a]**	**69.0 ± 9.6[abc]**
Kekiau	45.7 ± 1.6	79.5 ± 2.9	31.5 ± 3.4	40.5 ± 3.8	206.6 ± 14.7	67.4 ± 2.2	2.6 ± 0.1	89.3 ± 0.7	62.8 ± 0.6
Tomolo	43 ± 1.3	79.4 ± 1.7	27.4 ± 6	39.8 ± 1.8	228.2 ± 42.9	69.6 ± 1.6	2.7 ± 0.3	89.7 ± 0.6	64.1 ± 1.6
Mujuba	51.7	73.5	29.4	33.6	130.1	74.6	2.2	87.6	80.1
NPC-AB	**52.5 ± 2.9[a]**	**75.1 ± 2.1[b]**	**31.9 ± 3.2[a]**	**37.7 ± 3.9[ab]**	**210.3 ± 135.7[a]**	**62.7 ± 3.9[bc]**	**3.1 ± 0.4[a]**	**87.3 ± 2.5[a]**	**64.0 ± 4.6[bcd]**
Dwarf Kalapua	56.4 ± 4	76.4 ± 1.5	30.8 ± 5.8	33.3 ± 1.5	105.1 ± 17.6	56.3 ± 5.1	2.7 ± 0.2	84.7 ± 0.8	60.5 ± 1
Pelipita	48.3 ± 3.6	73.9 ± 2.1	27.2 ± 4	40.0 ± 4.5	130.2 ± 10	63.4 ± 1	3.0 ± 0.2	86.2 ± 1.1	59.4 ± 0.5
Iho-U-Maohi	53.7 ± 1.6	74.4 ± 1.8	34.6 ± 2.5	39.8 ± 1.9	166.9 ± 11.5	64.6 ± 3	3.0 ± 0.4	90.9 ± 0	69.8 ± 1.1
Kupulik	51.9	72.	32.2	41.5	443.1	66.5	3.8	86.1	68.1
Laknao	52.1 ± 1.1	78 ± 1.6	34.9 ± 1	33.6 ± 1.4	206.4 ± 18.2	62.8 ± 1.1	2.9 ± 0.3	88.7 ± 1.1	62.4 ± 1.2
PC-French	**50.4 ± 7[a]**	**77.1 ± 1.4[ab]**	**28.4 ± 7.4[a]**	**39.6 ± 4.3[a]**	**136.8 ± 28.4[a]**	**61.7 ± 2.9[c]**	**2.8 ± 0.2[ab]**	**87.4 ± 1.8[a]**	**61.4 ± 1.9[cd]**
French Rouge 18	54.8	77	28.6	41.3	136.3	60.3	2.7	89.3	63.1
Ntie	49.9	76.4	26.8	41.8	171.4	61.3	3.2	87.7	61.3
Mbeta 1	53.4 ± 1.5	79.5 ± 1.9	36.2 ± 3.4	38.1 ± 3.2	169.4 ± 1.5	67.2 ± 1.2	2.8 ± 0.3	89.3 ± 0.3	64.7 ± 2
Rouge de Loum	57.2	76.6	34.1	39.0	167.3	58.1	3.2	87.9	62.4
Banane Tigree	37 ± 2	74.3 ± 1.2	10.3 ± 1	43.7 ± 1.2	111.0 ± 6.7	59.8 ± 2.6	2.8 ± 0.2	86.2 ± 2.3	59.9 ± 2.2
Kar Ngou	43.6 ± 3	78.4 ± 1.9	25.0 ± 4.7	37.2 ± 1.3	107.0 ± 5.7	61.8 ± 1.7	3.0 ± 0.3	83.8 ± 0.9	58.0 ± 0.1
French Sombre	42.7	76.5	25.8	43.1	158.0	63.0	3.0	86.7	60.1
Kelong Mekintu	56.6	77.7	33.0	29.7	130.9	64.9	2.5	88.7	62.2
Meki	51.7	77.4	31.4	44.3	93.4	58.0	2.8	85.8	60.3
Red Yade	56.9 ± 1	76.6 ± 2.3	33.3 ± 3.5	37.8 ± 0.5	123.3 ± 25.3	62.8 ± 3.9	2.6 ± 0.1	88.5 ± 0.7	61.7 ± 1
PC-Horn	**51.2 ± 12.1[a]**	**76.2 ± 2[ab]**	**27.2 ± 5.9[a]**	**36.6 ± 6.8[ab]**	**221.9 ± 83.2[a]**	**64.8 ± 4.5[bc]**	**3.1 ± 0.4[a]**	**86.6 ± 2[a]**	**60.8 ± 1.4[d]**
Batard	56.4	75.4	33.8	41.9	190.2	65.2	2.9	88.3	60.4
3/4 Nain	55 ± 1.5	75.8 ± 1.4	33.4 ± 3.8	40.8 ± 0.8	296.7 ± 39	67.2 ± 3.9	3.4 ± 0.2	87.0 ± 1.2	61.3 ± 0.7
Mbouroukou no. 1	63.9 ± 2.5	76.2 ± 1.8	24.3 ± 4.1	37.4 ± 1.4	292.2 ± 47	66.5 ± 2.8	3.6 ± 0.3	90.7 ± 1.3	63.8 ± 1.5
76–17	58	77.4	32.0	37.8	341.1	66.0	3.3	85.2	59.8
Niangafelo	25.3 ± 0.9	80.9 ± 0.7	17.5 ± 2.2	20.5 ± 1	107.0 ± 11.7	54.6 ± 1.6	3.2 ± 0.4	84.8 ± 1.5	60.6 ± 2.2
Essang	42.5 ± 5.1	79.7 ± 2	23.5 ± 5.3	36.1 ± 1.1	225.9 ± 56.1	67.2 ± 2.4	2.9 ± 0.2	84.9 ± 1	60.6 ± 1.7
Moto Ebanga	55.2 ± 3.9	75.6 ± 2.4	23.2 ± 3.5	38.1 ± 1.6	129.3 ± 12	68.9 ± 1.6	2.3 ± 0.2	85.6 ± 0.8	59.0 ± 0.7
Ihitism	53.3	76.809	29.8	40.2	192.5	62.7	3.1	86.3	60.5
Hybrid									
C 292	53.9 ± 0.4	76 ± 2.1	34.0 ± 2.5	35.1 ± 1.6	208.4 ± 26.3	61.3 ± 0.7	3.1 ± 0.5	88.5 ± 0.5	69.3 ± 1.4
F 568	50.3 ± 2.5	76.7 ± 0.7	30.0 ± 0.8	34.7 ± 2.1	114.2 ± 15.1	58.8 ± 1.7	2.8 ± 0.3	88.1 ± 1	69.3 ± 1.8

[#]See Table 1 for the significance of the group names. FW: fresh weight. For each cultivar, the value is the mean of two (standard deviation not shown) to three biological replicates, each in duplicate. Superscript a, b, and c result from the comparison of groups using Tukey's test. Groups connected by the same letter are not significantly different.

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Table 3. Physicochemical Characteristics (Total Soluble Solids, pH, Total Ash, and Total Phenolic Compounds) of *Musa* sp. Fruits at Harvest$^{\#}$

groups and accession names	peel total soluble solids (°Brix)	pulp total soluble solids (°Brix)	peel pH	pulp pH	peel total ash content (mg/100 g FW)	pulp total ash content (mg/100 g FW)	peel total phenolic compds. (mg/100 g FW)	pulp total phenolic compds. (mg/100 g FW)
D-A	**2.8 ± 0.6**^{bc}	**4.2 ± 1.3**^{a}	**6.1 ± 0.2**^{a}	**5.3 ± 0.1**^{b}	**1236.1 ± 103.5**^{a}	**854.6 ± 29.1**^{a}	**299.7 ± 7.8**^{a}	**247.3 ± 76.3**^{a}
Figue Rose Naine	2.1	3.0	6.4	5.4	1355.1	860.5	252.1	161.2
Khom Bao	3.0 ± 0.1	4.0 ± 0.4	6.0 ± 0.2	5.3 ± 0	1167.5 ± 47.4	823.0 ± 35.1	263.5 ± 67.6	274.4 ± 22.3
Yangambi km5	3.2	5.6	6.0	5.3	1185.6	880.3	383.5	306.4
D-AB	**2.5 ± 0.3**^{c}	**3.5 ± 0.6**^{a}	**6.1 ± 0**^{a}	**5.8 ± 0.3**^{a}	**1558.1 ± 17.8**^{a}	**942.5 ± 101.6**^{a}	**224.9 ± 51.8**^{a}	**103.7 ± 33.2**^{b}
Figue Pomme Ekona	2.4	2.9	6.1	6.1	1569.4	871.8	165.6	105.9
Safet Velchi	2.9 ± 0.6	3.5 ± 0.6	6.1 ± 0.3	5.8 ± 0.1	1567.4 ± 84.5	896.8 ± 50.9	247.5 ± 68.6	135.8 ± 20.7
Rana	2.2	4.2	6.1	5.4	1537.6	1059.0	261.6	69.5
NPC-A	**3.5 ± 0.5**^{abc}	**4.1 ± 0.5**^{a}	**5.9 ± 0.7**^{a}	**6.1 ± 0.9**^{a}	**1544.5 ± 496.6**^{a}	**932.7 ± 115.1**^{a}	**186.6 ± 35.2**^{a}	**65.4 ± 23**^{b}
Kekiau	3.7 ± 0.6	4.6 ± 0.4	6.2 ± 0.1	6.5 ± 0.3	1665.0 ± 258.6	933.5 ± 48.7	166.3 ± 32.8	83.2 ± 9.7
Tomolo	3.9 ± 0.7	4.1 ± 0.1	6.4 ± 0	6.7 ± 0	1969.8 ± 172	1047.3 ± 79.5	166.2 ± 43	73.7 ± 22.3
Mujuba	3.0	3.6	5.1	5.1	998.8	817.2	227.3	39.5
NPC-AB	**3.8 ± 0.3**^{a}	**4.5 ± 0.5**^{a}	**6.0 ± 0.1**^{a}	**5.8 ± 0.3**^{a}	**1392.1 ± 115.5**^{a}	**890.7 ± 65.8**^{a}	**275.5 ± 159.9**^{a}	**146.8 ± 106.2**^{ab}
Dwarf Kalapua	4.1 ± 0.3	5.1 ± 1.3	5.9 ± 0.2	6.1 ± 0.1	1376.9 ± 39.6	940.9 ± 25.3	341.0 ± 26	72.3 ± 3.4
Pelipita	4.0 ± 0.8	4.3 ± 0	6.1 ± 0.3	5.8 ± 0.4	1298.9 ± 48	789.1 ± 47.3	522.7 ± 31.3	319.5 ± 70.4
Iho-U-Maohi	3.4 ± 0.1	4.8 ± 0.5	5.7 ± 0.2	5.7 ± 0.1	1422.7 ± 57.7	863.6 ± 48	160.5 ± 30.7	54.3 ± 1
Kupulik	3.9	4.5	6.0	5.5	1288.7	947.6	222.1	168.1
Laknao	3.6 ± 0.6	3.8 ± 1.1	6.0 ± 0.4	6.1 ± 0.2	1573.3 ± 173.1	912.4 ± 34.4	131.4 ± 32.5	119.8 ± 32.6
PC-French	**3.4 ± 0.5**^{ab}	**3.8 ± 0.4**^{a}	**5.8 ± 02**^{a}	**5.9 ± 0.2**^{a}	**1677.1 ± 325.3**^{a}	**947.1.0 ± 198.9**^{a}	**293.9 ± 120.3**^{a}	**132.7 ± 33**^{b}
French Rouge 18	3.1	4.1	5.8	5.7	1387.6	808.5	230.8	123.7
Ntie	3.2	3.6	6.0	5.9	1537.8	832.2	307.4	133.1
Mbeta 1	3.8 ± 0.2	4.4 ± 0.5	5.4 ± 0.1	5.8 ± 0	1612.8 ± 116.9	923.4 ± 38.3	181.0 ± 140.7	154.5 ± 12
Rouge de Loum	3.2	3.5	5.9	5.8	1494.2	870.0	209.6	154.6
Banane Tigree	3.8 ± 0.4	3.8 ± 0.5	5.9 ± 0.1	6.0 ± 0.3	2546.1 ± 773.1	1498.9 ± 420.4	587.6 ± 290.5	163.4 ± 48.3
Kar Ngou	2.6 ± 0.4	3.0 ± 0.6	6.2 ± 0	6.3 ± 0.2	1674.7 ± 207.9	948.4 ± 55.1	303.4 ± 95.4	170.1 ± 39.6
French Sombre	4.1	4.0	5.7	6.2	1516.4	890.9	173.7	99.8
Kelong Mekintu	2.9	3.5	5.7	5.8	1602.4	940.7	290.3	136.3
Meki	3.5	3.9	5.6	5.7	1808.5	892.8	366.7	59.7
Red Yade	3.5 ± 0.3	4.3 ± 0.4	5.9 ± 0.1	5.8 ± 0.2	1590.4 ± 95.5	865.6 ± 56.1	288.4 ± 25.9	131.5 ± 21.5
PC-Horn	**3.6 ± 0.4**^{ab}	**4 ± 0.4**^{a}	**5.7 ± 0.3**^{a}	**6 ± 0.2**^{a}	**1693.3 ± 157.1**^{a}	**943.2 ± 43.3**^{a}	**302.1 ± 94.6**^{a}	**153.9 ± 34**^{ab}
Batard	3.4	4.2	5.5	5.7	1622.5	940.9	313.5	135.4
3/4 Nain	3.8 ± 0.9	4.1 ± 0.5	5.6 ± 0.2	6.2 ± 0.4	1779.5 ± 134.5	956.6 ± 19.1	224.4 ± 54.2	152.1 ± 17.4
Mbouroukou no. 1	2.9 ± 0.7	3.6 ± 0.7	5.8 ± 0.1	5.7 ± 0	1368.7 ± 84.3	1019.6 ± 35.5	127.2 ± 87.6	88.4 ± 28.5
76–17	3.5	3.5	6.1	6.0	1688.2	902.8	323.8	145.3
Niangafelo	4.3 ± 0.5	4.6 ± 0.4	5.6 ± 0.1	6.2 ± 0.2	1822.5 ± 239.1	893.5 ± 19.2	407.2 ± 81.8	198.4 ± 28.9
Essang	3.6 ± 1.3	3.8 ± 1.3	5.7 ± 0.2	6.0 ± 0.2	1656.0 ± 203	965.7 ± 33.3	262.5 ± 73.3	151.2 ± 31.7
Moto Ebanga	4.1 ± 0.2	4.5 ± 0.3	5.5 ± 0.1	6.1 ± 0.3	1882.2 ± 173.4	898.9 ± 21.1	401.1 ± 22.7	182.1 ± 27.4
Ihitism	3.3	3.4	6.1	6.0	1726.9	967.2	356.6	177.9
Hybrid								
C 292	3.2 ± 0.2	3.6 ± 0.3	5.8 ± 0.5	5.8 ± 0.2	1477.2 ± 204.4	1001.4 ± 9.5	167.6 ± 49.4	98.4 ± 15.6
F 568	3.9 ± 0.9	3.9 ± 0.9	5.6 ± 0.2	5.6 ± 0.1	1347.3 ± 319.9	1176.0 ± 232.5	220.0 ± 24.1	164.3 ± 45.6

$^{\#}$FW: fresh weight. For each cultivar, the value is the mean of two (standard deviation not shown) to three biological replicates, each in duplicate. Superscript a, b, and c result from the comparison of groups using Tukey's test. Groups connected by the same letter are not significantly different.

bananas (74. Two ±1.1% FW) was higher than those of the plantain cooking bananas (61.4 ± 1.9% FW and 60.8% ± 1.4 FW for French plantain and Horn plantain cooking bananas, respectively) Table 2 is in agreement with the results obtained by Gibert et al.[15] According to the direction of the fruit mass vector, AB nonplantain and plantain cooking banana groups had the heaviest fruits. In addition, the highest mean value of pulp total phenolic compounds was observed for the A dessert banana group (247.3 ± 76.3 mg/100 g FW) whereas the lowest mean value was registered for the A nonplantain cooking banana group (65.4 ± 23 mg GAE/100 g FW).

Interestingly, this study shows that the content in pulp total phenolic compounds is one of the most important attributes, which has made the difference between both genomic constitutions (A and AB) within nonplantain cooking bananas and within dessert bananas.

Table 4 presents the nonstandardized coefficients of the estimated classification functions for the six cultivar groups. The two hybrid banana plant under investigation can then be classified by simply multiplying the values of the physicochemical attributes of their fruits with these coefficients and then taking the sum. Table 5 shows the results obtained for the three

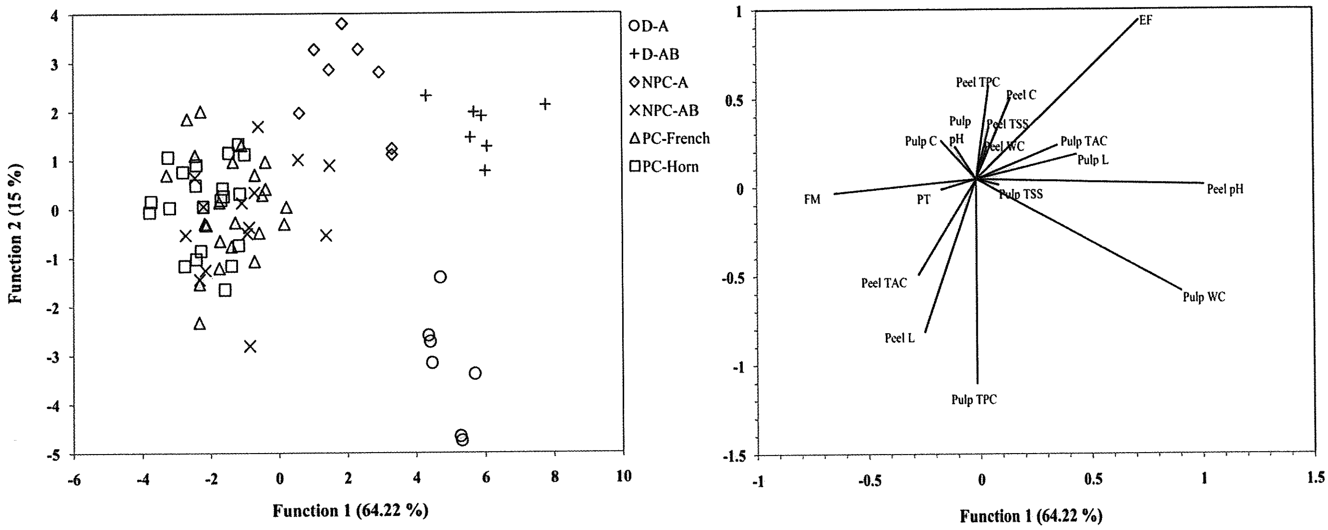

Figure 1. Scatterplot of fruit scores (A) and loading plot of the attribute scoring coefficients (B) from the linear discriminant analysis of cultivar groups at harvest. D, dessert; NPC, nonplantain cooking; PC, plantain cooking; L, lightness; C, chroma; FM, fruit mass; TSS, total soluble solids; TAC, total ash content; TPC, total phenolic compounds; EF, edible fraction; PT, peel thickness; WC, water content.

Table 4. Coefficients of the Classification Functions of the Six Cultivar Groups: Two Groups of Dessert Bananas (D-A and D-AB), Two Groups of Non-Plantain Cooking Bananas (NPC-A and NPC-AB), and plantain cooking bananas (PC-French and PC-Horn)

	banana groups					
	dessert		nonplantain cooking		plantain cooking	
attributes	D-A	D-AB	NPC-A	NPC-AB	PC-French	PC-Horn
constant	−6149	−6199	−6092	−5756	−5768	−5742
pulp L index	46.025	46.764	45.513	44.111	45.074	45.256
peel L index	1.764	1.250	1.229	1.479	1.584	1.690
pulp C index	7.235	7.187	7.581	7.279	7.576	7.391
peel C index	−5.773	−5.272	−5.381	−5.275	−5.526	−5.803
fruit mass (g)	−0.646	−0.666	−0.625	−0.598	−0.612	−0.577
edible fraction (%)	16.471	17.947	17.075	15.971	16.020	16.162
peel thickness (mm)	77.742	78.029	77.279	78.943	79.702	80.944
pulp water content (% FW)	23.642	22.400	22.308	21.587	21.304	21.015
peel water content (% FW)	40.304	40.437	40.951	40.353	40.382	40.283
pulp total soluble solid (°Bx)	−15.451	−14.873	−16.142	−15.996	−16.850	−15.741
peel total soluble solid (°Bx)	67.649	68.200	71.280	70.125	67.745	67.487
pulp pH	134.519	128.306	143.008	137.790	134.589	135.025
peel pH	183.918	187.257	175.114	168.686	162.929	158.509
pulp total ash content (mg/100g FW)	0.053	0.063	0.054	0.050	0.044	0.038
peel total ash content (mg/100g FW)	−0.157	−0.164	−0.167	−0.163	−0.155	−0.155
pulp total phenolic compds. (mg/100 g FW)	−0.218	−0.320	−0.325	−0.289	−0.279	−0.283
peel total phenolic compds. (mg/100 g FW)	0.722	0.741	0.745	0.734	0.727	0.735

Table 5. Classification Functions Evaluated by Introducing the Physicochemical Attributes of Fruit Sample from Each Plant of the Two Hybrids in Equation 1[a]

hybrids	plant no.	D-A[b]	D-AB[b]	NPC-A[b]	NPC-AB[b]	PC-French[b]	PC-Horn[b]	closest match group	second closest group
C 292	1	5635.159	5624.706	5632.933	**5643.053**	5638.656	5629.607	**AB-NPC**	PC-French
	2	5808.170	5797.560	5819.661	5828.004	**5828.487**	5824.287	**PC-French**	NPC-AB
	3	5785.908	5770.814	5797.766	**5807.890**	5805.193	5803.327	**AB-NPC**	PC-French
F 568	1	5805.211	5780.102	5792.958	**5806.956**	5804.187	5794.410	**AB-NPC**	D-A
	2	5838.463	5837.402	5855.108	**5859.519**	5852.975	5844.481	**AB-NPC**	NPC-A
	3	5805.542	5786.669	5802.703	5811.853	**5815.021**	5808.155	**PC-French**	NPC-AB

[a]The closest matches to the cultivar groups are indicated in bold. [b]A, B: genomic constitution of *Musa accuminata* and *Musa balbisiana*, respectively. D, dessert; NPC, nonplantain cooking; PC, plantain cooking. French, Horn: agro-morphological character within plantain cooking bananas, indicating respectively the presence or the absence of the male bud at harvest.

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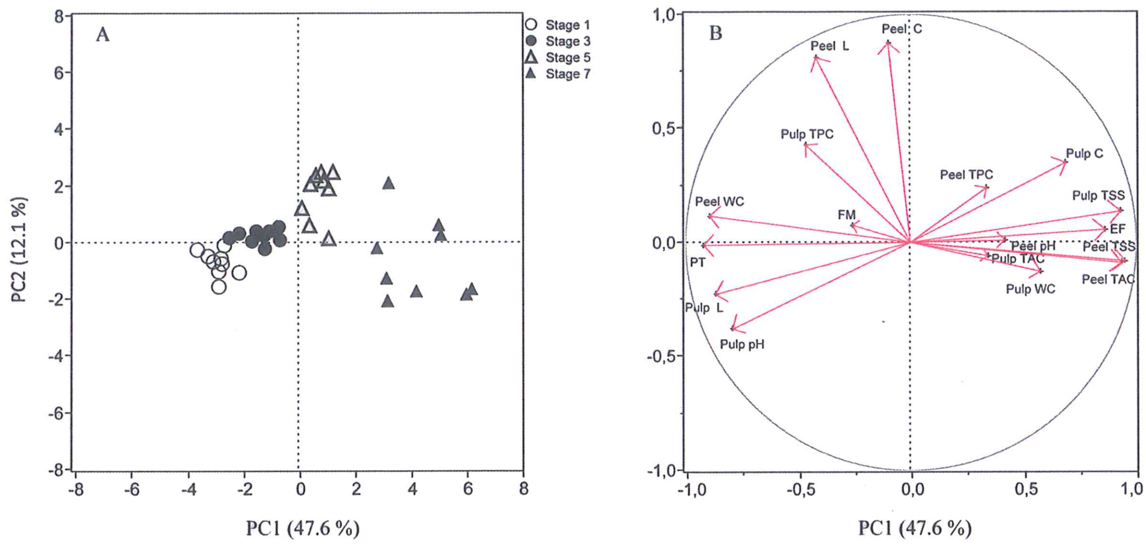

Figure 2. Scatterplot (A) and loading plot (B) of the principal component analysis performed on standardized data physicochemical tributes obtained from three plantain genotypes (Mbeta 1, Red Yade, and 3/4 Nain) at different ripening stages 1, 3, 5, and 7 (n = 3). L, lightness; C, chroma; FM, fruit mass; TSS, total soluble solids; TAC, total ash content; TPC, total phenolic compounds; EF, edible fraction; PT, peel thickness; WC, water content.

plants of each of these two hybrids. It can be observed that the highest values correspond to AB nonplantain cooking (NPC-AB) and French plantain cooking groups (PC-French), which means that the hybrids appear closer to those groups. Interestingly, the two hybrids had in their family tree, monospecific (AA) and interspecific (AB) cooking bananas. In fact, their parents are also hybrids, obtained following two different crossings, one between the A nonplantain cooking banana Tomolo (AA) and the A cooking hybrid Crbp060 (AA), and another between the French plantain cooking banana Red Yade (AAB) and the wild species Calcutta 4 (AA) (which was shown to be close to the A dessert banana group, data not shown). This shows that the interspecific cooking banana physicochemical characters were dominant. However, for the hybrid F568, the plants nos. 1 and 2 also appear to be close to the A dessert group (D-A) and to the A nonplantain cooking group (NPC-A), respectively.

Physicochemical Changes during the Ripening Process of Plantains. *Description.* In order to study the evolution of the physicochemical attributes of plantains during ripening, we performed a principal component analysis on three cultivars, namely Mbeta 1, Red Yade, and 3/4 Nain. Stages 1, 3, 5, and 7 were evaluated. The results are presented as a scatterplot of the scores of the different ripening stages, and a loading plot of the attributes (Figure 2).

On the scatterplot, four clusters corresponding to each ripening stage can be observed. The four groups are separated along the principal component 1 (PC1) axis in an ascending order from the left to the right (Figure 2A). A simultaneous analysis of the vector positions of the attributes in the loading plots (Figure 2B) shows that the physicochemical attributes are distributed in three groups. Two of them are correlated with the ripening stage and negatively correlated with each other. The first group is positively correlated with the ripening stage and includes pulp and peel total soluble solids, peel total ash content, edible fraction and pulp C index, suggesting that these parameters increased during the ripening. Peel total phenolic compounds, pulp water content, pulp total ash content, and peel pH also appear positively correlated with the ripening stage but to a lesser extent. The second group consists of peel thickness, peel water content, pulp L index, and pulp pH, which are, on the other hand, negatively correlated with the ripening stage. The third group including peel C and peel L indexes and to a lesser extent pulp total phenolic compounds separated the ripening stage group 5 from the other ripening stage groups on the PC2 axis. This suggests that the values of these three attributes reached a maximum at stage 5 and then decreased.

Peel and pulp color changes associated with the ripening process could be described by the evolution of L and C indexes. The increase of peel lightness and chroma to a maximum level at stage 5 could express the change from the green color to the yellow color due to the chlorophyll degradation and the accumulation of carotenoids.[39] Their subsequent decrease could be related to the apparition of black spots that might involve enzymatic browning due to the activity of the polyphenol oxidase and of other oxidative enzymes.[39,40] In pulp, the decrease of lightness and the increase of chroma reflect the decrease of whiteness and the increase of the color intensity.

Changes in fruit firmness can be considered as another means by which the ripening is perceived. Fruit firmness was not measured in this study but it has been reported that the softening of the fruit results from the disruption of cell walls and the hydrolysis of starch under the actions of amylase and other enzymes.[39] In general terms, the ripening process in the pulp results in the release of water-soluble solids, which include proteins, minerals, and predominantly soluble sugars from the starch hydrolysis and are evaluated by the total soluble solid measurement. The subsequent osmotic transfer of water from the peel into the pulp may have resulted in the increase of pulp water content and pulp edible fraction.[41,42] A transfer of water and other volatile compounds (carbon dioxide, ethylene, and aroma) from the peel to the environment[31] has probably also contributed to the decrease of peel water content and peel thickness. The decrease of peel water content might have resulted in the increase of the peel total ash concentration.

A decrease of pulp pH was registered upon ripening, which fits with an increase of acidic taste. The pH decrease is believed

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Table 6. Models Proposed for the Prediction of the Ripening Stages of Plantains after Performing the Logistic Regression on Each Biological Replicate of 12 Genotypes[a]

		prediction models				prediction ability[b]				
models	attributes involved	cumulative logits	R^2	AICc criteria	n[c]	ripening stages 1	3	5	7	n/stage[d]
1	pulp TSS	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}6.94\\13.85\\27.23\end{bmatrix} - 1.48\ \text{pulp TSS}$	0.75	82.46	108	7	7	8	1	8
2	pulp TSS, pulp pH, peel TAC, peel C	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}-7.20\\10.84\\42.7\end{bmatrix} - 2.20\ \text{pulp TSS} + 5.47\text{pulp pH} - 0.01\ \text{peel TAC} + 0.38\ \text{peel C}$	0.92	38.78	108	7	4	8	6	8
3	pulp pH, peel TAC	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}-97.94\\-87.43\\-80.20\end{bmatrix} + 20.37\ \text{pulp pH} + 0.019\ \text{peel TAC} - 0.005\ \text{pulp pH}\cdot\text{peel TAC}$	0.81	70.50	108	8	6	7	6	8
4	pulp and peel L index, pulp and peel WC, PT	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}-125.35\\-116.8\\-103.7\end{bmatrix} + 0.96\ \text{pulp L} - 0.14\ \text{peel L} + 0.69\ \text{pulp WC} + 1.06\ \text{peel WC} + 3.76\ \text{PT}$	0.82	70.45	108	8	5	7	7	8
5	peel TSS and peel TPC	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}33.67\\44.09\\65.20\end{bmatrix} - 6.72\ \text{peel TSS} - 0.022\ \text{peel TPC}$	0.88	23.30	36	5	1	1	6	6
6	EF, pulp pH, pulp TPC	$\text{logit}\begin{bmatrix}1\\3\\5\end{bmatrix} = \begin{bmatrix}-71.14\\-66.21\\-47.61\end{bmatrix} - 0.86\text{EF} + 23.42\ \text{pulp pH} + 0.39\ \text{pulp TPC} - 0.074\ \text{pulp pH}\cdot\text{pulp TPC}$	0.79	37.97	36	6	5	5	0	6

[a]Prediction abilities of the proposed equation on each biological replication of 3 genotypes characterized by a green peel with chestnut pigments are also presented. Abbreviations; TSS, total soluble solids; TAC, total ash content; TPC, total phenolic compounds; EF, edible fraction; PT, peel thickness; WC, water content; L, lightness; AICc, Akaike information criterion. [b]Number of samples determined to be at the corresponding ripening stage according to the corresponding prediction model. [c]Number of observations. Each observation represents one biological replicate of a cultivar, at one ripening stage. [d]Number of samples collected at each ripening stage according to the color scale.

to be associated with the accumulation of some organic acids such as malic acid.[43]

Pulp total phenolic compounds increased up to the ripening stage 5 and then decreased, whereas peel total phenolic compounds increased throughout the ripening process. This suggests a tissue specific regulation of the ripening process as mentioned by Bruno Bonnet et al.[44] and Inaba et al.[45] for *Musa* species. A different result was found by Ngoh Newilah et al.,[36] who obtained an increase in pulp total phenolic compounds of plantains from stage 1 to stage 7. During the ripening, it is generally reported that anthocyanin-rich fruits increase their content in total phenolic compounds, whereas many other fruits have their total phenolic compounds decreasing.[46]

The observed separation of the ripening stage groups suggests that, whatever the cultivar, a ripening stage could be characterized by a certain behavior of same physicochemical attributes. Under this hypothesis and considering the great importance of the identification of the ripening stage in food processing, physicochemical attributes were used to model the ripening stages.

Modeling the Ripening Stages Using Logistic Regression. Table 6 presents the proposed prediction equations in the form of the cumulative logit function as explained in the Materials and Methods section. The ability of those models to predict the ripening stages of three plantain genotypes are also presented. The number of well classified plantain samples over the total sample investigated at each ripening stage is reported. Each model presents the cumulative logit of each of the 3 first ripening stages, which have different constant values but the same coefficient per attribute. Lower AICc values indicate better fittings.

For each model, the involved attribute coefficients were found to be significant ($P < 0.05$) according to the likelihood-ratio χ-square test. When performing stepwise regression control in the forward direction, pulp total soluble solids was the first attribute selected by the software and model 1 was proposed. This indicates that its contribution to the ripening was the most important. When the stepwise process ended, pulp pH, peel total ash content and peel C index were additionally selected. Model 2 was then proposed as the best model and was used as a reference. Its R^2 and AICc values were 0.92 and 38.78, respectively (Table 6).

We investigated many combinations of attributes to find other models with fitting parameters and prediction abilities similar to those of the reference model (model 2). Models 3 and 4 were found to be among the best. They had lower R^2 values (0.81 and 0.82, respectively) and higher AICc values (70.50 and 70.45, respectively) than model 2 but their prediction abilities were close to those of model 2. They may offer an alternative when there is a lack of material needed to assess some attributes involved in model 2. Model 6, involving edible fraction, pulp pH, and pulp total phenolic compounds, had good fitting parameters when compared to models 3 and 4, and its prediction ability was almost similar to those of the model 1. Models 1 and 6 had acceptable prediction abilities up to stage 5 but were not effective to make the difference between stages 5 and 7.

All the models had ripening stage predictions below 100%. This supports the fact that the monitoring of the ripening stage based on the color scale and using a subjective assessment might lead to wrong classifications. Applying a model as a ripening stage control method, which uses objective parameters can increase the homogeneity within a ripening stage group and could be therefore relevant. Moreover, it is worth noting that the best models involved more than one physicochemical attribute, which stresses the importance of considering diverse attributes in the determination of the ripening stage of plantain.

CONCLUSIONS

We aimed at investigating the involvement of some *Musa* sp. fruit postharvest physicochemical characteristics in the differentiation between diverse *Musa* sp. cultivars, as well as in the prediction of the plantain ripening stages. The discriminant analysis highlighted the importance of the edible fraction, the peel pH, the pulp water content, and the pulp total phenolic compounds in the distinction between cultivar groups at ripening stage 1. The great contribution of the pulp total phenolic compounds in the differentiation between interspecific and intraspecific groups within the dessert bananas and the nonplantain cooking bananas called for a deeper understanding of the specific phenolic composition. The physicochemical attributes considered in the present study did however not allow differentiating French and Horn plantain cooking bananas. They also showed that interspecific nonplantain cooking bananas are very close to plantain cooking bananas. The hybrids seemed to have physicochemical characteristics close to those of interspecific cooking bananas. This result seems to meet the breeder expectations who created these hybrids to be like plantain. It also emerged from this study that the use of logistic regression could be successfully applied in the control of the fruit ripening stages. The involvement of pulp total phenolic compounds in the model that had good evaluations according to R^2 and AICc criterion aroused the interest for monitoring the phenolic compound profiles during the ripening process. These results allow to consider applying the proposed analytical approaches to a whole collection such as that of the CARBAP. The genomic constitution in its entirety (ploidy level and composition in A and B genomes) will be thus taken into account for the characterization of *Musa* cultivars. This broadening of samples will also enhance the search of the ripening stage prediction models easily applicable to a wide range of cultivars.

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Notes

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