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Differentiation between Cooking Bananas and Dessert Bananas. 1. Morphological and Compositional Characterization of Cultivated Colombian Musaceae (*Musa* sp.) in Relation to Consumer Preferences

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The morphological, physical, and chemical characteristics of 23 unripe cultivated varieties of Colombian Musaceae were assessed. Fresh pulp dry matter helped to discriminate the following consumption subgroups: FHIA dessert hybrids (*hydes*: 24.6%) < dessert bananas (*des*: 29.4%) < nonplantain cooking bananas (*cook:* 32.0%) < FHIA cooking hybrids (*hycook:* 34.2%) < plantains (*pl:* 41.1%). Banana flour starch content on dry basis (db) varied from 74.2 to 88.2% among the varieties, with: *pl:* 86.5% > *cook* and *hycook:* 84% > *des:* 81.9% > *hydes*: 79.7% ($p \leq 0.01$). Flour pH varied in the range 4.8 to 6.2, with the highest pH for the plantain subgroup (5.6), which also had lower titratable acidity than those of the cooking banana and FHIA groups with 7.9, 13.6, and 15.6 mEq H^+/100 g db, respectively ($p \leq 0.05$). *pl* and *hycook* presented the highest glucose and fructose contents at 0.8% and 1.5% ($p \leq 0.05$). No significant differences were observed between the groups in proteins (3.2%), total soluble sugars (1.7%), and crude fibers (3%). *pl* had lower ash, calcium, and magnesium contents (2.7%; 8.4 and 90.7 mg/100 g db) than *des* (3.2%; 9.3 and 117.9 mg/100 g db) and *hydes* (3.9%; 23.7 and 125 mg/100 g db) ($p \leq 0.05$). *pl* and *des* had significantly lower peel percentages (38%) than the other subgroups (42−45%). The principal components analysis (PCA) highlights the strong relationship between some of the varietal characteristics and the consumption pattern, which is especially marked for the plantain subgroup in relation to stakeholder and the consumer preferences.

KEYWORDS: *Musa* sp.; sampling; dry matter content; starch; soluble sugars; minerals; plantain

INTRODUCTION

As a major staple food, bananas are cultivated in over 130 countries throughout the tropical and subtropical regions on five continents. The world production of dessert and cooking landraces is estimated to be about 104.3 million tons. The main producers of dessert bananas are India, Brazil, China, Ecuador, and the Philippines, while the main exporters are Ecuador, Costa Rica, the Philippines, and Colombia. The latter is the leading producing country of plantain subgroup cooking bananas. Colombia and Ecuador are the world's two leading plantain exporting countries (*1*).

As a product of parthenocarpy, banana fruits (dessert and cooking) and plantain fruits belong to the Eumusa section. Edible Musa plants (genus Musa) are classified in different genomic groups, AA, AB, BB, AAA, AAB, ABB, AAAA, AAAB, and ABBB (*2*). The current botanical classification based on agromorphological variations helps us in the differentiation of landraces of dessert bananas (AA, AAA, AAB), cooking bananas (AAA, AAB, ABB), and plantain cooking bananas (AAB). However, more complete morpho-descriptors or molecular markers have led to the classification of genomic groups for triploid bananas (*2*). Dessert bananas are consumed raw at a full stage of maturity. Cooking bananas are cooked to be consumed at various stages of maturity and are disliked when uncooked (absence of sweetness, unpleasant texture, with a granular and hard feels in the mouth). For a century, genetic improvement programs have been mainly oriented toward the development of disease and pest resistant varieties. Breeding strategies have been focused on agronomic aspects: yields, appearance, stress tolerance, shelf life, mineral and water uptakes and mechanical strength (*2*). Among the tetraploid species introduced, the FHIA hybrids

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(from the *Fundación Hondureña de Investigación Agricola*) are advantageous in terms of productivity and pest resistance. Nevertheless, hybrids are often rejected by consumers due to some visual, sensorial, and textural flaws, as well as low dry matter content and green life duration (*3*, *4*).

In many tropical countries where export bananas (mainly the Cavendish subgroup, *Musa* sp. AAA) are produced (*1*), culled dessert bananas could be sold at a much lower price than cooking bananas and then cooked for consumption. Nevertheless, a strong local demand remains for green cooking bananas. This observation suggests that the consumers have a relevant appreciation of the quality of the clones, and prefer costly cooking landraces for their traditional recipes (*5*). Neglected varieties (cultivated by stakeholders) are usually described without establishing any link to consumer preferences and uses. While most research into preferences and uses has been reported in Africa and the Pacific area, a recent socio-economic study conducted in Northern Cauca (Colombia) identified about 30 "locally produced" dessert bananas and cooking bananas (*6*). The food consumption survey confirmed the stakeholders' knowledge regarding diversity, tastes, and preferences in relation to the specific uses of bananas (*5*−*9*).

The agro-morphotaxonomic analysis has now been standardized with more than 119 descriptors (*2*). The most cited morphological criteria investigated for the comparison between bananas were: the bunch and fruit weight, the number of fruits, and the pulp to peel percentage (*10*−*13*). Moreover, the physical and chemical characteristics were often investigated for comparison between varieties at various stages of ripeness. The dry matter content (DM) is one of the main investigated criteria, with a high trait stability within various cropping environments (*12*, *13*); various ranges are reported in the literature for bananas from 22.2 to 27.3% (*10*, *12*−*14*), and from 26.5 to 42.5% (*10*−*12*, *14*, *15*) for cooking bananas.

Recently, two bibliographic studies were published and reviewed to compare the composition and the physical and chemical characteristics of the pulps and flours of banana fruits at different ripening stages (*4*, *7*). Since numerous methodologies were used to describe proximal analyses of dessert bananas (*13*, *16*−*18*), of plantains, or of cooking bananas (*11*, *14*, *15*, *19*−*22*) and at various stages of maturity, a concentration range can be estimated for a given analysis without any significant differences between groups or consumption modes established.

At a green stage of maturity, the pH of the fruits or of the flours ranges from 4.4 to 6.2 (*4*); the titratable acidity fluctuates from 1 g malic acid/kg equivalent (*18*) to 1.7 g of citric acid/kg equivalent (*23*). The titratable acidity could rise during maturation to 4.6 g citric acid/kg whereas the pH could fall to 4. The ash content varies from 2 (*19*) to 4.7% (*17*). At the green stage of maturity, the total sugars range from 2.2 to 12.1% (*11*) with the soluble sugars listed by some authors as glucose, fructose and sucrose (*13*, *15*, *23*). Proteins content varies from 2.5 (*16*) to 5.3% (*13*), whereas lipids content varies from 0.33 (*16*) to 2.7% (*17*), fibers content varies from 3.8 (*20*) to 12.6% (*16*), and dietetic fibers content varies from 8.9 to 14.5% (*17*, *19*, *20*, *22*). The starch percentage of the flours is reported from 59 (*11*) to 86.6% (*15*), whereas the total carbohydrates are estimated at up to 90.2% (*21*).

Regarding the macrominerals in bananas on fresh matter basis (wb), the potassium content (K in mg/100 g wb) is reported in the range 256 to 534; the calcium content (Ca in mg/100 g wb) is reported in the range 3.8 to 19.9, whereas the magnesium content (Mg in mg/100 g wb) is in the range 17 to 45.8 (*22*, *24*−*26*). The additional K, Ca and Mg contents (wb) in cooking bananas are estimated at 499 mg, 3 mg and 37 mg respectively (*22*). Few other studies have focused on intrabunch variability (*18*, *27*). However, in many of those studies, just a few varieties were considered: the literature still lacks some comparison between many varieties to define some objective criteria to differentiate clones and genomic groups.

This study aimed at investigating the morphological, physical and chemical characteristics of the Colombian cultivated varieties previously described in relation to consumer preferences and uses (*6*). This work attempted to differentiate among the banana cultivars through morphological and compositional analysis, and to find some acceptance criteria that could explain the adoption or rejection of varieties by consumers and industry. These criteria may be used for detecting the neglected cultivars with some potential for home consumption and for industrial processing. These analyses should contribute to the understanding of the relationship existing between cooking behavior and consumer preferences, as well as being helpful for future breeding strategies for the creation of suitable new clones of banana germplasms.

MATERIALS AND METHODS

Varieties and fruit samples. Twenty-three edible *Musa* L. section Eumusa ($2n = 2x = 22$, $2n = 3x = 33$ and $2n = 4x = 44$) cultivated varieties by intercropping with cocoa on smallholdings, including 6 dessert bananas (2 AA, 4 AAA genome types), 4 banana FHIA hybrids (1 AAAA, 3 AAAB), 6 plantain landraces (AAB), 2 cooking FHIA hybrids (AAAB), and 5 cooking banana landraces (1 AAA, 2 AAB, 2 ABB) were collected after two crop cycles from homogeneous and nonintensive farming systems in the states of Cauca, Valle del Cauca, Caldas and Quindío in Colombia (**Table 1**). The stakeholders estimated the *Musaceae* optimal green stage of maturity for harvest using the banana fruit fullness-plumpness visual criterion (disappearance of fruit angularity at round-full stage) (*12*). The 23 cultivars were classified according to their usual consumption mode: as "dessert bananas" eaten raw and "cooking bananas" cooked to be consumed. All genetic groups were identified using the vernacular names, combined with the description of the varieties (*2*, *6*, *28*, *29*).

Physical Characterization. Physical characterizations were performed for 21 varieties using 45 bunches ("Cavendish" and "FHIA 18" were not characterized). Full bunch characterizations were repeated depending on availability.

Fruit Labeling and Description. Clusters of fruits (hands) were labeled from the basal (spike) to distal hand (raquis) of the bunch. Fruits (fingers) were labeled from the left-hand side with the inner curvature on top (outer curve side facing the bench). Hands distributed in one or two rows, according to the variety, were also identified as internal row A (top row clusters nearest to the stalk) and external row B of the hand. Fruits from the same bunch were all collected at the same time. The bunch weights, hand weights, volumes, lengths, number of fingers per bunch, proximal median, and distal girths of fingers, weight, and volumes per hand were recorded for individual plants. Immediately after peeling, the peel and pulp were weighed; the pulp lengths, girths, and volumes were also measured (*30*). Standardized pictures of representative fingers and their median cross sections were taken for 20 varieties (**Figure 1**).

Specific Gravity. The specific gravities of fingers and pulps were estimated in duplicate, using the ratio of fruit weight in air to fruit volume (*30*).

Peel Percentage. The percentage of peel (Peel %, w/w of finger) was determined by the percentage ratio of peel to finger.

Composition and Chemical Characterization. *Dry Matter Content and Dry Weight Yield of Edible Food*. Except for "Bocadillo" (hand label 6) and "Cavendish" (unknown hand label), pulp samples were collected from each hand of the varieties for DM determination in triplicate using a using a ventilated oven at 104 ± 1 °C overnight. The mean bunch DM was estimated by averaging pulp dry weight per hand. The total dry weight yield of edible food (EFY/kg plant) was calculated (*10*, *12*) using Peel %, DM, and bunch weight without raquis.

pH and Titratable Acidity. About 0.6 g of dried flour was blended with about 6 mL deionized water (10% w/V) for 30 min using a magnetic stirrer. The pH of the blended solution was determined at ambient

Table 1. Consumption Mode, Classification, Origin, and Number of Bunches Sampled

	local name	genome	subgroup	collecting area	bunch
dessert bananas	bocadillo (Bo)	AA	sucrier	Cauca[a]	1
	primitivo (Pr)	AA	sucrier	Cauca[b]	1
	cavendish (Cav)	AAA	cavendish	Valle del Cauca[c]	1
	gros Michel (GM)	AAA	gros michel	Quindío[d]	1
	rollizo (Ro)	AAA	/	Cauca[e]	1
	tafetan morado (TM)	AAA	red dacca	Cauca[b]	1
	fhia 17 (F 17)	AAAA	hybrid	Quindío [f]	1
	fhia 1 (F 1)	AAAB	hybrid	Valle del Cauca[g]	1
	fhia 18 (F 18)	AAAB	hybrid	Valle del Cauca[g]	1
	fhia 25 (F 25)	AAAB	hybrid	Valle del Cauca[g]	1
cooking bananas	guineo (Gui)	AAA	mutika - lujugira	Quindío[h], Cauca[b]	4
	africa (Af)	AAB	plantain	Caldas[i]	3
	dominico (Do)	AAB	plantain	Quindío[h]	1
	dominico harton (DH)	AAB	plantain	Caldas[i], Cauca[b] Quindio[h]	7
	harton (Ha)	AAB	plantain	Cauca[b]	4
	cubano blanco (CB)	AAB	plantain	Cauca[b]	4
	maqueño (Ma)	AAB	plantain	Cauca[b]	3
	guayabo (Gua)	AAB	mahia-maoli	Cauca[c]	1
	hua moa (HM)	AAB	mahia-maoli	Quindío[h]	1
	cachaco (Ca)	ABB	bluggoe	Cauca[j]	3
	pelipita (Pe)	ABB	pelipita	Cauca[b]	1
	fhia 20 (F 20)	AAAB	hybrid	Caldas[i]	3
	fhia 21 (F 21)	AAAB	hybrid	Caldas[i]	2

[a] Caloto (1100m). [b] Puerto Tejada (970m). [c] Unknown city. [d] Buenavista (1360m). [e] Morales (1670m). [f] La Tebaida (1180m). [g] Palmira (1000m). [h] Armenia (1360m). [i] Palestina (1050m). [j] Guachene (1000m).

temperature. The total acidity was then measured without filtration by titration with 0.1 N NaOH to equivalent point (pH 7), using an automatic Titroline apparatus (Schott Schweiz AG, St. Gallen, Switzerland). The result was calculated in milliequivalent hydrogen ions per 100 g dry matter (mEq H^+/100 g DM).

Ash Content. Banana flour ash content was calculated following heating to 550 °C for 3 h as per AOAC (1996) official method **923.03**.

Crude Fiber Content. The fiber content was determined for the loss on ignition of dried residue remaining after digestion of banana flour (2 g) with 1.25% H_2SO4 and 1.25% NaOH as per AOAC (1996) official method **962.09**.

Total Nitrogen Content. The percentage protein was determined through the quantification of total nitrogen using an elementary analyzer (Thermoquest-CN) following Dumas" method, using 50−150 mg aliquots of banana flour. The nitrogen content was quantified by gas chromatography with suitable calibration (EDTA, Glycine) as per AFNOR (1998) NF ISO **13878**. The coefficient used for converting banana nitrogen content into total proteins used was 5.32 (*31*). The analyses were conducted at CIRAD US49 central laboratory (Montpellier, France).

Soluble Sugars by HPAEC-PAD. Thirty mg aliquots of dried and ground banana flours were weighted into 2 mL centrifuge tubes. Sugars were extracted twice using 1 mL of 80% ethanol at 80 °C for 30 min, and centrifuged at 10 000 rpm for 15 min. An additional extraction was performed using 1 mL of 50% ethanol in the same conditions. The supernatant fractions were mixed, introduced into a vial, the volume adjusted to 5 mL and then filtered via a 0.45 μm cellulose acetate screen.

The soluble sugars were separated using a Dionex DX600 with a Carbopac MA-1 Column (Dionex corp., Sunnyvale, CA). All determinations were carried out at a temperature of 30 °C and at a flow rate of 0.4 mL/min, and 1 μL of sample was injected. The detection process used a pulsed amperometric detector (HPAE-PAD). After 10 min elution with 0.8 M sodium hydroxide, alkaline gradients from 0.8 to 0.6 M at 0.02 M/min, and then from 0.6 to 0.8 M at 0.02 M/min and then 10 min at 0.8 M were generated in succession. The soluble sugars were determined in duplicate, and the result was calculated in mg/100 g db.

Total Sugars. Sugars were extracted from 2 g of banana flour using an 85% ethanol solution, a Fehling reagent, and a glucose standard curve. Sugar concentration was estimated at 520 ηm (*15*, *32*) using a Cecil spectrophotometer model CE 2021-series 2000 (Cecil Instruments Ltd., Cambridge, UK).

Starch Content. After removal of sugars by extraction with ethanol, 0.25 g of flour residue was incubated with thermostable α-amylase and then with amyloglucosidase. After reaction with ABTS containing glucose oxidase and peroxidase included, the released glucose was measured by absorbance at 560 ηm (*15*, *32*). Starch content was estimated as 90% of glucose content. The data were corrected with a soluble starch percentage recovery of around 96%.

Minerals. The potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na) content of 1 g of dried and ground flour from the second hand of each variety was determined on dry matter basis by Varian-Vista Pro inductively coupled plasma-atomic emission spectrometry (ICP-AES: Varian Inc., Palo Alto, CA, USA) using a coupled charge device detector, as per AOAC official analysis method **985.01**. A two-stage dry mineralization procedure (HCl, HF) was carried out with double oven incineration at 500 °C, prior to ICP-AES multiwavelength determination. A resolution of 5, 15, 6, and 50%, respectively, was permitted for K, Ca, Mg, and Na using the standardized protocol with internal standards. The mineral content was then calculated on fresh matter basis using individual dry matter contents of the pulp (second hand DM), except for "Bocadillo" (hand 6 DM), "Cavendish" (unknown hand DM used) and "FHIA 18" (mean bunch DM used). The analyses were performed at CIRAD US49 central laboratory (Montpellier, France).

Statistical Analysis. The physical and chemical results represent the mean values of triplicate analysis or more, depending on the availability of the data. Analysis of variance (ANOVA) was performed on raw data using the following class variables: banana variety, consumption group (dessert or cooking banana), consumption subgroup (dessert banana, dessert hybrid, cooking banana, cooking hybrid, and plantain), hand label, finger label, and row label, to differentiate varieties and to assess biological variability. Principal component analysis (PCA) was performed using The Unscrambler V.9.2 software package (Camo Inc., Woodbridge, New Jersey) on 23 varieties, even though some morphological data were missing for "Bocadillo" and "Primitivo" clones. Chemical variables were selected on fresh wet basis. Mean separations were performed by Tukeys' Honestly Significantly Difference test (HSD posthoc test) at $p \leq 0.05$ and $p \leq 0.01$, using the Statistica V.6.1 software package (StatSoft Inc., Tulsa, Oklahoma).

Data Normalization and Graphical Combination. The most relevant parameters highlighted by statistical analysis were selected. The parameters were individually normalized in the interval 0−1 (where 0 and

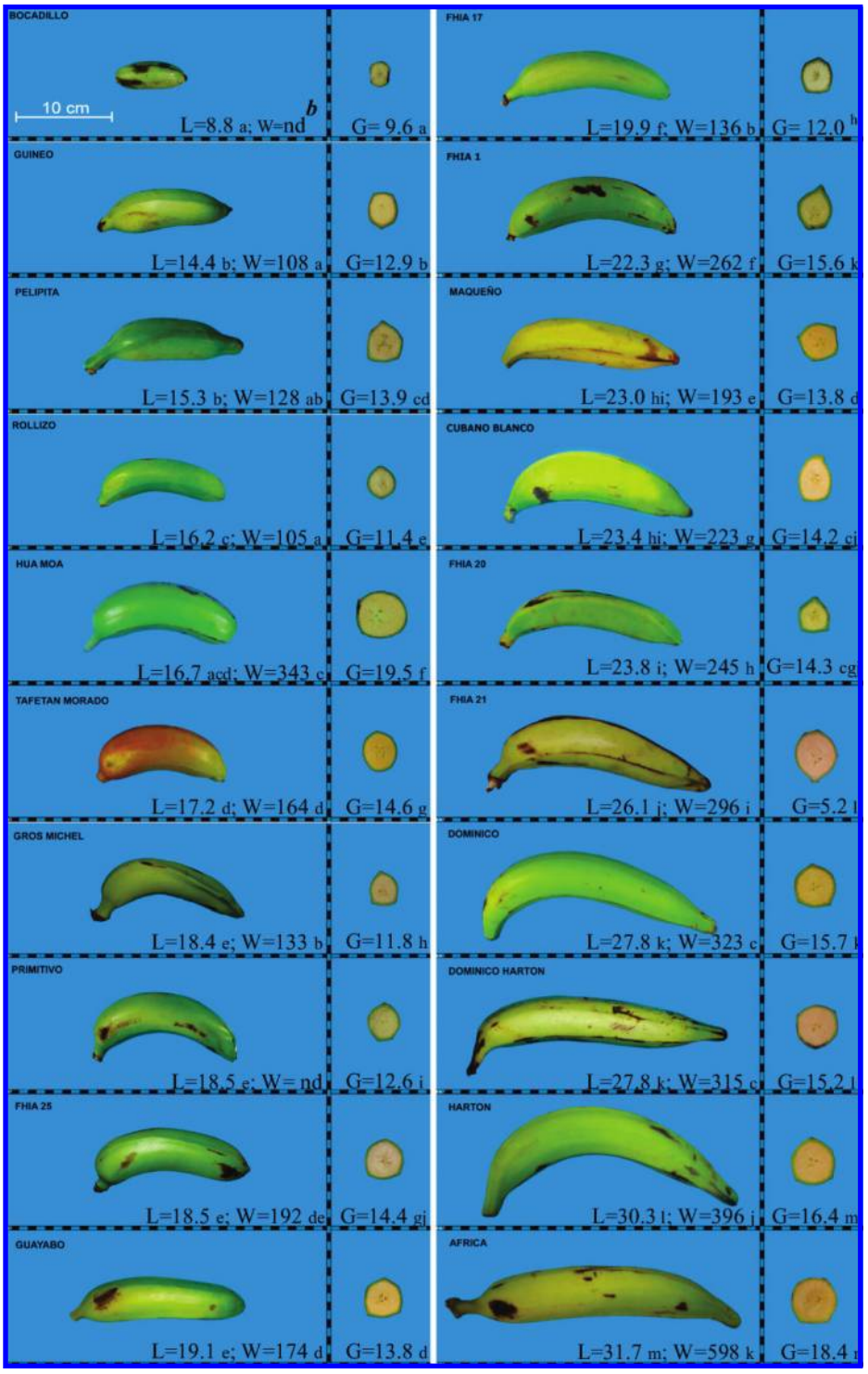

Figure 1. Mean variety length distribution (length: L, cm) with corresponding median section (girth: G, cm) and finger weight (weight: W, g).[a] Significant difference is indicated by different letters within the same row ($p \leq 0.01$). [b] Not determined.

1 represent the smallest and the highest value respectively for each parameter) combining the data of the 6 dessert banana landraces without hybrids, the 6 plantains, and the 5 nonplantain cooking bananas without hybrids. The normalized data were averaged per subgroup prior to being graphically combined within a radar chart.

RESULTS

Physical Characterization. A wide distribution of lengths, finger weights and cross sections were revealed (**Figure 1**). Most industrial varieties had big lengths, finger weights and diameters. The three main industrial plantain clones: "Dominico", "Dominico Harton" and "Harton" (*6*) exhibited a relatively low variability. Those three varieties exhibited significant differences in banana length, weight and girth from other cultivars ($p \leq 0.01$). Except for "FHIA 25", plantains and cooking hybrids were the largest varieties ("FHIA 20", "FHIA 21", "Dominico", "Dominico Harton", "Harton", and "Africa"). With a mean fruit length of over 30 cm, "Africa" and "Harton" were distinctly longer than the other clones. Dessert and cooking bananas were heterogeneously distributed and smaller.

Most dessert bananas had small circumferences. Except for the "Hua Moa" cooking banana, the two extreme cultivars in terms

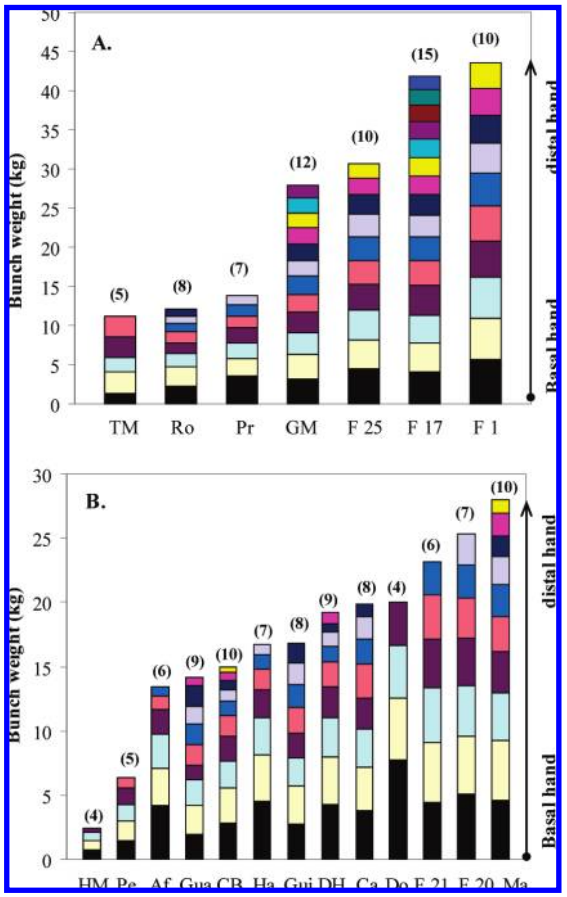

Figure 2. Bunch weight and hand weight distribution of dessert bananas, with total number of hands per variety in parentheses: TM, Tafetan Morado; Ro, Rollizo; Pr, Primitivo; GM, Gros Michel; F 25, FHIA 25; F 17, FHIA 17; F 1, FHIA 1 (**A**); Bunch weight and hand weight distribution of plantains and nonplantain cooking bananas, with total number of hands per variety in parentheses: HM, Hua Moa; Pe, Pelipita; Af, Africa; Gua, Guayabo; CB, Cubano Blanco; Ha, Harton; Gui, Guineo; DH, Dominico Harton; Ca, Cachaco; Do, Dominico; F 21, FHIA 21; F 20, FHIA 20; Ma, Maqueño (**B**).

of length ("Bocadillo" and "Africa") were also the two extremes in terms of circumference. The "Africa" variety had an attractively large cross section, even though its productivity proved to be low. Such varieties could be useful for production of chips. Length, finger weight, and median girth of fingers proved to be suitable for partially discriminating varieties on an individual basis ($p \leq 0.01$). Some peel color variations within/between varieties were observed. The visual differences within/between varieties also took the form of various shapes and apical appearances.

The mean calculated weight of banana bunches and hand weights were combined from basal to distal hands of dessert bananas (**Figure 2A**) and of cooking bananas (**Figure 2B**). The mean bunch weight distribution covered a range from 2.7 to 49.4 kg, with "Hua Moa" and hybrid "FHIA 1" at the extremes. The hybrids of FHIA are known for having a very high yield (*3*). Except for most hybrids, "Gros Michel" had the heaviest bunch (**Figure 2A**). The mean hand weight per cultivar varied from 549 to 4352 g. Hybrids exhibited the highest average weight per hand. Except for "Gros Michel", mean comparisons demonstrated a significant reduction of hand weights from basal to distal hand in most varieties ($p \leq 0.01$). The absence of significant differences within some other varieties ("Primitivo", "Tafetan Morado", and "Guineo") suggested high heterogeneity between hands and in particular concerning the extreme hands. These results are consistent with some other studies showing that there are significant differences in weight and/or size between basal and distal banana fruits (*27*). This is the consequence of banana bunch growth starting at the proximal hand and spreading, after a lag, to the distal hand of the bunch. This sort of intrabunch variability was also linked to a difference in cell number and age. Some clones exhibited a relatively low number of hands per bunch whereas some other exhibited numerous hands per bunch.

The circumference decreased from the proximal to the distal hand of the bunch (**Figure 3A**). In addition, the proximal and distal girths were observed as heterogeneous: no significant statistical trends were observed when considering proximal and distal girths, which proved to be strongly dissimilar. The median girths of the varieties were larger than proximal and distal circumferences. Four varieties, "Tafetan Morado", "FHIA 1", "FHIA 21", and "Dominico", exhibited a low relative variation for median girth (as well as for finger length). The latter was the only industrial variety to exhibit such relatively low variability for the axial and longitudinal dimensions.

Specific Gravity. Except for "Cachaco" and "FHIA 1", individual pulp densities were higher than finger densities (**Figure 3B**). A weak correlation was established between peeled finger (pulp) and finger specific gravities. Five subgroups were defined from the two consumption groups. The dessert banana group was divided into two subgroups, as dessert bananas (des) and dessert hybrids (hydes), whereas the cooking consumption group was divided into a plantain (pl), a cooking hybrid (hycook) and a nonplantain cooking banana subgroup (cook). The corresponding mean separations (**Table 2**) were relatively poor at discriminating dessert bananas from cooking hybrids and plantains ($p \leq 0.01$).

Peel Percentage. From an industrial point of view, the varieties with low peel percentages are obviously attractive, such as "Africa", "FHIA 25", "Dominico", and the atypically heterogeneous "Hua Moa" (**Figure 3C**). Nevertheless, the latter was previously shown to have the smallest bunch and one of the smallest hand weights and number of fruits per hand. With a peel percentage in the range 35−40%, a cooking banana variety could be expected to be used in industry. The varieties "Pelipita" and "Cachaco" clones used in the Colombian industry (*6*), as well as "FHIA 20", had an average peel percentage in the range 40−45%, which is a disadvantage due to the high loss of raw material and the quantity of agro-industrial waste. The dessert FHIA hybrids were even worse. Significant differences in peel percentages were found between plantains and the other cooking bananas on the one hand, and the dessert hybrid subgroups on the other hand at $p \leq 0.01$ (**Table 2**).

Dry Weight Yield of Edible Food. The highest total dry weight yield of edible food was found in dessert hybrids ("FHIA 17" and "FHIA 1" > 5.9 kg/plant), in "Gros Michel" (5.28 kg/plant) and to a lesser extent in cooking hybrids and plantains (Ma, Do, F 20, DH, F 21, Ha and CB with respectively 4.99, 4.82, 4.56, 4.32, 4.1, 4.04, and 4.03 kg/plant). Nevertheless, "Africa" exhibited a significantly lower EFY than other plantain landraces. Low EFY (below 3 kg/plant) was obtained for "Hua Moa", "Guineo", "Tafetan Morado", "Rollizo", "Pelipita", and "FHIA 25". Their low bunch weights could be suggested as a major contribution to the yield. Higher data for EFY are here reported than earlier workers (*10*), probably due to the relatively higher dry matter content of clones, as well as the fact that bunch weights without raquis were used here for the calculation. The posthoc testing partially differentiated subgroups (**Table 2**): nonplantain cooking bananas from dessert hybrids, and from the other subgroups ($p \leq 0.01$). Nevertheless, because EFY is a combination of various parameters it could be of relevance for the industrial selection of clones.

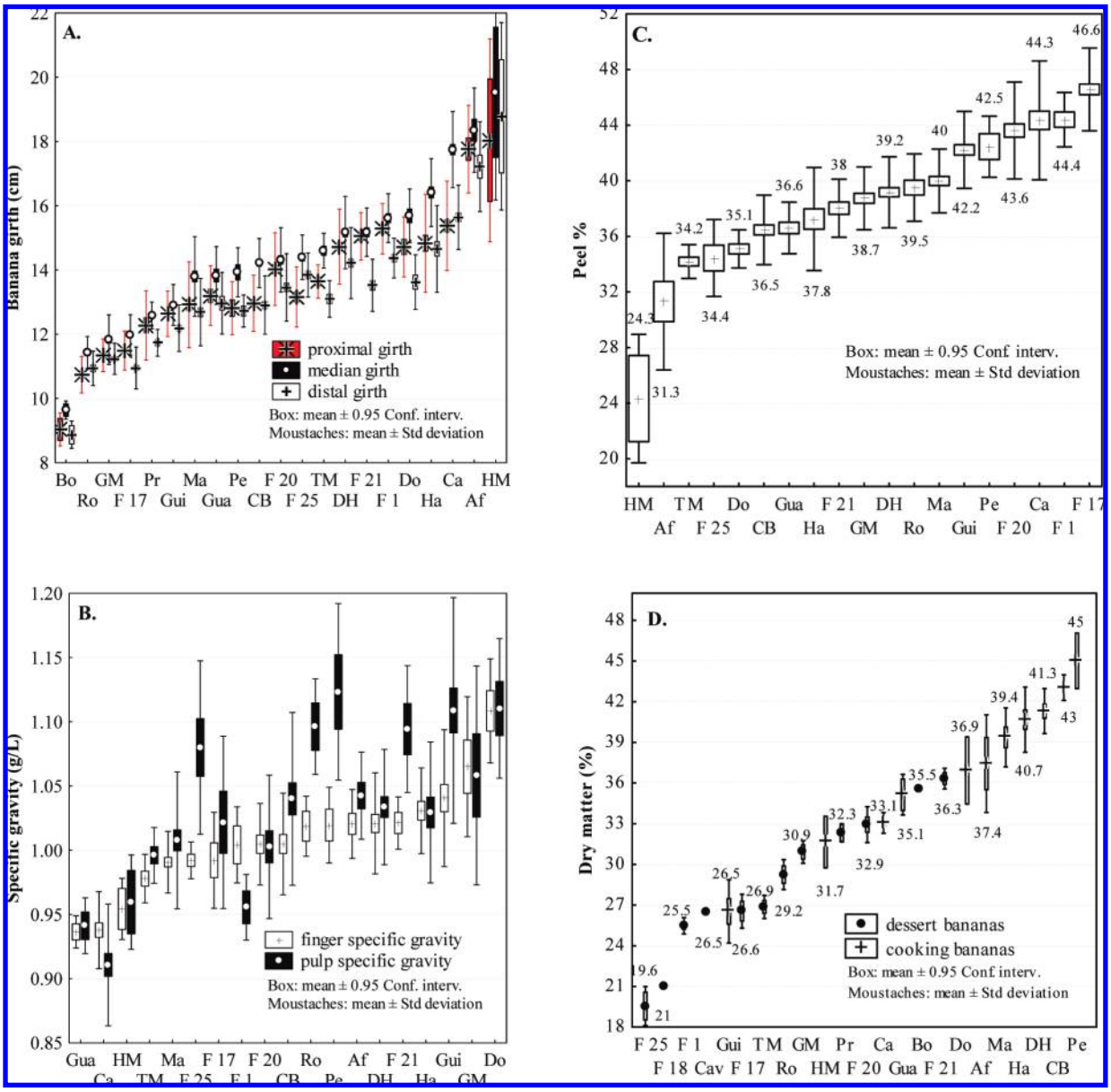

Figure 3. Physical and chemical characterization of banana varieties: Proximal, median, and distal girth distribution of fingers within varieties (**A**). Specific gravities of individual fingers and pulps (**B**). Peel percentage distribution (**C**). Whole hand dry matter distribution of dessert and cooking bananas (**D**). Af, Africa; Bo, Bocadillo; Ca, Cachaco; CB, Cubano Blanco; Do, Dominico; DH, Dominico Harton; F 1, FHIA 1; F 17, FHIA 17; F 20, FHIA 20; F 21, FHIA 21; F 25, FHIA 25; GM, Gros Michel; Gua, Guayabo; Gui, Guineo; Ha, Harton; HM, Hua Moa; Ma, Maqueño; Pe, Pelipita; Pr, Primitivo; Ro, Rollizo; TM, Tafetan Morado.

Table 2. Finger and Pulp Density, Percentage of Peel, Dry Matter Content, and Edible Food of the Varieties[a]

consumption modes and subgroups	finger density* (g/L)	pulp density** (g/L)	peel % **	DM** (%)	EFY* (/kg plant)
dessert bananas	1.01 a (n = 89)	1.03 a (n = 89)	38.0 a (n = 299)	29.4 a (n = 48)	3.15 ab (n = 3)
dessert hybrids	0.99 bc (n = 87)	1.03 a (n = 87)	44.8 b (n = 325)	24.6 b (n = 49)	5.40 c (n = 3)
cooking hybrids	1.01 ac (n = 106)	1.02 ab (n = 106)	42.0 c (n = 298)	34.2 c (n = 38)	4.45 ac (n = 5)
nonplantain cooking bananas	0.98 b (n = 263)	1.01 b (n = 263)	41.6 c (n = 492)	32.0 d (n = 94)	2.50 b (n = 10)
plantains	1.01 a (n = 557)	1.03 a (n = 557)	37.8 a (n = 812)	41.1 e (n = 216)	4.25 ac (n = 21)

[a] Values followed by the same letters in the same column are not significantly different at *, ** ($p \leq 0.01$, $p \leq 0.05$).

Composition and Chemical Properties of Banana Pulps. *Dry Matter Content*. Similar posthoc testing performed on mean bunch dry matter contents significantly differentiated most of the varieties (15 clones out of 21 individually separated on DM at $p \leq 0.01$). The significant differences in dry weights are in accordance with some previous works where 14, 24, and 24 *Musa* genotypes were discriminated (*10*, *12*, *14*). The dry matter contents of dessert bananas fluctuated from 19.6 to 30.9% (**Figure 3**D). It suggests a low starch content in the pulps consumed uncooked (100 g edible portion), thereby making cooking sweet bananas for consumption a useless action. At a green stage of maturity, no varieties are consumed uncooked. Consumers usually prefer a sweet and mellow pulp for raw consumption (*9*). DM of cooking landraces fluctuated from

Table 3. pH, Titratable Acidity, and Soluble Sugar Content of the Banana Flours on Dry Weight Basis[a]

consumption modes and subgroups	pH	TA mEq H^+/100 g	glucose mg/100 g	fructose mg/100 g	sucrose mg/100 g
			Dessert bananas		
bocadillo	5.6	6.77	0.46	0.94	1.00
primitivo	5.1	14.58	0.33	0.84	1.29
cavendish	5.1	15.54	0.25	0.84	0.32
gros michel	5.1	14.41	0.28	0.85	1.48
rollizo	5.4	7.61	0.59	0.89	0.77
tafetan morado	5.1	15.61	1.83[b]	3.56[b]	7.21[b]
mean ± std	**5.3 ± 0.2 ab**	**11.98 ± 4.16 ab**	**0.37 ± 0.12 a**	**0.87 ± 0.06 a**	**1.02 ± 0.41 a**
			Dessert hybrids		
fhia 17	5.2	14.64	0.07	0.34	1.55
fhia 1	5.0	15.425	0.07	0.20	0.25
fhia 18	4.9	17.22	0.03	0.07	0.07
fhia 25	5.1	16.18	0.14	0.42	0.97
mean ± std	**5.1 ± 0.1 a**	**15.87 ± 1.1 a**	**0.08 ± 0.04 b**	**0.26 ± 0.14 b**	**0.71 ± 0.63 ab**
			Cooking hybrids		
fhia 20	5.2	13.20	0.25	0.70	0.59
fhia 21	5.0	16.95	1.29	2.88	1.84
mean ± std	**5.1 ± 0.1 ab**	**15.08 ± 2.65 a**	**0.77 ± 0.59 c**	**1.79 ± 1.26 c**	**1.21 ± 0.73 a**
			Nonplantain cooking bananas		
guineo	5.1	15.92	0.31	0.81	1.63
guayabo	5.3	11.09	0.13	0.56	1.16
hua moa	5.1	13.24	0.04	0.27	1.59
cachaco	4.8	16.72	0.26	0.75	0.83
pelipita	5.1	11.20	0.44	0.66	0.52
mean ± std	**5.1 ± 0.2 a**	**13.64 ± 2.61 a**	**0.24 ± 0.15 ab**	**0.61 ± 0.20 ab**	**1.15 ± 0.45 a**
			Plantains		
africa	5.69	9.47	1.11	1.68	1.24
dominico	5.14	10.99	0.60	1.39	0.15
dominico harton	5.69	6.79	0.84	1.05	0.22
harton	5.28	8.70	0.48	1.05	0.56
cubano blanco	5.82	6.46	1.1	1.66	0.67
maqueño	6.21	4.90	0.78	1.72	0.16
mean ± std	**5.6 ± 0.4 b**	**7.89 ± 2.24 b**	**0.86 ± 0.25 c**	**1.46 ± 0.30 c**	**0.56 ± 0.44 b**

[a] Mean values followed by the same letters in the same column are not significantly different ($p \leq 0.05$). [b] Values for the glucose, fructose, and sucrose of the variety Tafetan Morado not included for mean, standard deviation calculation and HSD posthoc test.

26.5 to 45%. Thus, significant DM differences were demonstrated here between dessert and cooking bananas ($p \leq 0.01$).

The variety "Pelipita" exhibited the highest DM as observed previously (*10*). The East African Highland banana "Guineo", highly prized by local consumers, does not represent a major product and is well-known (with dessert hybrids) for partially or completely disintegrating in boiling water (*6*) and has a relatively low DM. When considering the DM at subgroup level, significant differences in DM between subgroups were demonstrated here at $p \leq 0.05$ (**Table 2**), as could also be observed from some previous data (*10*, *12*), or as it has been mentioned without any raw data (*14*).

However, genetic and nongenetic contributions and their interaction may interfere depending on the trait under consideration. DM content is reported being more stable than some other traits such as bunch weight and pulp weight across environments (*12*). Altitude is known for having a significant influence on the physicochemical properties of bananas. However, between 50 and 300 m of altitude, a dry matter mean variation below 2% for Cavendish banana was reported (*33*). Our study confirmed the environmental effects on the dry matter, probably related to the altitude for both "Gui" and "DH" landraces between distant areas (HSD tests at 95% confidence level). The coefficients of variation (CV) observed for both varieties were about 8.8 and 4.4% for "Gui" and "DH", respectively.

Some varieties grown under the same conditions with limited environmental contribution, such as Fhia25 "F25" and Africa "Af", exhibited similar or even larger dry matter coefficients of variation (CV > 7.3% and > 9.6% respectively).

Therefore, the differences in dry matter between varieties and between genotypic subgroups can be considered as significant, in spite of non-negligible environmental contributions at altitudes ranging from 970 to 1360 m.

No significant correlations were found between finger specific gravities and dry matter contents as well as between pulp specific gravities and dry matter contents ($r^2 < 0.2$). This suggests that density is not suitable for establishing a precise relationship between specific gravity and dry matter content when considering all banana varieties belonging to different genome types at a full green stage of maturity.

pH and Titratable Acidity of Flour. The pH of the flour at a green stage of maturity fluctuated in the range 4.8−6.2 and the

Table 4. General Composition of Banana Flours on Dry Weight and Fresh Weight Basis[a]

consumption mode and subgroups	total sugar * %	ash ** %	protein ** %	starch * %	total fiber ** %
		Dessert bananas			
bocadillo	1.7 ± 0.2	2.9 ± 0.2	3.06	82.6 ± 2.9	2.2 ± 0.1
primitivo	1.4 ± 0.3	3.2 ± 0.1	3.14	82.0 ± 2.5	2.7 ± 0.5
cavendish	*nd*[c]	3.4	3.69	82.3 ± 1.5	*nd*[c]
gros michel	2.3 ± 0.4	3.2 ± 0.2	4.01	83.5 ± 1.7	2.1 ± 0.5
rollizo	1.8 ± 0.2	3.5 ± 0.1	4.88	86.3 ± 1.4	3.8 ± 0.6
tafetan morado	8.4 ± 3.1[b]	3.3 ± 0.2	3.18	77.0 ± 3.6	3.2 ± 0.6
Mean (g /100 g db)	**1.7 ± 0.4 a**	**3.2 ± 0.2 a**	**3.49 ± 0.42 a**	**81.9 ± 3.9 ab**	**2.8 ± 0.8 a**
± **std** (*g/100 g wb*)	*0.5 ± 0.1 ab*	*1.0 ± 0.1 ab*	*1.04 ± 0.12 a*	*24.8 ± 3.2 a*	*0.8 ± 0.2 a*
		Dessert hybrids			
fhia 17	1.0 ± 0.1	4.3 ± 0.2	4.12	86.5 ± 2.5	2.3 ± 0.1
fhia 1	1.5 ± 0.4	3.6 ± 0.1	3.10	82.9 ± 2.2	3.4 ± 0.2
fhia 18	0.6 ± 0.0	3.7 ± 0.3	2.10	74.2 ± 2.5	4.2 ± 1.3
fhia 25	1.2 ± 0.3	3.9 ± 0.4	3.91	79.6 ± 1.8	4.4 ± 0.2
Mean (g /100 g db)	**1.1 ± 0.4 a**	**3.9 ± 0.4 b**	**3.31 ± 0.92 a**	**79.7 ± 5.2 b**	**3.7 ± 1.1 a**
± **std** (*g/100 g wb*)	*0.3 ± 0.1a*	*0.9 ± 0.2 b*	*0.77 ± 0.27 a*	*18.2 ± 3.3 b*	*0.8 ± 0.2 a*
		Cooking hybrids			
fhia 20	2.0	3.3 ± 0.1	2.94	80.3 ± 4.8	2.1 ± 0.0
fhia 21	4.8 ± 0.6	2.8 ± 0.2	3.20	82.2 ± 1.2	3.7 ± 0.5
Mean (g /100 g db)	**4.2 ± 1.4 b**	**3.1 ± 0.3 ac**	**3.07 ± 0.18 a**	**81.2 ± 3.4 ab**	**2.9 ± 1.0 a**
± **std** (*g/100 g wb*)	*1.5 ± 0.5c*	*1.0 ± 0.1 ab*	*1.06 ± 0.15 a*	*27.9 ± 2.3 ac*	*1.0 ± 0.4 a*
		Nonplantain cooking bananas			
guineo	1.7 ± 0.2	3.9 ± 1.0	4.09	84.1 ± 1.2	2.5 ± 0.2
guayabo	1.2 ± 0.3	3.0 ± 0.2	3.35	83.7 ± 2.9	4.1 ± 0.3
hua moa	1.2 ± 0.1	4.1 ± 0.0	4.30	86.6 ± 1.8	5.0 ± 0.1
cachaco	1.4 ± 0.2	2.9 ± 0.1	2.48	83.3 ± 3.6	2.7 ± 0.5
pelipita	1.7 ± 0.1	2.3 ± 0.2	2.20	88.2 ± 2.8	1.9 ± 0.3
Mean (g /100 g db)	**1.4 ± 0.3 a**	**3.2 ± 0.7 a**	**3.29 ± 0.94 a**	**84.9 ± 3.0 ac**	**3.3 ± 1.2 a**
± **std** (*g/100 g wb*)	*0.5 ± 0.2 ab*	*1.1 ± 0.1 a*	*1.09 ± 0.20 a*	*28.3 ± 5.0 c*	*1.1 ± 0.4 a*
		Plantains			
africa	2.5 ± 0.9	3.4 ± 0.0	3.14	88.2 ± 2.8	2.6 ± 0.6
dominico	1.4 ± 0.3	2.4 ± 0.3	2.76	86.9 ± 2.0	4.2 ± 0.1
dominico harton	1.1 ± 0.0	2.6 ± 0.2	2.93	85.5 ± 3.8	2.4 ± 1.1
harton	1.3 ± 0.3	2.6 ± 0.0	2.32	85.2 ± 1.7	2.6 ± 0.1
cubano blanco	1.4 ± 0.3	2.5 ± 0.1	3.30	87.8 ± 4.9	3.1 ± 0.3
maqueño	1.7 ± 0.3	2.5 ± 0.1	2.29	86.1 ± 2.7	1.8 ± 0.6
Mean (g /100 g db)	**1.6 ± 0.6 a**	**2.7 ± 0.4 c**	**2.79 ± 0.42 a**	**86.5 ± 3.2 c**	**2.8 ± 0.9 a**
± **std** (*g/100 g wb*)	*0.7 ± 0.3 b*	*1.1 ± 0.2 a*	*1.13 ± 0.21 a*	*35.1 ± 2.3 d*	*1.1 ± 0.3 a*

[a] Mean values followed by the same letters in the same column are not significantly different at *, ** ($p \leq 0.01$, $p \leq 0.05$). [b] Values for the total sugar of the variety "Tafetan Morado" not included for mean, standard deviation calculation and HSD posthoc test. [c] Not determined.

titratable acidity in the range 4.9−17.2 mEq H^+/100 g on dry matter basis (**Table 3**). Hybrids had the highest titratable acidity. A significant difference was found in pH and titratable acidity between on the one hand the plantain subgroup, and on the other hand dessert hybrids and nonplantain cooking bananas ($p \leq 0.01$).

Ash Content. The ash content varied in the range 2.3−4.3% (**Table 4**) and is consistent with the literature range (*16*, *17*, *19*, *20*, *22*). Some significant differences between banana subgroups are observed ($p \leq 0.05$). In particular, the highest ash content is associated with dessert hybrids. The plantain subgroup exhibited the lowest amount of ash ($p \leq 0.05$). The mineral analysis should subsequently confirm this result.

Crude Fiber Content and Total Nitrogen Content. Fiber content fluctuated in the range 1.8−5% db (**Table 4**). The precision and the coefficient of variation of the nitrogen standard were checked (below 0.1% and 0.3%, respectively), as well as an autocontrol at random on two samples. Nitrogen content was estimated in the range 2.1−4.9% (**Table 4**). Similar results were reported previously (*13*, *16*, *20*) and (*13*, *16*, *19*, *20*, *22*, *23*), respectively. No significant differences were highlighted between banana subgroups on dry weight and fresh weight basis, for either crude fiber content or total nitrogen content.

Soluble Sugars by HPAEC-PAD. The amount of soluble sugars was revealed as really low at a green stage of maturity (**Table 3**), with significant differences in glucose and fructose amounts between plantains and nonplantain cooking bananas and the one hand, and dessert bananas (including dessert hybrids) on the other. The highest amounts of glucose and fructose were found in plantains and cooking hybrids. A significant correlation ($r^2 = 0.91$) was observed between Musa flours glucose and fructose contents, thus allowing the determination of the content

Table 5. Mineral Composition of the Banana Flours[a]

consumption modes and subgroups	K	Ca	Mg	Na
	mg/100 g db	mg/100 g db	mg/100 g db	mg/100 g db
	mg/100 g wb	*mg/100 g wb*	*mg/100 g wb*	*mg/100 g wb*
dessert bananas (n = 6)	1172 a	19.3 a	117.9 ab	4.9 a
	349.8 ab	*5.7 a*	*35.4 a*	*1.5 ab*
dessert hybrids (n = 4)	1451.4 b	23.7 a	125.0 a	4.5 a
	323.8 a	*5.3 a*	*28.1 a*	*1.0 a*
cooking hybrids (n = 2)	1053.0 a	15.5 ab	95.9 bc	4.9 a
	380.0 ab	*5.6 a*	*34.6 a*	*1.8 b*
nonplantain cooking bananas (n = 5)	1107.5 a	18.3 ab	105.0 abc	4.3 a
	379.4ab	*6.2 a*	*36.8 a*	*1.5 ab*
plantains (n = 6)	958.6 a	8.4 b	90.7 c	4.0 a
	391.0 b	*3.5 a*	*37.1 a*	*1.6 b*

[a] Values followed by the same letters in the same column are not significantly different ($p \leq 0.05$). Mineral composition is indicated in mg/100 g dry wet basis (db) and on fresh matter basis (wb) in italic.

of one sugar when the other is known (*13*). The sucrose concentration appeared unrelated to the other soluble sugars contents, even though the sucrose content was significantly lower for the plantain subgroup than dessert bananas, nonplantain cooking bananas and cooking hybrids. The sucrose to total sugar ratio was shown to be lowest in the plantain subgroup (18.4%), whereas the sucrose content could represent about 52% of the total sugars for nonplantain cooking bananas, 50.5% for the dessert hybrid subgroup, 41.3% for dessert bananas, and 32.1% for the cooking hybrid subgroup ($p \leq 0.01$). While some works previously described the amount of sugars appearing along the ripening process (*13*, *34*), so far no study has reported any differences in sugar composition between banana subgroups at a full green stage of maturity.

Total Sugars. Low amounts of alcohol soluble sugars were quantified at green stage of maturity (**Table 4**). The "Tafetan Morado" variety was not considered and may have started its climacteric crisis by the time of the analyses or may have an atypical soluble sugar profile at full green stage of maturity. While those results are similar to previous works at a green stage of maturity (*15*, *18*, *20*, *23*), no significant differences were revealed between subgroups.

Starch Content. The starch content analyses showed that starch is the main ingredient of the green Musa flours. The starch amount fluctuated in the range 74.2−88.2% (**Table 4**), as in some other works (*11*, *15*, *17*, *19*, *20*, *23*). Complementary statistical analysis demonstrated significantly higher starch content in the plantain subgroup than with cooking and dessert hybrids and dessert bananas (86.5%, 81.2%, 79.7%, and 81.9% respectively at ($p \leq 0.01$). For the first time, the study has shown a significant difference in starch content of flours in relation to consumption groups. On fresh weight basis, the difference between subgroups was accentuated, with 35.1%, 28.9%, 27.9%, 24.8%, and 18.2% of starch respectively for plantains, nonplantain cooking bananas, cooking hybrids, dessert and dessert hybrids ($p \leq 0.01$). Approximately 100 g of plantain pulp contains twice as much starch as dessert hybrid pulp. Most of the differences in variety preferences and consumption modes could be explained by the amount of starch in the pulps and the flours.

Mineral Contents. As expected, the banana potassium content on dry weight basis was high (**Table 5**). Nonplantain cooking bananas exhibited a large variation from 814 to 1378 mg K/100 g db. Similarly to the ash content, dessert hybrids exhibited high K contents, whereas most cooking hybrids and plantains exhibited low K contents. An antagonistic trend is observed on fresh matter basis. The variety "Hua Moa" is the only one which exhibited high K content on both dry matter and fresh matter basis (1378 and 434 mg/100 g respectively). Similar K concentrations in bananas of various origins have been reviewed (*25*). Dessert hybrids had a significantly higher K content on dry matter basis than other banana subgroups ($p \leq 0.05$). Unlike previous observations, the posthoc test conducted on a fresh matter basis only showed differences in K contents between subgroups of plantains and dessert FHIA hybrids.

A large variation in Ca and Mg concentrations was observed between subgroups and within varieties in dried flours. Cooking hybrids and most plantains had the lowest quantities of Mg (db). The mean calcium and magnesium agreed with previous reports (*24*, *26*) and (*25*, *26*), respectively). Though calcium is a macro-element involved in the intracellular cement, surprisingly, the Ca content was the lowest in plantains, known for having a good textural resistance (*10*, *11*). Further studies to investigate the relationship between Ca content, cell wall composition and heat resistance are needed to improve our understanding of the cooking behavior of Musa genotypes.

Sodium content was very low. The mean Na content found in dessert bananas and plantains were consistent with other studies (*24*, *25*, *22*). No significant differences were observed for Na content between subgroups on a dry matter basis. On a fresh matter basis, the sodium content was significantly lower in dessert hybrids than in cooking hybrids and plantains at $p \leq 0.05$. Except for a weak correlation between K and Na contents on a wet basis ($r^2 = 0.47$), no significant correlations were found between macro-elements.

Regarding the discriminancy of the mineral content traits under the influence of environmental factors, a maximal significant variability of mineral content (K, Ca, and Na) of about 10% between the north and the south of the Tenerife Island was reported (*25*). The comparison of the potassium content for the same clone at Tenerife Island and in Ecuador showed 15% variation on K rates (*24*), whereas higher differences for 2 clones (60 and 200 mg per 100 g wb) cultivated in 7 areas of Hawaii were also demonstrated in another study (*26*). However, the results were not directly comparable with the others since the results were given on fresh matter basis. Using conventional and organic growing conditions, except for N, no difference in mineral contents were also reported in different works (*24*, *35*). In addition, if the influence of the soil composition was earlier stressed and reviewed (*4*), the soils of the alluvial valley of Cauca in Colombia (Northern part of Cauca state and state of Valle del Cauca)

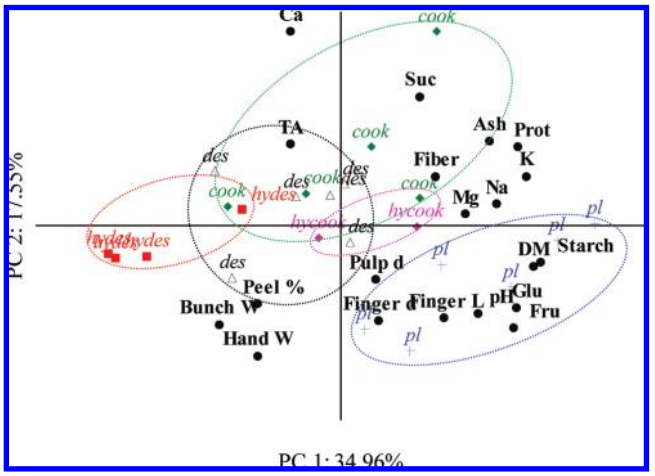

Figure 4. Principal components plot of morphological, physical and chemical variables: first and second component; DM, dry matter content; Pulp d, pulp density; Finger d, finger density; Finger L, finger length (cm); Hand W, hand weight (kg); Peel %, ratio of peel to banana; Bunch W, bunch weight (kg); K, potassium content (wb); Ca, calcium content (wb); Mg, magnesium content (wb); Na, sodium content (wb); starch, starch content (wb); Glu, glucose content (wb); Fru, fructose content (wb); Suc, sucrose content (wb); Ash, ash content (wb); Fiber, crude fiber content (wb); TA, titratable acidity mEq (wb). Superimposed plots of the banana subgroups on the first and second components of principal component analysis: pl, plantain; des, dessert banana; hydes, dessert hybrid, hycook, cooking hybrid; cook, nonplantain cooking banana.

have all a similar composition and an identical climate, where most of varieties were collected (30 varieties out of 47).

Under the same soil and edaphoclimatic conditions, the comparison of the mineral contents of 6 cultivated varieties showed that the variability between clones (80% for K) was higher than the variability related to the growing conditions applied (*36*). Our study stressed significant differences between consumption groups, with a 40% difference for K content between the dessert hybrids and the dessert banana group (10 clones) and about a 100% difference regarding Ca content for the plantain subgroup (6 landraces analyzed) compared with other subgroups (17 varieties). Such large differences never observed before were thus suggested to be mainly related to the differences between genetic groups.

Principal Component Analysis on Physical and Chemical Characterization. PCA was performed to evaluate the most relevant variables. A limited number of variables (as far as possible noncorrelated and mutually independent) were selected for describing banana physical and chemical diversity. In addition, the variables able to discriminate consumption subgroups were assessed. Respectively, the first five components accounted for 34.96%, 17.55%, 9.36%, 9.33%, and 7.68% of the variation. The first component was positively related to starch content, DM, K, and to a lesser extent to the glucose and fructose content (**Figure 4**), whereas the second component was related to Ca content (wb) and sucrose content, and negatively correlated to hand weight. Magnesium content, titratable acidity and peel percentage were plotted against banana pulp density for the third component.

Superimposed plots of the consumption subgroups on the plans assessed the percentage variation associated with the first and second components. Unlike plantains, the dessert hybrids were mainly characterized by high bunch weights, hand weights and peel percentages, low K, Na, Mg contents, low starch content and low DM content. Dessert bananas were mainly characterized by intermediate responses, whereas cooking bananas were mainly associated with significant low finger lengths, hand weights, bunch weights, and high Ca contents (wb).

The plantains differed in their ability to be clearly separated from other banana subgroups on the first two components of PCA based variance. Nevertheless, differentiation of all the banana subgroups can be seen on the basis of the consumption mode (cooking bananas mainly located in the positive PC1 area and partially in the positive PC2 area, whereas dessert bananas are mainly located in the negative PC1 area). As expected, cooking hybrids (genetically derived from plantains) are located close to plantain clones. The diversity of Ca for nonplantain cooking bananas is supposed to induce a strong contribution of subgroup variance, which may explain such differences between the posthoc test and the principal component analysis, and the large spatial dispersion observed for cooking bananas.

DISCUSSION

Varietal Diversity and Variability: a Key for Sampling and Differentiating Clones and Subgroups. The description of the physical and chemical parameters suggested some intravariety heterogeneity, in particular between extreme hands. A significant reduction of hand weights, lengths and girths from basal to distal hand was observed in most varieties. Most of the heterogeneity was probably intrinsic to the clones, whereas some heterogeneity was possibly due to some extent to the replicates (varietal, environmental and agronomic factors). At "hand level", without considering rows, the HSD tests showed some significant influences of finger position on banana length and weight in some varieties ($p \leq 0.05$). The first and last fingers labeled proved to be particularly heterogeneous. When considering statistics at "row level", significant effects were observed on finger and pulp median girths for some varieties: girths seemed to be smaller on the external row ($p \leq 0.05$). Bananas on the external rows were shown to be bigger in terms of finger lengths ($p \leq 0.05$).

Observations like this could explain why sampling strategies are often oriented toward selecting an intermediate hand instead of proximal and distal hands of bunches (*10*, *14*, *24*), or selecting from all hands (*8*) or "at row level" (*27*). The use of a random sampling strategy is sometimes suggested (*10*, *25*, *34*), and could be justified by the heterogeneity observed at bunch, hand and row level. However, the present work suggested complete characterization of the extreme finger and intermediate finger on both rows of the bunch's proximal, median, and distal hand, for optimum consideration of the intrabunch, intrahand and inter-row morphological variability.

Synthesis on Varietal Differentiation and Consumers or Stakeholder Preferences. A wide distribution of lengths, finger weights and cross sections was revealed. Length, finger weight and median finger girth proved to be suitable for partially discriminating varieties on an individual basis. Most industrial varieties had big lengths, finger weights and diameters. *Musa* genotypes were discriminated on their respective dry weights (*10*, *12*, *14*). Some data, based on the banana knowledge of some experts and on field experience were reported previously. The differentiation of the banana subgroups was based on dry weights with no relevant statistics shown (*12*, *15*), or without any raw data shown (*17*). For the first time, a significant differentiation between the five consumption subgroups has been demonstrated here using the dry matter and the starch content criteria on dry and wet basis. This result is enhanced by the high trait stability within various cropping environments reported previously (*12*, *13*). The synthesis of the morphological, physical and chemical differentiation of 3 banana subgroups was highlighted within the normalized radar chart (**Figure 5**) On the one hand, the

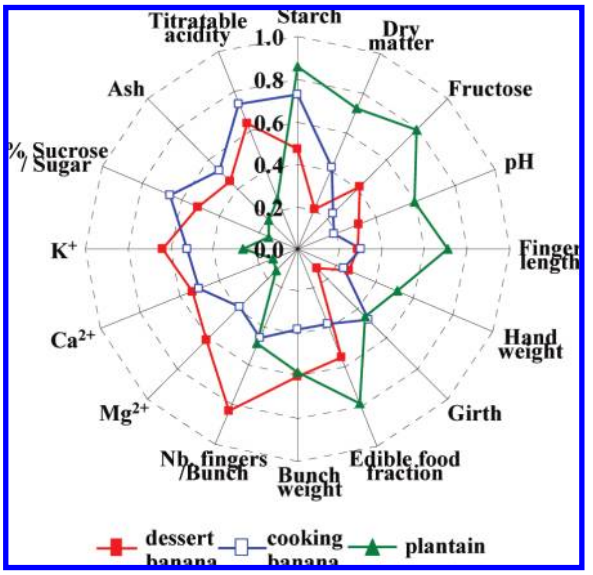

Figure 5. Radar chart of the normalized morphological and physicochemical criteria of dessert bananas, cooking bananas and plantains. Nb fingers/Bunch, number of fingers per bunch; Mg^{2+}, magnesium content (db); Ca^{2+}, calcium content (db); K^{+}, potassium content (db); % Sucrose/Sugar, ratio of sucrose to total sugar in percentage.

following normalized parameters: Starch, Dry matter, Fructose, pH, Finger length, Hand weight, girth and Edible food fraction were higher for plantains than for dessert bananas and nonplantain cooking bananas. The latter's girth was equivalent to that of plantain, whereas starch and dry matter were intermediate between plantain and banana, and pH and fructose contents were lower than banana and plantain. On the other hand, the normalized criteria: numbers of fingers per bunch, minerals (Mg, Ca, and K on wb) were higher for dessert bananas than plantains, and to a lesser extent for nonplantain cooking bananas. The ratio of sucrose to total sugars, ash and titratable acidity are useful criteria to distinguish nonplantain cooking bananas (higher) from dessert bananas (intermediate) and primarily from the plantain subgroup (lower).

In Colombia, a cooking banana could be expected to be used industrially if it has a peel percentage without raquis below about 39−40%. (*6*). The peel percentage helps to significantly differentiate plantains and dessert bananas from nonplantain cooking bananas, and cooking hybrids from dessert hybrids, and could be a determinant criterion for agro-industrial waste generated in the banana industry.

Major banana industrial production in Colombia is oriented toward fried products (chips, "*moneditas*" and "*patacones*") and flour production for children's beverages, using "Dominico Harton", "Dominico", "Harton", "Guayabo", and "Pelipita" clones (*6*). Those industrial clones have massive dry matter content, between 35.1 and 45%. The varieties "FHIA 21", "Africa", "Cubano Blanco", and "Pelipita" not used industrially in Colombia also had high dry weights and the highest starch content (around 86%). These varieties could be an opportunity for the diversification of the deep fat frying process resources. A consumer preference for these clones is reported when targeting fried products. The frying process quality in terms of oil uptake has already been demonstrated to be strongly influenced by the banana variety used (*15*). A higher water loss was correlated to a higher oil uptake, but probably as the consequence of the fried product microstructure (*32*). Obviously, a lower water loss due to a higher dry weight and higher starch content is supposed to induce much more limited fat uptake into plantains than that of other cooking bananas. Other cooking bananas (namely "Guayabo" and "Dominico") are usually preferred for boiling at a green stage of maturity (in a soup locally called "*Sancocho*") or at a ripe stage of maturity for producing pan-fried or oven-cooked or microwave-cooked "*tajadas*", a very sweet and aromatic dessert (*6*).

The Colombian industry usually controls the °Brix of green and ripened cooking banana raw materials to ensure the quality of the fried product (lower than 8 to 9 °Brix when targeting plantain chips, and up to 29 to 30 °Brix for ripened deep-fried sweet chips "madurito" or "tajadas"). The total sugar must be as low as possible for chips and the highest for "madurito". Few varieties could reach the highest value, for "maduro" or "madurito" processing. The peel percentage, the ease of peeling at green stage, dry matter, starch content, total sugar content, and total dry weight yield of edible food are some relevant parameters for industrial selection of varieties.

The integration of the knowing how to differentiate banana cultivars and of the criteria for the acceptance of the cultivated Colombian Musa should significantly contribute to the acceptability of new varieties derived from breeding strategies, and the use of neglected ones.

A further study will report on the evaluation of starch and flour thermal and functional properties for the 23 Colombian cultivated varieties described here (*37*). However, some additional work on the quality assessment at different stages of ripeness is needed to better explain varietal adoption and consumer preferences. Other studies should be conducted subsequently to estimate differences between ripened varieties (color, sugar content at different ripening stages, °Brix, texture, taste, aromas and flavor), while taking into account consumer perceptions and preferences. Some additional work is also needed to be able to quantify the contribution of the environmental factors and their interaction with genetic origin of the traits (*12*), to confirm the main genetic origin of the differences observed between varieties, consumption groups and genotypes of cultivated Colombian varieties. Investigations using banana samples obtained from germplasm collections will be required to confirm the results while limiting nongenetic contributions.

Many varieties have never been reported as being used in the industry. However, some clones are widely distributed among producers and consumers with a high degree of acceptability (*6*): definitely "not commercial but good food security items". This study contributes to describing and explaining the wide banana diversity maintained by the small stakeholders in rural Colombia (mainly Afro farmers, as descendents of slaves) and to opening up new prospects for adding value to some neglected varieties.

The priority for research should be oriented according to the targeted uses (household or industrial). At industrial level, research may subsequently be oriented toward the green life duration, ripening response to ethylene, the enzymatic browning after peeling, transport, and storage behavior of peeled bananas mentioned as potential useful raw material. Further research is also needed to investigate the fermentability and digestibility of the unique fully ripe "Guineo" landrace, mutika-lujugira group (AAA) traditionally used for fermentation in Africa and Latin America (*38*) for producing beer, alcohol or vinegar.

ABBREVIATIONS USED

CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement; CIAT, International Center for Tropical Agriculture; FHIA, Fundación Hondureña de investigación Agrícola; AA, AB, BB, AAA, AAB, ABB, AAAA, AAAB, ABBB genotypes of *Musa* acuminata genome A and of *Musa* balbisiana B; Af, Africa; Bo, Bocadillo;

Ca, Cachaco; CB, Cubano Blanco; Do, Dominico; DH, Dominico Harton; F 1, FHIA 1; F 17, FHIA 17; F 20, FHIA 20; F 21, FHIA 21; F 25, FHIA 25; GM, Gros Michel; Gua, Guayabo; Gui, Guineo; Ha, Harton; HM, Hua Moa; Ma, Maqueño; Pe, Pelipita; Pr, Primitivo; Ro, Rollizo; TM, Tafetan Morado; Peel %, percentage of peel; DM, dry matter content; EFY, total dry weight yield of edible food; K, potassium; Ca, calcium; Mg, magnesium; Na, sodium; HCL, hydrochloric acid; HF, hydrofluoric acid; ICP-AES, inductively coupled plasma-atomic emission spectroscopy; PCA, Principal Component Analysis; HSD, Honestly Significant Differences; db, dry weight basis; wb, fresh matter basis; pl, plantain; des, dessert banana; hydes, dessert hybrid, hycook, cooking hybrid; cook, nonplantain cooking banana; F density, finger density; Hand W, hand weight; F length, finger length; Bunch W, bunch weight; Nb. F/bunch, number of fingers per bunch.

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Supporting Information Available: The report of *Quintero, D. A.; Garcia, V. M.* (*6*). This material is available free of charge via the Internet at http://pubs.acs.org.

LITERATURE CITED

(1) Lescot, T. La diversité génétique des bananiers en chiffres. *Fruitrop* **2008**, *155*, 29–33.

(2) Bakry, F.; Carreel, F.; Jenny, C.; Horry, J. P. Genetic Improvement of Banana, Chapter I. In *Breeding Plantation Tree Crops: Tropical Species*; Jain, S. M., Priyadarshan, P. M., Eds.; Springer: Dordrecht, The Netherlands, 2008; pp 3−50.

(3) Dzomeku, B. M.; Darkey, S. K.; Bam, R. K.; Ankomah, A. A. Sensory evaluation of four FHIA Tetraploid hybrids for *Kaakle* (a local dish) in Ghana. *J. Plant Sci.* **2007**, *2*, 640–643.

(4) Arvanitoyannis, I. S.; Mavromatis, A. Bananas Cultivars, Cultivation practices, and physicochemical properties. *Crit. Rev. Food Sci. Nutr.* **2009**, *49*, 113–135.

(5) Dury, S; Bricas, N.; Tchango Tchango, J.; Temple, L.; Bikoi, A. The determinants of urban plantain consumption in Cameroon. *Food Qual. Pref.* **2002**, *13*, 81–88.

(6) Quintero, D. A.; Garcia, V. M. Saberes y sabores. El plátano en el norte del Cauca. Proyecto estrategias que contribuyan a la competitividad de los mercados de productos de Musáceas cultivadas en Colombia: valor nutricional y nutracéutico, mejoramiento y desarrollo de productos de interés para el sector industrial de alimentos. Informe final. Universidad del Valle, Facultad de Ciencias Sociales y Económicas, Santiago de Cali, Colombia, 2008; pp 51.

(7) Aurore, G.; Parfait, B.; Fahrasmane, L. Bananas, raw materials for making processed food products. *Trends Food Sci. Techno.* **2009**, *20*, 78–91.

(8) Dufour, D.; Giraldo, A.; Lopez, X.; Castellanos, F. J.; Sanchez, T.; Fernandez, A.; Díaz, A. Diversidad del plátano de cocción consumido en Colombia. In *Congreso Iberoamericano de Ingeniería en Alimentos* (CIBIA VI), November 05−08 2007, Ambato, Ecuador. *Aliment. Cienc. Ing.* (*ECUA*) **2007**, *16*, 168-172.

(9) Dufour, D.; Giraldo, A.; Gibert, O.; Sánchez, T.; Reynes, M.; González, A.; Fernández, A.; Díaz, A. Propiedades físico-químicas y funcionales de los bananos de postres, plátanos de cocción y FHIA híbridos: preferencia varietal de los consumidores en Colombia. In *Memories of XVIII ACORBAT meeting, November 10−14 2008*; Borja J. S., Nogales C., Orrantia C., Paladines R., Quimi V., Tazan L., Eds.; Guayaquil: Ecuador, 2008; pp 33.

(10) Ferris, R. S. B.; Ortiz, R.; Vuylsteke, D. Fruit quality evaluation of plantains, plantain hybrids, and cooking bananas. *Postharvest Biol. Technol.* **1999**, *15*, 73–81.

(11) Eggleston, G.; Swennen, R.; Akoni, S. Differences in composition and texture among plantains, plantain hybrids and cooking banana. In *Proceedings of a Regional Workshop on Traditional African Foods − Quality and Nutrition, November 25−29 1991*; Westby A., Reilly, P. J. A., Eds.; IFS: Stockholm, Sweden, 1992; pp 179−185.

(12) Baiyeri, K. P.; Mbah, B. N.; Tenkouano, A. Yield Components of Triploid and Tetraploid *Musa* Genotypes in Nigeria. *HortScience* **2000**, *35*, 1338–1343.

(13) Forster, M. P.; Rodriguez Rodriguez, E.; Romero, C. D. Differential characteristics in the Chemicals composition of bananas from Tenerife (Canary Islands) and Ecuador. *J. Agric. Food Chem.* **2002**, *50*, 7586–7592.

(14) Ngalani, J. A.; Tchango Tchango, J. Evaluation des qualités physicochimiques du fruit de bananiers d'autoconsommation au Cameroun. *Fruits* **1996**, *51*, 327–332.

(15) Díaz, A; Trystram, G.; Vitrac, O.; Dufour, D.; Raoult-Wack, A. L. Kinetics of moisture loss and fat absorption during frying for different varieties of plantain. *J. Sci. Food Agric.* **1999**, *79*, 291–299.

(16) Da Mota, R. V.; Lajolo, F. M.; Ciacco, C.; Cordenunsi, B. R. Composition and functional properties of banana flour from different varieties. *Starch/Stärke* **2000**, *52*, 63–68.

(17) Juarez-Garcia, E.; Agama-Acevedo, E.; Sáyago-Ayerdi, S. G.; Rodríguez-Ambriz, S. L.; Bello-Pérez, L. A. Composition, digestibility and application in breadmaking of banana flour. *Plant Foods Hum. Nutr.* **2006**, *61*, 131–137.

(18) Mustaffa, R.; Osman, A.; Yusof, S.; Mohamed, S. Physicochemical changes in Cavendish banana (*Musa* cavendishii L var Montel) at different positions within a bunch during development and maturation. *J. Agric. Food Chem.* **1998**, *78*, 201−207.

(19) Pacheco-Delahaye, E.; Maldonado, R.; Pérez, E.; Schroeder, M. Production and characterization of unripe plantain (*Musa paradisiaca l.*) flours. *Interciencia* **2008**, *33*, 290–296.

(20) Suntharalingam, S.; Ravindran, G. Physical and biochemical properties of green banana flour. *Plant Foods Hum. Nutr.* **1993**, *43*, 19–27.

(21) Yomeni, M. O.; Njoukam, J.; Tchango Tchango, J. Influence of the stage of ripeness of plantains and some cooking bananas on the sensory and physicochemical characteristics of processed products. *J. Sci. Food Agric.* **2004**, *84*, 1069–1077.

(22) U.S. Department of Agriculture, Agricultural Research Service, 2008. USDA National Nutrient Database for Standard Reference, Release 21. Nutrient Data Laboratory Home page, http://www.ars.usda.gov/ba/bhnrc/ndl.

(23) Sakyi-Dawson, E.; Asamoah-Bonti, P.; Amponsah Annor, G. Biochemical changes in new plantain and cooking banana hybrids at various stages of ripening. *J. Sci. Food Agric.* **2008**, *88*, 2724–2729.

(24) Forster, M. P.; Rodriguez, E. R.; Martin, J. D.; Romero, C. D. Statistical differentiation of bananas according to their mineral composition. *J. Agric. Food Chem.* **2002**, *50*, 6130–6135.

(25) Hardisson, A.; Rubio, C.; Baez, A.; Martin, M.; Alvarez, R.; Díaz, E. Mineral composition of the banana (*Musa* acuminata) from the island of Tenerife. *Food Chem.* **2001**, *73*, 153–161.

(26) Wall, M. M. Ascorbic acid, vitamin A, and mineral composition of banana (*Musa* sp.) and papaya (*Carica* papaya) cultivars grown in Hawaii. *J. Food Compos. Anal.* **2006**, *19*, 434–445.

(27) Jullien, A.; Malézieux, E.; Michaux-Ferrière, N.; Chillet, M.; Ney, B. Within-bunch variability in banana fruit weight: importance of developmental lag between fruits. *Ann. Bot.* **2001**, *87*, 101–108.

(28) Lescot, T. La culture du bananier plantain en Colombie et dans les pays andins. Spécial bananes II: systèmes de production du bananier plantain. *Fruits* **1993**, *48* (2), 107–114.

(29) Castrillón, C.; Valencia, J. A.; Urrea, C. F. Reacción de diferentes materiales del banco de germoplasma de Musáceas al ataque del Picudo negro Cosmopolites sordidus Germar (Coleoptera: Curculionidae), In *Proceedings of XVth ACORBAT International meeting*, October 27−November 02 2002, Cartagena de Indias, Colombia. Augura; Medellķn: Colombia, 2002; pp 90−97.

(30) Dadzie, B. K.; Orchard, J. E. Routine Post Harvest Screening of Banana/Plantain Hybrids: Criteria and Methods. In *INIBAP Technical Guidelines 2*; INIBAP; IPGRI: Rome, Italy, 1997; p 77.
(31) Sosulski, F. W.; Imafidon, G. I. Amino acid composition and nitrogen-to protein conversion factors for animal and plant foods. *J. Agric. Food Chem.* **1990**, *38*, 1351–1356.
(32) Vitrac, O.; Dufour, D.; Trystram, G.; Raoult-Wack, A. L. Deep-fat-frying of cassava: influence of raw material properties on chip quality. *J. Sci. Food Agric.* **2000**, *81*, 227−236.
(33) Bugaud, C.; Chillet, M.; Beauté, M. P.; Dubois, C. Physicochemical analysis of mountain bananas from the West Indies. *Sci. Hort.* **2006**, *108*, 167–172.
(34) Cano, M. O. P.; Ancos, B.; Matallana, M. C.; Camara, M.; Reglero, G.; Tabera, J. Differences among Spanish and Latin-American banana cultivars: morphological, chemical and sensory characteristics. *Food Chem.* **1997**, *59*, 411–419.
(35) Nyanjage, M. O.; Wainwright, H.; Bishop, C. F. H.; Cullum, F. J. A comparative study on the ripening and mineral content of organically and conventionally grown Cavendish bananas. *Biol. Agri. Hort.* **2001**, *18*, 221–234.
(36) Davey, M. W.; Stals, E.; Ngoh Newilah, G. B.; Tomekpe, K.; Lusty, C.; Markham, R.; Swennen, R.; Keulemans, J. Sampling strategies and variability in fruit pulp micronutrient contents of West and Central African bananas and plantains (Musa species). *J. Agric. Food Chem.* **2007**, *55*, 2633–2644.
(37) Dufour, D.; Gibert, O.; Giraldo, A.; Reynes, M.; Pain, J. P.; González, A.; Fernández, A.; Díaz, A. Differentiation between cooking bananas and dessert bananas. 2. Thermal and functional characterization of cultivated Colombian Musaceae (*Musa* sp.). *J. Agric. Food Chem.* **2009**, DOI: 10.1021/jf900235a.
(38) Price, N. S. Highland bananas in Colombia. *InfoMusa* **1999**, *8*, 26–28.

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