

Characterisation of bananas and cooking bananas cultivated in Colombia: morphological, physicochemical and functional differentiation between genetic groups, consumption patterns and preferences.

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Abstract

The morphological and physicochemical characteristics of 23 varieties cultivated in Colombia were assessed. The study permitted to describe the phenotypic diversity and the heterogeneity within-bunches and within-hands of 47 plants. A sampling strategy was suggested accordingly. Dry matter content helped to significantly discriminate consumption groups or subgroups of bananas ($P \leq 0.01$): FHIA dessert hybrids (24.6%) < dessert bananas (29.4%) < non plantain cooking bananas (32.0%) < FHIA cooking hybrids (34.2%) < plantains (41.1%). Plantain group showed significantly lower mineral contents for calcium and magnesium on dry weight basis (db) than the dessert banana genetic group, with 8.4 and 90.7 mg/100g db respectively. Wide variation in potassium contents was revealed among varieties (814 to 1550 mg/100g db). FHIA dessert hybrid group showed the highest content with an average amount of 1451 mg/100g db. Onset temperature of starches varied from 59.7 to 67.8°C and permitted to significantly differentiate ($P \leq 0.01$) dessert bananas (63.2°C), from non plantain cooking bananas (65.7°C), from FHIA hybrids (66.6°C) and plantains (67.1°C). FHIA hybrids (cooking and dessert) are significantly discriminated from dessert banana landraces but not from cooking groups ($P \leq 0.01$). The amylose content of starches varied from 15.4% to 24.9%. A strong relationship was demonstrated between the consumption mode and the amylose content measured by Differential Scanning Calorimetry (DSC). Most amylose contents of dessert bananas were below 19% whereas cooking bananas percentages were higher than 21%. Rheological properties were studied using a standardised protocol by Rapid Visco Analyser (RVA) irrespective to the α -amylase content of the flour using silver nitrate 0.002M. Flour pasting temperature was relevant to differentiate dessert bananas (69.5°C) from FHIA dessert hybrids and non plantain cooking bananas (72.8°C), from cooking hybrids and plantains (75.8°C). The cooking ability criterion also helped to differentiate dessert bananas and FHIA hybrids (236s) from cooking bananas (183s) at $P \leq 0.01$.

The investigation permitted to better understand the selection of the varieties by the producers and the uses by consumers according to the consumption mode. A close relation between selection and uses of cultivars with the morphological, physicochemical and rheological specificities were highlighted for the cultivated Musaceae. Some clones were also pointed out to have a substantial interest for the industry.

Keywords: diversity; sampling; minerals; amylose; Onset temperature; pasting property; plantain.

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1. Introduction

As major staples, bananas are cultivated in over 130 countries throughout the tropical and sub-tropical regions on five continents. The world production of dessert (Musa sp. AA, AAA) and cooking landraces (Musa sp. AAB, ABB) is estimated to about 104.3 million of tons. Main producers of dessert bananas are India, Brazil, China, Equator and Philippines while the mains exporters are Equator, Costa Rica, Philippines and Colombia. The latter is the first producing country of cooking bananas of the plantain subgroup. Colombia and Equator are the two world first exporting countries (Lescot, 2008).

For a century, the genetic improvement programmes have been mainly oriented towards the development of varieties resistant to diseases and pests. In addition, breeding strategies have been focused on socio-economic and agronomic aspects (yields, appearance, tolerance to stresses, shelf-life, mineral and water uptakes and mechanical resistance) as reported by Bakry et al. (2009).

In many tropical countries where export bananas are produced (mainly subgroup Cavendish AAA that represents about 46.6 millions of tons according to Lescot (2008), sorted dessert bananas could be sold at a much lower price than cooking bananas and then being cooked for consumption. Nevertheless, a keen local demand remains for green cooking bananas. Such observation suggests that the consumers have a relevant appreciation of the quality of the clones and prefer costly cooking landraces for their traditional recipes. Among studies on sensorial aspects, Dzomeku et al. (2006) and Nowakunda et al. (2000) reported that the FHIA hybrids are especially interesting in term of productivity and resistance to pests. Nevertheless, those clones are rejected by consumers since a lack of taste and

flavour is noted. In addition, few publications were oriented towards the diversity of traditionally consumed products from dessert and cooking bananas around the world (Aboua, 1994), (Cable, 1983), (Dadzie and Wainwright, 1995), (Davey et al., 2007), (FAO, 1990), (Mosso et al., 1991), (Ngoh Newilah et al., 2005), (Tchango Tchango and Ngalani, 1999), (Wainwright, 1992). To a lesser extent, neglected varieties (cultivated by small local producers) are usually described without establishing any link to the consumer preferences and uses. Most investigations done on the preferences and uses were reported in Africa and Pacific area (Aked and Kyamuhangire, 1996), (Almazan, 1990), (Englberger et al., 2003), (Ferris et al., 1999), (Gensi-Mafara et al., 1994), (Gold et al., 2002), (Lemchi et al., 2005), (Mengue Efaden et al., 2003), (Vigheri, 1999). The complementary socio-economic study done by Quintero and Garcia (2008) in Northern Cauca (Colombia) has permitted to identify about thirty “locally produced” dessert and cooking bananas. The food consumption survey confirmed the knowledge of the small producers regarding diversity, tastes and preferences in relation to the specific uses of bananas (Dufour et al., 2007; Dufour et al., 2008; Alvarez et al., 2008).

Both molecular markers and morphological basis are useful tools to distinguish clones belonging to various genotypes. The agro-morphotaxonomic analysis has now been standardised with more than 119 descriptors (Bakry et al., 2009). In addition, some post-harvest criteria had been often investigated to differentiate varieties. Apart from the numerous studies aiming at studying the effect of the stage of ripeness, the dry matter content (Baiyeri et al., 1999; Baiyeri and Tenkouano, 2008; Diaz et al., 1999; Ferris et al., 1999; Ngalani and Tchango Tchango, 1996) the pasting properties (da Mota et al., 2000; Eggleston et al., 1992; Steele, 1997), the water absorption (Ngalani and Tchango Tchango, 1998), the swelling and

solubilisation patterns (Eggleston et al., 1992; Bello Pérez et al., 1999; Coulibaly et al., 2006), the processing behaviour (Almazan, 1990; Qi et al., 2000), the amylose (Kayisu and Hood, 1981; Steele, 1997; da Mota et al. 2000), the micronutrients (Davey et al., 2007; Forster et al., 2002; Hardisson et al., 2001; Wall, 2006) the texture (Ferris et al., 1999; Baiyeri et al., 1999, Qi et al., 2000) and the characterisation of the structures (Eggleston et al., 1992; Steele, 1997; Qi et al., 2000; Coulibaly et al., 2006) are some major parameters that had been earlier studied. However, a relative low number of varieties were in general investigated. The literature still lacks some comparison between many varieties of different genetic groups to define some objective criteria to distinguish clones and genotypes. It could then contribute to the comprehension of the relation between cooking behaviour and consumer preferences as well as being helpful for future breeding strategies. In addition, the effect of the α -amylase is a general concern when describing pasting properties of flours. Among the literature, Crosbie et al. (1999) studied and stressed the efficiency of AgNO_3 for an efficient amylase inactivation in Japanese ramen. So far, no methodology has been yet reported for guarantying an optimal characterisation of the banana flours functional properties independently of the amylase activity. Moreover, among numerous publications, few studies were focused on the plant variability (mainly Hughes and Wainwright, 1994; Mustaffa et al., 1998; Ahmad et al., 2001; Jullien et al., 2001; Davey et al., 2007). No standardised sampling strategy was so far suggested at full bunch level of bananas, which takes into account the global pulp heterogeneity.

This study aimed at investigating the morphological and physicochemical characteristics of the diversity of the cultivated varieties earlier described by Quintero

and Garcia (2008) in order to better understand the consumer preferences and uses. The work attempted to explain why some of the varieties are accepted or rejected by consumers and to highlight some neglected cultivars with a potential for home consumption or industrial processing. The investigation of the within-bunch variability was done for establishing a sampling strategy. The mineral composition, the dry matter and amylose content of the starches were also estimated and compared among clones and genotypes. In addition to a standard DSC approach, a protocol to characterise the pasting properties of the flours by RVA was investigated irrespective to the α -amylase content of the flours.

2. Material and methods

2.1 Varieties and fruit samples

Twenty three edible Musa L. section Eumusa (2n = 22) cultivated varieties including 6 dessert bananas (2 AA, 4 AAA genome types), 4 banana hybrids (1 AAAA, 3 AAAB), 6 plantains landraces (AAB), 2 cooking hybrids (AAAB) and 5 landraces of cooking bananas (1 AAA, 2 AAB, 2 ABB) were produced for self-consumption using non-intensive farming systems and collected in the states of Cauca, valley of Cauca, Caldas and Quindio in Colombia (Table 1).

Table 1

Consumption mode, classification, origin and number of bunches analysed per variety

All genetic groups were identified using the vernacular names combined with the description of the varieties according to Bakry et al. (2009), Castrillón Arias et al.

(2002), Lescot (1998), Pillay et al. (2006) and Tezenas du Montcel et al. (1983). No subsequent verification was performed to check the genotypes of the cultivars. The growers estimated the optimal green stage of maturity of the Musaceae for harvest with the optimal fullness/plumpness of banana fruits according to Sanchez Nieva et al. (1968).

2.2 Morphological characterisation

Clusters of fruits (hands) were labelled from basal (spike) to distal hand (raquis) of the bunch. Fruits (fingers) were labelled from left hand side with the inner curvature on top (outer curve side is facing the bench). Corresponding rows were also identified as internal row A (clusters of the top row, the nearest to the stalk) and external row B of the hand.

Fruits of the same bunch were all harvested at the same time. Bunch weights, number of hands, volumes, lengths, proximal median and distal girths of fingers, weights, volumes and number of fingers per hand were recorded for individual plants. Immediately after peeling, peel and pulp were weighed; lengths, girths and volumes of the pulps were similarly measured according to Dadzie and Orchard (1996). The specific gravities of full hands, full peeled hands, fingers and pulps were estimated in duplicate using the ratio of fruit weight in air to fruit volume (Bainbridge et al., 1996). Percentage of peel (w/w of finger) was also determined by the ratio of peel to finger in percentage. Full characterisation of bunches were repeated depending on availability. Standardised pictures of the representative fingers and their median sections were done for twenty varieties.

2.3 Flour preparation and starch production

Pulps from the second hands of the varieties were dried in a ventilated oven at 40°C during 48 h. After fine-powder grinding, flours were stored at 4°C in sealed plastic bags for further analyses.

Freshly cut pulp pieces randomly sampled from each hand of the bunch were suspended in distilled water and crushed in a 4 L capacity Waring blender (New Hartford, CT, USA). The slurry was filtrated through a 100 μ m sieve, three times washed and decanted off. After removal of the dark highest layer, starch was centrifuged three times (10000 rpm and 4°C) and then finally oven dried at 50°C during 48 h.

2.4 Physicochemical characterisation

After pulp dry matter determination (DM) in triplicate using a ventilated oven at 104°C overnight, the total dry weight yield of edible food in 10³ g plant⁻¹ (EFY) was calculated according to Ferris et al. (1999) using the bunch weights without raquis.

Potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na) contents of the 1 g dried and ground flour (from the second hand of each variety) were determined by inductively coupled plasma-atomic emission spectrometry (ICP-AES) Varian-Vista Pro (Varian Inc., Palo Alto, CA, USA) using a coupled charge device detector, according to AOAC (2000) official method 985.01. A two-steps dry mineralisation procedure (HCl, HF) was carried out with a double oven incineration at 500°C according to Pinta (1973), prior to the ICP-AES multi-wavelengths determination. A respective resolution of 5, 15, 6 and 50% was admitted for K, Ca, Mg and Na using the standardised protocol.

The method reported by Mestres et al. (1996) was used. Analyses were performed on a Differential Scanning Calorimeter (DSC) Perkin-Elmer DSC 7 device

(Perkin-Elmer, Norwalk, VA, USA) using sealed stainless-steel pans. The sample pan (10-11 mg of starch and 50 μ L of lyso-phospholipid 2% w/V in water) and the empty reference pan were heated from 25 to 160°C at 10°C min⁻¹, hold at 160°C for 2 min, and then cooled to 60°C at 10°C min⁻¹. The onset temperatures (onset) were determined on the thermograms. Amylose content was also estimated, from the energy of amylose-lysophospholipid complex formation. The analysis was performed in duplicate, and mean values were calculated.

2.5 Rheological properties

Hot flour dispersion viscosity profiles were investigated using a Rapid Visco Analyser (RVA) model RVA-4 series (Newport Scientific, Warriewood, Australia). Viscosity was recorded using the following temperature profile: holding at 50°C for 1 min, heating from 50 to 90°C at 6°C min⁻¹, holding at the 90°C plateau for 5 min, and then cooling down to 50°C at 6°C min⁻¹, with continuous stirring at 160 rpm and using a flour suspension of 6, 7 and 8% (w/V distilled water). Six parameters were measured on the viscoamylogram: pasting temperature (PT) and pasting time (Pt), peak viscosity (PV) and peak viscosity time (Pvt), hot paste viscosity the lowest hot paste viscosity (HPV), the viscosity at the end of the plateau (VEP) and the cool paste viscosity at 50°C (CPV). Four additional parameters were then calculated: cooking ability (CA), estimated as Pvt - Pt; breakdown (BD), estimated as PV - HPV; setback (SB), estimated as CPV - PV; and consistency (CS), estimated as CPV - HPV.

The variety having the highest HPV was dispersed to 6, 7 and 8% suspension using then two additional plateaux at 93 and 95°C. From the optimal suspension-temperature couple, the incidence of a silver nitrate amylase inhibitor (AgNO₃ 0.002

mol L⁻¹) according to Crosbie et al. (1999), a phosphate buffer pH 6.5, a citrate buffer pH 7 and a combination of AgNO₃ with phosphate or citrate buffer were investigated. All parameters were obtained in duplicate and mean values were calculated.

2.6 Statistical analysis

Experimental data regarding morphological and physicochemical analyses are the mean of various replications. When possible, standard errors and deviations were also computed. Analysis of variance (ANOVA) was performed on morphological parameters between groups and subgroups of clones, between-plants, within-bunch, within-hand and rows to assess biological variability. Means separations were done using the Honestly Significantly Differences (HSD post-hoc test) at $P \leq 0.05$. Statistics were performed using Statistica software package V.6.1 (StatSoft Inc., Tulsa, Oklahoma, USA).

3. Results and discussion

3.1 Varietal diversity of weights and dimensions

The twenty three cultivars are classified according to their usual consumption mode: as 'dessert bananas' eaten raw and 'cooking bananas' cooked for being consumed, as suggested by Lescot (1998), Quintero and Garcia (2008). Table 1 describes, the genomic classification, subgroups, sampling areas and respective number of bunches analysed per variety. Among the 10 dessert bananas and 13 cooking bananas. Some clones are used in industry in Latin America such as Dominico Harton, Harton, Dominico, Cachaco and Pelipita (Arcila P.M.I. et al., 2002; Dufour et al., 2007; Herrera J.W.M. and Aristizábal M.L, 2003; Lescot, 1993; Morales et al., 2000; Price, 1999; Quintero and Garcia, 2008), in addition to the exported

dessert landraces Cavendish and Gros Michel. Figure 1 shows a wide distribution of lengths and sections. Differences in colour (peel and pulp) and shape are also visible in relation to the agromorphological variations.

Fig. 1. Length distribution and median section of bananas.

The increasing length distribution highlights that plantains and cooking hybrids are the widest varieties (FHIA 20 & 21, Dominico, Dominico Harton, Harton and Africa). Most industrial varieties have large lengths and diameters. Dessert and cooking bananas are heterogeneously distributed and smaller. The Hua Moa variety presents the specificity of being a small banana with the apparent largest cross-section area. Its apparent low peel percentage is supposed. In addition, some peel colour variations among varieties could be observed, from the smallest green spotted Bocadillo, to the strong green FHIA 25, the red Tafetan Morado or the yellow Maqueño. The visual differences among varieties are also brought about with various shapes and apical appearances, as earlier attempted at classifying, cultivated bananas (Simmonds and Shepherd, 1955 cited by Bakry et al., 2009) and plantains (Tezenas du Montcel et al., 1983). Even though all hands, fingers were characterised, the complementary Table 2 gives the mean characteristics of banana bunches, fingers and pulps for simplifying the comparison between clones. The variability within-bunches and within hands will be later discussed.

Table 2

Bunch weight, fruits and pulps characteristics of the dessert and cooking bananas

The bunch weight distribution covers a range from 2.7 to 49.4 kg where Hua Moa and hybrid F 17 are the extremes. FHIA hybrids are well known for having a very high production yield (Gonzalez et al., 2003). Except from most hybrids, Gros Michel and Bocadillo have the heaviest bunches. The mean hand weight per cultivar varies from 549 to 4352 g. Hybrids present the highest average weight per hand over 2790 g. The mean comparison between hand weights gives some significant differences at 99% confidence level. Nevertheless, the absence of significant differences between some other varieties (Bocadillo, Primitivo, Tafetan Morado and Guineo with 5 identified groups using Tukey's HSD test), suggests a strong heterogeneity between hands. Some clones present a relative low number of hands per bunch (Bocadillo, Tafetan Morado, Dominico, Pelipita or FHIA 21) or fruits per hand (Hua Moa, Africa). No clear relationship can be established between number of hands per bunch, number of fruits per hand and bunch and hand weights.

As earlier shown, strong differences in fruit lengths are observed. Cooking and dessert bananas are heterogeneously length distributed. Except from FHIA 25, hybrids and plantains show the widest lengths. With a mean fruit length over 30 cm, Africa and Harton are especially larger than the other clones. Corresponding fruit girths are also significant. Both Hua Moa and Cachaco present massive mean median girths while most dessert bananas have smaller circumferences. Both length and median girth of fingers are revealed been suitable to partially discriminate varieties one by one ($P \leq 0.01$). Similar trends are obtained when considering median pulp girths and lengths when compared to that of finger dimensions. The two extreme cultivars for lengths (Bocadillo and Africa) are also the two extremes for circumferences. It is interesting to note that the three main industrial clones of

plantain: Dominico, Dominico Harton and Harton present a relatively low variability. Those three varieties present significant differences in length and girth criteria with other cultivars (miscellaneous statistical letters on length and girth criteria at $P \leq 0.01$). Contrary to, the Hua Moa cooking banana is suggested being particularly length heterogeneously distributed. The hypothesis is confirmed by the full raw data observation (not shown). In addition, proximal and distal girths were observed being also heterogeneous: no significant statistical trends were observed when considering proximal and distal girths (data not shown), revealed being strongly dissimilar.

Except from Bocadillo, FHIA 25 and Pelipita, full hand densities are homogeneous, in the range of 0.96 to 1.03 (Table 2). Individual finger densities are also homogeneous. Nevertheless, a weak correlation could be established between hand and finger densities as well as peeled hand and finger specific gravities. Corresponding mean separations are relatively poor to discriminate banana clones. Such descriptors are revealed not relevant for an optimal discrimination of the varieties using the HSD test.

3.2 Varietal variability of dimensions

The statistical description of the hand weights, girths and hand/finger densities suggested some heterogeneity between and within-varieties. Labels of hands, fingers and rows aimed at investigating the variability, taking into account the complete morphological characterisation done. The results of the exhaustive ANOVA and HSD tests investigations at bunch, hand and finger level are discussed below.

A common mathematical parameter was introduced to describe the evolution of morphological data: the relative variation percentage (RV%) as the mean difference between the initial and the final value for a given criterion out of the initial one. Then,

a 0% relative variation means that the parameter does not fluctuates in the initial-final interval.

The first statistical analysis consisted in evaluating the influence of the hand location, on finger and pulp length as well as finger and pulp median girth. At 95% confidence, significant differences in lengths and girths were observed for peeled and unpeeled bananas. Mean comparisons demonstrated a significant reduction of fingers and pulps lengths from basal to distal hand of most varieties (data not shown). Such result had been abundantly described in the literature as the consequence of banana bunch growth starting at the proximal hand and spreading after a lag to the distal hand of the bunch. Jullien et al. (2001) related such variability within the bunch to a difference in cell number and age. The values of the RV% for both pulp lengths and median girths of all varieties are shown in Fig. 2.

Fig. 2. Pulp lengths and girths relative variation percentages from proximal to distal hands of bunches.

Gros Michel (GM) presents the specificity of a negative girth relative variation around -10% which tells that the variety circumference is increased by 10% from the proximal to the distal hand of the bunch. The other bananas show a decreasing girth size from about 4 to 31% along bunches. Similarly, all fingers lengths of the varieties were reduced from proximal to distal hand in various proportions. It is interesting to note that complementary to a non correlated RV% between lengths and girths, some bananas have low girth relative variations (below 7%) while their pulp length exceed 21% (Primitivo, Africa, Guineo, Cachaco and Rollizo). Contrary to the Harton clone, Hua Moa and Maqueno present an extreme variability within bunch (both $RV > 15\%$).

Four varieties, Tafetan Morado, FHIA 1, FHIA 21 and Dominico show a low RV% for both length and median girth. The later is the only industrial variety which presents such relatively low variability within axial and longitudinal dimensions. Complementary statistical analysis performed that consisted in evaluating the influence of the hand number, on weight of hands, weights of fingers, peel percentages and individual specific gravity of the fingers (data not shown) highlighted significant differences in percentages of peel for 10 varieties and in finger weights for all varieties. This last result is consistent to Sanchez Nieva et al. (1968), Jullien et al. (2001), Arcila et al. (2002) works where significant differences in weights and/or sizes between basal and distal banana fruits were described.

At “hand level”, without considering rows, the statistical analysis was oriented towards the influence of the finger number on weight, length and girth (for both finger and pulp), individual specific gravities, dry matter and peel percentage. Non significant differences were obtained for most of the parameters. However, the HSD tests clearly showed a significant effect of banana length and weight on some varieties. However, first and last fingers labelled were revealed particularly heterogeneous. Such variability between extreme fingers probably partially ‘hides the weight and length trends’. The strong girth variability noted earlier between proximal, median and distal part of the fingers implies to focus statistics on median section to expect any significant differences in girths at hand level. Nevertheless, no relevant differences were here observed.

When considering statistics at “row level”, significant effects were observed on median girths (fingers and pulps) for some varieties: Girths seem smaller on the external row. Controversially, larger bananas on the external rows are shown when considering finger lengths. No significant effects were revealed on the other

morphological parameters expect from the peel percentages later noted, then justifying the use of the RV% only for the dimensions.

Such observations could explain why sampling strategies are usually oriented towards the selection of an intermediate hand instead of proximal and distal hands of bunches (Ngalani and Tchango Tchango, 1996 and 1998, Forster et al., 2002) or a specific strategy “at all hands level” (Arcila et al. 2002) or “at row level” (Jullien et al. 2001). The use of a sampling strategy at random is often used (Cano et al., 1997; Ferris et al., 1999; Hardisson et al., 2001) and could be either justified by the noted heterogeneity at bunch, hand and row levels. However, the present work suggests a full characterisation of the extreme fingers and the intermediate one, on both rows of the proximal, median and distal hand of the bunch to optimally take into account the within-bunch and within-hand variability.

3.3 Other physicochemical characteristics

The complementary investigation of the peel percentage, the dry matter and the total dry weight yield of edible food has highlighted some relevant parameters for the industrial selection of varieties. Five subgroups were defined from the two previous consumption groups. The dessert banana group was divided in two subgroups, as dessert bananas and dessert hybrids whereas the cooking group was spread into a plantain, a cooking hybrid and a non plantain cooking banana subgroups (table 3).

Table 3

Peel percentage, dry matter and edible food of the varieties

The computed peel percentages fluctuate from 24.3 to 46.6% among cultivars (Table 3). From an industrial point of view, the varieties having low peel percentages are obviously attractive, such as Africa (31.3%), FHIA 25 (34.4%), Dominico (35.1%) and the atypical Hua Moa (24.3%). Nevertheless, the latter was previously shown having the smallest bunch and one of the smallest hand weight and number of fruits per hand. Plantains are in the 31.3-40% range, while other cooking bananas (except from Hua Moa) and dessert bananas are in the 38-46.6% range. Significant mean differences among peel percentages of varieties are shown at 99% confidence level. Dessert bananas and plantains present the smallest peel percentage (38 and 37.8% respectively). As indicated above, the statistical investigation down on variability at row level also showed some predominantly lower peel percentages on the external row (B) of the hands of the varieties (data not shown).

Similar post-hoc test done on dry matter contents permit to significantly differentiate most of the varieties (15 clones individually separated out of 21 on DM at $P \leq 0.01$). The dessert and cooking landraces dry matter contents respectively fluctuate from 19.6 to 30.9% and 26.5 to 45%. FHIA 25 has the lowest DM (19.6%) and Guineo has a relatively low dry weight (26.5%) as compared to that of the other cooking bananas. Hua Moa and Primitivo contain intermediate dry weights between dessert and cooking bananas contents. Mean comparison done on consumption mode confirms the significant differences observed between desserts and cooking bananas at $P \leq 0.01$. The complementary HSD test performed on banana subgroups highlights some significant differences in DM between dessert banana hybrids (24.6%), dessert bananas (29.4%), cooking bananas (32%), cooking hybrids (34.2%) and plantains (41.1%). These results are in accordance with those obtained by Ferris

et al. (1999), Ngalani and Tchango Tchango (1996), Baiyeri et al. (1999) works, where respectively 16, 24 and 36 Musa genotypes were discriminated according to their respective dry weights. Nevertheless, a significant differentiation among the five subgroups was here demonstrated for the first time.

The combination of full hands specific gravities and dry matters of the pulps (Figure 3) suggests a weak relationship between the given set of data ($r^2 < 0.2$).

Fig. 3. Correlation between specific gravities and dry matter contents of banana subgroups.

The attempts to correlate dry matters with the other calculated densities (not shown) gave also weak relationships. The density criterion is possibly not suitable for establishing a precise relation between sets of data when comparing banana varieties belonging to different genome types at a full green stage of maturity. However, it is interesting to note the spatial repartition of data into fine zones corresponding to the five subgroups earlier defined. This result is probably strongly influenced by the significant differences in dry weights among subgroups when combined with some relatively homogeneous densities (were no significant differences were earlier observed). A large scale investigation on a core collection may be attempted as 'a preliminary check' of the belonging group/subgroup of a supposed variety.

Highest total dry weight of edible food (EFY) are shown for dessert hybrids (FHIA17 and FHIA 1 >5.9 kg) and to a lower extent for cooking hybrids and plantains (4 to 5 kg). Nevertheless, Africa presents a significantly lower EFY than other

plantain landraces. Low EFY (below 3 kg) is obtained for Hua Moa, Guineo, Tafetan Morado, Rollizo, Pelipita and FHIA 25. A major contribution of their low weights of bunches to the yield could be suggested. Data obtained are significantly higher than those reported by Ferris et al. (1999), probably due to some extent to the relative higher dry matter of clones as well as the use for of the bunch weight without raquis for the computation. The complementary post-hoc test does not permit to significantly differentiate varieties. However, EFY presents the interest of combining various parameters and could be a relevant criterion among others, for the industrial selection of clones.

From a nutritional point of view, a role of satiation and a major source of minerals are usually assigned to pulps of banana. In particular, potassium is often cited as the predominant mineral (Suntharalingam and Ravindran, 1993). Nevertheless, the comparison of edible bananas minerals is often limited to few varieties. The K, Ca, mg and Na contents of the second hands of the flours of the pulps of the 23 varieties are given in Table 4, as well as the corresponding dry matter.

Table 4

Mineral composition of the second hands of the banana flours

As expected, the potassium content of bananas is important. Among dessert bananas, the K content fluctuate from about 1009 to 1347 mg/100g DM, but well below the quantity determined on dessert hybrids (1311 to 1497 mg). The USDA database (2008) and the review done by Hardisson et al. (2001) showed similar amounts in bananas of various origins. The plantain and cooking hybrids contents are relatively low (mean value about 959 and 1053 mg/100 g dried flour) whereas

non plantain cooking bananas present a strong diversity from 814 to 1378 mg. The later atypical K contents estimated in both Hua Moa and Pelipita could explain the large standard deviation obtained and non significant mean differences between non plantain cooking bananas and the other subgroups. Only dessert FHIA hybrids are here shown having larger K content on dry basis ($P \leq 0.05$). Contrary to previous observations, the post-hoc test conducted after fresh matter basis correction shows only differences between subgroups of plantains and dessert FHIA hybrids K contents.

A large variation in calcium and magnesium concentrations could be observed among subgroups and varieties, within the 5.1-29.5 mg and 83-141 mg per 100 g dried flour range respectively. The Ca and Mg amount in plantains is lower than in sweet bananas (dessert and dessert hybrids) but is not significantly different to other cooking varieties at 95% confidence level. Important amount of Ca are found in Hua Moa, Rollizo and FHIA 25, while Maqueño, Dominico and Dominico Harton present the lowest quantities. Primitivo (Dessert banana) and hybrid FHIA 1 present the highest quantity of magnesium whereas FHIA 21 hybrid and most plantains are the poorest. No significant differences between subgroups are observed when the calcium and magnesium amounts are expressed on fresh matter basis. However, the large standard deviations shown (coefficient of variation > 30%) are probably a good the expression of the Musa diversity. The mean calcium and magnesium contents (respectively with 3.5 to 6.2 and 28 to 37 mg/kg fresh matter) are in agreement with some of the results reviewed by Hardisson et al. (2001) and Wall estimations (2006). Calcium is a major macro-element involved in the intracellular cement (Qi et al., 2000; Voragen et al., 1995). Surprisingly, the calcium content is lower in plantains, known for having a better textural resistance during heating than dessert bananas.

Some later investigations onto the cell wall composition in relation to calcium and heat resistance, may contribute to a better understanding of the various cooking behaviour of Musa genotypes.

If various sodium contents were determined among the varieties, no significant differences can be observed between subgroups on db (from 2.7 to 6.1 mg/ 100g with a mean value about 4.4mg/100g DM). On fresh matter basis, the sodium content is statistically lower in dessert hybrids than cooking hybrids and plantains ($P \leq 0.05$) even though a large analytical resolution was admitted. If the mean estimated Na content (about 1.5mg/ 100 g fresh matter) is similar to Forster et al. (2002) and some data reviewed by Hardisson et al. (2001), one third of the USDA data base values (2008) are obtained for both dessert bananas and plantains. Except from a weak correlation between K and Na contents in wet basis ($R^2 \approx 0.47$), no significant correlations were found between macro-elements (data not shown).

The starches physical property (Onset temperature) and the amylose contents evaluated by DSC are summarised in Table 5. The mean comparisons performed on varieties and at subgroups level are summarised.

Table 5

Starches physical properties (Onset temperature and percentages of amylose)

Various onsets are obtained in the 59.7 – 67.8°C range (respectively Bocadillo and Dominico). Some significant different onset temperatures could be observed

among varieties. Some cultivars, such as Gros Michel, Tafetan Morado, Dominico Harton and Harton present significant mean differences, which are probably due to their extreme onset temperatures. Da Mota et al. (2000) and de la Torre-Gutiérrez et al. (2008) reported even higher onset temperatures: 64.3 - 72°C and 71.6°C respectively. When comparing subgroups, significant differences in the onset temperature means are observed between dessert bananas (63.2°C), non plantains cooking bananas (65.4°C) and plantains (67.1°C). Significant differences among subgroups imply that the heat resistance is a suitable criterion to differentiate dessert and cooking bananas, even though the hybrids have a similar behaviour to cooking bananas.

Regarding the amylose content, it fluctuates from 15.4 to 24.9%. Among varieties, Cavendish, Rollizo and FHIA 18 present the smallest amylose content, whereas Pelipita, Cubano Blanco and Cachaco show the highest amounts. Various amylose percentages are reported in the literature. Eggelston et al. (1992) indicated low amylose contents for unripe plantain and other cooking banana starches (about 9 to 17%) using a colorimetric method. Amylose contents between 18.8 and 22.4% were indicated by da Mota et al. (2000) without any established relationship between genotypes. Concordant amylose contents for green unripe dessert banana starches (about 16%) had been reported by Kayisu and Hood (1981). The individual comparison of the means shows some significant differences between varieties at $P \leq 0.01$. Complementary HSD test performed on subgroups clearly highlights two groups of varieties: sweet bananas (dessert and dessert hybrids) and the others, as illustrated (Fig. 4).

Fig. 4. Mean amylose contents with standard errors and standard deviations of the consumption groups of bananas.

Apart from Guineo and Bocadillo clones, the mean contents of amylose are well distributed. Low to intermediate amylose contents are represented by dessert bananas (15.4 to 20.9%) while intermediate to high amylose amounts correspond to cooking bananas (19.7 to 24.9%). Dessert hybrids present lower amylose contents than dessert bananas whereas cooking hybrids show lower amylose contents than cooking bananas. Some varieties have been characterised in duplicate or more, presenting large standard deviations. It does affect the final statistical result but contributes to a better comprehensiveness in regard to the variability. Steele (1997) earlier noted some differences in amylose contents between cooking (2 plantains and 1 non plantain cooking clone) and dessert banana starches (2 varieties).

A clear relationship between consumption mode and starches amylose contents of bananas is here demonstrated. The study based on cultivated bananas might even be improved if the analyses were carried out on clones from a core collection. Such parameter is probably a relevant post-harvest quality criterion which may be integrated in future genetic strategies.

3.4 Rheological properties

To settle a methodology for studying the pasting properties of banana flours irrespective to the α -amylase content, the influence of the dry matter content on RVA profiles has been at first investigated. The Cavendish flour sample was selected as

the variety presenting the highest hot paste viscosity. The corresponding profiles of the banana flours done at 6, 7 and 8% dry matter using water are shown (Fig. 5).

Fig. 5. Cavendish banana flour RVA profiles using water with 6, 7 and 8% dry matter and 95, 93, 90°C temperature of plateau.

The influence of the concentration on the pasting properties could be here observed. The 8 % concentration permits to obtain higher viscosity with larger amplitudes. Such phenomenon was earlier described by Kayisu et al. (1981), Lii et al. (1982), Eggleston et al. (1992) using a Brabender viscoamylograph. The complementary study of the influence of the temperature of the plateau on the pasting profile shows that the 95°C plateau of temperature induces some major undesired variations of the viscosity just after the peak. The 90°C plateau induces less noise than the 93°C plateau, which is relatively closer to the critical 96.5°C temperature where the water boils at such altitude (1100m above the sea level in Cali, Colombia). The concentration of 8% flour db and the 90°C plateau are then defined prior to the selection of the other methodological steps.

The complementary study of the influence of the use of an amylase inhibitor on the three varieties presenting the highest pasting temperature (Cavendish, FHIA 1 and FHIA 18) is shown on the following figure (Fig. 6). The 8% concentration and 90°C plateau were used according to previous observations.

Fig. 6. Comparison between Cavendish, FHIA 1 and FHIA 18 RVA profiles using water or AgNO₃ amylase inhibitor at 8% dry matter.

According to Collado and Corke (1999), the silver nitrate does not affect the pH of the flour mixture. Nevertheless, the AgNO_3 has various effects on the pasting profiles of the three varieties. If some limited effects of the inhibitor could be observed on Cavendish (small PV increase and a slight decrease of CPV), a strong influence could be observed for both FHIA 1 and FHIA 18. The hypothesis of a lower amount of amylase in the Cavendish flour as compared to that of hybrids could be then supposed. Such hypothesis is consistent to Collado and Cork (1999) where a large difference in PV in distilled water and AgNO_3 solution (0.05mM) were obtained and successfully combined to estimate α -amylase content. The pasting viscosities in distilled water were also suggested to reflect inherent resistance of the α -amylase to hydrolysis. Peak, hot, cold paste and final viscosities are then significantly higher using the AgNO_3 . The FHIA 1 PVt is lowered with water. In addition, the PT seems not to be affected by the use of the amylase inhibitor. The latter has then a significant positive effect on the pasting profiles done by RVA using banana flours at 8% concentration with the 90°C plateau and then, justifying its use in a later optimised protocol.

Moreover, the use of a phosphate buffer on its own, or combined with the amylase inhibitor, the use of a citrate buffer or the same citrate buffer combined with the previous AgNO_3 inhibitor were separately tested with previous solutions of water or amylase inhibitor (Fig. 7). The Cavendish flour was again selected at this step.

Fig. 7. Cavendish banana flour RVA profiles done with 8% dry matter until 90°C, using water, phosphate buffer, citrate buffer, citrate buffer with AgNO₃ inhibitor, phosphate buffer with AgNO₃ inhibitor and AgNO₃ inhibitor only.

As noted earlier, a significant variation of the peak and cold paste viscosity is induced when using an amylase inhibitor as compared to that of water. No modification of the pasting temperature is induced. However, the use of a phosphate buffer on its own or combined with AgNO₃ has a strong influence on the pasting temperature as it could be seen on the zoomed area. The lag in pasting temperature (PT delayed) with the phosphate buffer is even enhanced using the citrate buffer on its own or combined with AgNO₃. In addition, the phosphate buffer or combined buffer solution induces a significant decrease in PV whereas the final viscosity is slightly increased as compared to that of the AgNO₃ inhibitor. The citrate buffer or combined with amylase inhibitor significantly lower the viscosity all along the temperature pasting profile.

From all these results, a standardised RVA methodology was developed which should guaranty optimal viscosities and the effectiveness of the inactivation of amylases using the AgNO₃ solution. No lag in pasting temperature should occur using such conditions with the 90°C temperature of the plateau and with 8% concentration of banana flour.

The changes in viscosity during heating and cooling stage are characteristic for flours of different varietal origin (Fig. 8). Among cultivars, a large pasting diversity can be observed among plantains and other cooking bananas (continuous line) and dessert bananas (dashed lines), using the standardised defined conditions.

Fig 8. RVA dessert and cooking banana flour profiles at 8% dry matter and 90°C using AgNO₃ inhibitor.

Large differences in the ten pasting parameters exist among the varieties. Since the individual specifics can not be properly described and distinguished with such combined graphical representation, the following table 6 details the most relevant criteria underlined by the statistical analysis at $P \leq 0.01$. Least significant factors include HPV, CPV, BD, SB and CS where few subgroups were differentiated.

Table 6

Functional properties of cultivars second hand flours

The first parameter highlighted was the pasting temperature which varies in the 66.5 – 77.4°C range among varieties. Tafetan Morado and Dominico Harton which presents the extreme onsets have also the widest PT. Some significant differences are observed between varieties pasting temperatures (or Pasting time). Moreover, if the onset criterion is relevant to distinguish plantains from other cooking bananas and also dessert bananas (without significantly differentiating dessert and FHIA cooking tetraploids), the pasting temperature analysis at subgroup level also permits to differentiate dessert FHIA hybrids (combined with non plantain cooking bananas) from the other FHIA tetraploids (combined with plantains). Then, the mean pasting temperature of dessert bananas (69.5°C) is revealed being significantly lower than dessert hybrids (71.8°C) and non plantain cooking bananas (72.9°C) and to a greater extent to cooking hybrids (75.4°C) and plantains (75.9°C). No similar results where so far highlighted the literature since no exhaustive comparison have ever

been carried out between all these subgroups. The mean comparison of the pasting time between the varieties showed some similar differences (data not shown).

Some relationships between PV and cultivars belonging groups are also established. A restricted swelling is only observed for two plantain varieties (Africa and Dominico), the other clones presenting intermediates peak viscosities. Plantain PV (1816 cP) are shown being significantly lower than other cooking bananas (2079 cP) and dessert hybrids (2097 cP). No differentiation between dessert bananas PV means and other subgroups are shown, probably due to the large diversity of the peak viscosity among the clones (1462 to 2230 cP). The statistical mean comparison done on cooking ability parameter shows some significant differences between varieties. In particular, the following cultivars: FHIA 18, Dominico Harton, Harton, Cubano Blanco Cachaco and pelipita present the lowest cooking abilities. FHIA 17, FHIA 20 and FHIA 25 exhibit broad peak viscosity and have the highest CA. If a relation could be suggested from the high pasting temperature of most cooking bananas and plantains with their low cooking ability, some varieties such as Africa or FHIA 20 present high PT and CA. Complementary HSD test done on CA clearly shows two groups of varieties. Dessert bananas and all hybrids have a significantly higher cooking ability (230 to 255 s) than cooking landraces (175 to 177 s). This result has to be brought together with the subgroups identified on amylose content. Apart from FHIA 21 (where both amylose and cooking abilities are similar to cooking bananas and plantain) and FHIA 20 which is significantly different (higher amylose and CA), similar statistical subgroups are identified regarding amylose and cooking ability for the other clones. Plantains present the lowest CA with the highest mean amylose content. A weak relationship ($R^2=0.45$) between pasting temperatures and the amylose contents was also observed (figure not shown). Steele (1997) reported

similar observation. The author concluded that the relationship between pasting characteristics of the Musa and the amylose contents of their starch granule is less clear as compared to that of cereal starches. In addition, a substantial increase of PT is shown with the rise of the amylose percentage, without establishing any strong relationship in between.

3.5 Synthesis on the differentiation of the varieties in regards to physical and functional properties

All investigations earlier carried out highlighted some significant differences between the modes of consumption. The relevant parameters earlier described were individually normalised in the 0-1 interval (where 0 and 1 represents the smallest and the highest value respectively for each parameter). Normalised data were then grouped and averaged per consumption subgroup. Mean criteria were selected and graphically combined within a radar chart (Fig. 9).

Fig. 9. Radar chart of the normalised physical and functional criteria of dessert bananas and plantains.

The radar chart above permits to describe the main differences observed between plantains and dessert bananas. Such graphical representation permits to differentiate consumption modes and to predict from the combined parameters the most suitable mode of consumption for a given clone.

On the one hand, the following parameters: DM, PT, onset, amylose and length are significant criteria for the plantain differentiation from dessert bananas. To a lesser extent, girth and edible fraction are also relevant. Plantains present the

highest dry weight and amylose content among banana subgroups and require a much higher temperature for hydration (pasting and gelatinisation temperature). On the other hand, except from the peel percentage (visually equivalent for both plantains and dessert bananas), all the mineral contents (K, Ca, Mg and Na on dry weight basis) and the cooking abilities are significantly lower within plantains varieties (on dry weight basis). After the critical pasting temperature, plantains require a shorter period to get a maximum starch viscosity under the continuous stirring strain than dessert bananas.

Complementary radars charts between groups and subgroups (not shown), illustrated additional results highlighted earlier. In particular, the comparison between dessert bananas and dessert hybrids are recalled. The dessert hybrids have a much lower dry matter and a higher percentage of peel but a higher edible food fraction. Their pulp is harder to cook (PT and onset temperature) and have a much higher mineral content (on dry weight basis) than dessert bananas.

Concerning the plantain subgroup, the dry weight, the pasting temperature, the gelatinisation temperature, the amylose content and the morphological criteria are the highest. Cooking hybrids have a quite similar profile to that of plantains, except from the higher cooking ability and peel percentage and the lower dry matter content.

3.6 Relation between the preferences of the consumers and the physicochemical and functional properties

Home consumption

The study have shown some differences between varieties and permitted to highlight correlations between consumption modes and the physicochemical

characterisation. In particular, some differences between dessert and cooking bananas were demonstrated considering minerals, amylose percentages, onset and gelatinisation temperatures, peak viscosities and cooking abilities. The investigation has also shown that all dessert bananas have low dry matters (mean value below 27.3%). It may explain why consumers prefer to eat sweet bananas without cooking. At a green ripe stage of maturity, no varieties are consumed without being cooked. Consumers usually prefer a sweet and mellowness pulp for raw consumption (Quintero and Garcia, 2008).

When considering processed banana varieties, they are usually consumed after water boiling or frying unit operation. The latter process quality related to oil uptake was earlier demonstrated being strongly influenced by the variety of banana used (Lemaire et al., 1997; Diaz et al., 1999). A higher water loss was shown being correlated to a higher oil uptake, but probably as the consequence of the fried product microstructure (as reported by Vitrac et al., 2002). Obviously, a lower water loss (due to a higher dry weight) is supposed to induce much limited fat uptake, as it has been reported by Lemaire et al.,(1997), whom compared the fat uptake of plantains (35%) to that of other cooking bananas (45%). Production costs are obviously strongly influenced by the final fat content of the fried products. Our study highlighted the high dry matter contents for the plantain subgroup and both FHIA 21 hybrid and the Pelipita landrace (ABB). These results are in agreement with Quintero and Garcia (2008) whom reported a consumer preference for these clones when targeting fried products.

The other cooking bananas are usually preferred for water cooking at a green stage of maturity (in soup locally called "Sancocho"). The varieties with low dry weights such as dessert hybrids and the Guineo cooking banana are well-known for

being partially or completely disintegrated in boiling water. The East African Highland banana Guineo was also reported being highly appreciated by local consumers but does not represent a major production (Price, 1999). Pelipita, Chachaco, Cubano Blanco, Harton, dominico Harton and Dominico clones with some mean amylose contents between 24.9% and 23.2% are mentioned as the hardest varieties to cook in water by consumers. Those varieties with hard textures present a tendency to become even hardened after cooking and during the cooling stage. Such phenomenon could be explained by some starch retrogradation. The Pelipita variety is usually consumed cooked at a ripped stage of maturity to probably avoid hardening. In addition, most consumers appreciate varieties in regards to their cooked texture, their colour, taste and flavour in soups. For instance, the Cachaco variety is usually preferred for flour production and children beverages (nutritional and cultural aspects).

Even though the study was only conducted on bananas at a green stage of maturity, the socio-economic investigation noted that many varieties are preferred at a ripped stage of maturity for water cooking and oven cooking and frying. The clones Guayabo, Cubano Blanco, Harton, Dominico Harton, Dominico and Pelipita are the most representative. Some additional studies should be later done to estimate differences between ripped varieties (colour, sugar content, texture, taste and flavour) while taking into account the preferences of consumers. The food consumption survey has also shown that a unique fully ripped clone is commonly used for fermentation: the Guineo cultivar (East African cooking banana AAA). Some additional investigations may be later done on fermentation and digestibility ability of this clone, already known in Uganda for being eaten as a cooked banana and processed into some beverages (Aked and Kyamuhangire, 1996; Gensi et al., 1994).

Other studies on the preferences of the consumers for a specific mode of consumption should help to better understand the adoption of clones by the producers and consumers.

3.6.2 Industrial uses of bananas

Major industrial productions in Colombia are oriented towards fried products (chips, “moneditas” and “patacones”) and the production of flours for children beverages, using Dominico Harton, Dominico, Harton, Guayabo and Pelipita clones. A cooking banana variety could be expected being industrially used if having a peel percentage without raquis below 39% about. Nevertheless, Pelipita and Cachaco clones (used locally used in the industry) as well as FHIA 20 have an average peel percentage in the 40 to 45% range, which is a disadvantage due to the important loss of raw material and the agro-industrial quantity of waste. The dessert FHIA hybrids are even worst with a peel percentage between 45 and 50% about.

The most interesting varieties are often the ones with the greatest diameter and length. Cubano Blanco clone could be a potential industrially used variety in addition to the ones already noted. In particular, Dominico, Harton and Dominico Harton industrial clones obviously present a relatively low variability.

Hua Moa and Africa have attractive large diameters, even though theirs respective low productivities were shown. Such varieties could be interesting for the chips production (“moneditas”). In table 3, it was confirmed that the industrial clones are those of greater dry matter, between 35.1 and 45%. The study also showed that the varieties FHIA 21, Africa and Cubano Blanco not industrially used in Colombia have a dry weight between 36.3 and 43%. These varieties could be an opportunity for diversification of the resources for frying process.

Besides the studied parameters, the investigation may be later oriented towards the sugar content at green stage and °Brix at ripped stage, the green life duration, the enzymatic browning after peeling, the transport and storing behaviour of peeled bananas, earlier mentioned for having a potential for the local industry.

4. Conclusion

This study pointed out a significant broad diversity and a variability within-bunch and within-hand. A sampling strategy has been suggested accordingly. Among physicochemical and functional parameters, dry matter content was confirmed being a relevant parameter to differentiate the five banana consumption subgroups, and to a lesser extent, the mineral composition of the flours on dry weight basis. The onset temperature helped to differentiate bananas, plantains and other cooking bananas, whereas the pasting temperature determined using an optimised protocol also permitted to distinguish dessert hybrids. A clear relationship was demonstrated between consumption modes and starches amylose contents. Moreover, lower cooking abilities were highlighted in cooking landraces as compared to that of hybrids and dessert bananas. Some agromorphological criteria were revealed being relevant to distinguish cultivars from each other as well as being good indicators for industrial applications.

All these parameters may be later included in some screening strategies for the evaluation of new clones of banana germplasms. These objective post-harvest keys should be beneficial to the future strategies of breeders as well as contributing to a further comprehension of the varieties selected by consumers in relation to their preferences and uses.

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