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ARTICLE

Differentiation between Cooking Bananas and Dessert Bananas. 2. Thermal and Functional Characterization of Cultivated Colombian Musaceae (*Musa* sp.)

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The starch and flour thermal and functional characteristics of 23 cultivated varieties of bananas in Colombia were assessed. Onset temperature for gelatinization of starches measured by differential scanning calorimetry (DSC) varied from 59.7 to 67.8 °C, thereby significantly differentiating dessert bananas (63.2 °C) from nonplantain cooking bananas (65.7 °C) from FHIA hybrids (66.6 °C) and plantains (67.1 °C). FHIA hybrids are significantly discriminated from dessert banana landraces but not from the cooking group. The starch amylose contents varied from 15.4 to 24.9%; most dessert banana starch amylose contents were below 19%, whereas in cooking banana starches the contents were over 21%. Flour functional properties were assessed by Rapid ViscoAnalyser (RVA) using silver nitrate as α-amylase inhibitor. The flour pasting temperature was relevant to differentiate dessert bananas (69.5 °C) from FHIA dessert hybrids and nonplantain cooking bananas (72.8 °C) from cooking hybrids and plantains (75.8 °C). Among other criteria, the cooking ability also helped to differentiate dessert bananas and FHIA hybrids from cooking bananas. A close relation between cultivar genotypes and uses with the thermal and pasting properties were revealed.

KEYWORDS: ***Musa*** **sp.; amylose; onset temperature; pasting properties; cooking ability; plantain**

Edible Musaceae (*Musa* sp.) represent a major staple food in the intertropical production area. Dessert bananas are eaten raw at a fully ripe stage of maturity and cooking bananas are mostly cooked to be consumed at different stages of maturity.

Musaceae constitute a hybrid-polyploid complex, derived from wild species *Musa* acuminata and *Musa* balbisiana. Edible varieties are classified according to their genome composition such as diploids (AA, AB), triploids (AAA, AAB, ABB) or even tetraploids (hybrids AAAA, AAAB, AABB).

Cultivars are consumed in various ways. Consumers may prefer one variety over the other depending on uses (*1*). A relationship was demonstrated between the genotype and the dry matter content (18−45% range) in relation to consumer preferences, for both traditional and industrial recipes (fried dishes, soups, flours). The mineral content also helped to differentiate genomic groups (*1*, *2*).

The earliest references in the literature dealing with starchy perishable resources investigated the structure and functional properties of tropical starch, and in particular plantain cooking banana starch (AAB) from Ghana and Cameroon (*3*, *4*). Many works were later conducted on *Musa* samples from various origins. The functional properties of Musaceae starches and flours have been characterized without considering or establishing any relationship between the consumption mode and the genotypes (*5*). Most studies reviewed dealt with dessert banana (mainly Cavendish group). Only 4 studies compared respectively 5, 5, 8, and 10 varieties of Musaceae at a green stage of maturity, for their flours and starches functional properties (*6*−*9*).

The pulp starch contents reported in the literature varies in the 61−82% range (*5*, *8*, *10*−*14*). Corresponding amylose contents were confusing since different devices and methods were used: 8.6% (*15*), 9.1−17.1% (*9*), 13.6% (*16*), 16% (*17*), 18.8−23% (*8*), 19.5% (*18*), 19.8−21.2% (*6*), 31−32% (*19*), 38.3% (*12*) or 16−40.7% (*5*). Thus, it is hard to establish a relationship between amylose contents, genomic groups, and modes of consumption.

Musaceae starches are known for their resistance to hydrolysis and their high resistant starch contents (*4*, *5*, *9*, *14*, *15*, *20*). Nevertheless, no study has been carried out so far comparing many varieties. The onset temperature of starch gelatinization is relatively high by DSC. Among sources, the authors report various onset temperatures (Tonset), from 62.3 to 72 °C (*8*), 65.8 °C (*14*), 68 to 74 °C (*21*), 69.5 °C (*15*), 69.6 to 71 °C (*22*, *23*), 75.5 °C (*24*), or 82.7 °C (*16*).

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The rheological properties of starches and flours of Musaceae have been investigated at different concentrations using various apparatus, such as the Brabender viscoamylograph using starch dispersions at 4.4−8% (*3*, *8*, *9*, *17*, *18*, *23*−*26*), using flour dispersions at 5−10% (*12*, *13*, *27*); the Rapid Visco Analyzer using starch dispersions at 4−16% (*8*, *13*, *22*), using flour dispersions at 10−12% (*11*, *13*); a rotative viscometer using starch dispersions at 1−6% (*24*, *28*, *29*), using flour dispersions at 7−10% (*11*, *26*); an intrinsic viscometer using 0.1−0.5% starch (*6*, *9*, *26*), or a rheometer (*21*). Pasting temperatures varied in the 50−93.3 °C range depending on devices and operating conditions (*8*, *9*, *12*, *13*, *21*, *23*, *26*). Thus, the comparison between studies of the viscosities or pasting temperatures is hazardous.

Both functional properties and the texture of edible Musaceae have been found to strongly contribute to the adoption of the varieties by the stakeholders and consumers. However, only few studies have so far established a relationship between genotypes, modes of consumption, and thermal and functional properties of flours and starches from Musaceae. Only two studies stressed some significant differences between functional properties of plantains and dessert bananas (*13*, *21*).

Using an optical polarizing hot stage microscope, the differences in pasting temperatures (Tpasting) between varieties can be observed (*9*). Varieties belonging to ABB group showed higher pasting temperatures than AAB, (66.3 and 62.1 °C respectively).

Five dessert bananas and cooking bananas were differentiated on starch swelling power and solubility patterns (*7*). The hypothesis of the dependency of starches swelling and solubility behavior on ploidy was suggested (*9*). Unfortunately, the study was only done on one diploid clone. AAB triploids exhibited a more restricted swelling. The analysis of intrinsic viscosity showed that the molecular size depends on the genotype and in the case of ABB cooking banana varies within the genomic group. In the most recent review on bananas, the authors (*30*) pointed out some varietal differences in physicochemical and sensory properties in relation to genotype and growing conditions.

This study aimed at investigating the diversity and variability of the starch thermal and flour functional properties on samples belonging to various genomic groups of *Musa* cultivated and consumed in Colombia. The main objective consists of establishing some relationship between thermal and functional properties, with genotypes, and with modes of consumption. The study also aimed at standardizing and optimizing the measurements using flours, while inhibiting α-amylase activity, to quickly screen pulps or flours from various *Musa* collections and sampling areas.

MATERIALS AND METHODS

Varieties and Fruit Samples. Twenty-three edible *Musa* L. section Eumusa were collected, identified, and classified according to their usual consumption mode (*1*).

Flour Preparation and Starch Production. Thin slices of the pulps from the second hand were dried in a ventilated oven at 40 °C for 48 h for all varieties. After being ground into a fine powder, the flours were stored at 4 °C in airtight 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). The slurry was filtrated through a 100 μm sieve, washed three times and decanted. After removal of the dark top layer, the starch was centrifuged three times (10 000 rpm and 4 °C). The isolated starch was oven-dried at 50 °C for 48 h., carefully ground in a mortar, and stored at 4 °C in airtight plastic bags for further analyses.

Thermal Properties. The onset temperature and the amylose content were determined on DSC Perkin-Elmer DSC 7 device (Perkin-Elmer, Norwalk, VA) using sealed stainless-steel pans (*31*). The sample pan (10−11 mg of starch and 50 μL of lysophospholipid 2% w/V in water) and the empty reference pan were heated from 25 to 160 at 10 °C min^{-1}, held at 160 °C for 2 min, and then cooled to 60 at 10 °C min^{-1}. The Tonset was determined on the thermograms. Amylose content was estimated from the energy of amylose-lysophospholipid complex formation. The peak temperature, the end temperature and the enthalpy of gelatinization were not considered since those are affected by the use of the lysophospholid. The analysis was performed in duplicate, and the mean values were calculated.

Pasting Properties. Hot flour dispersion viscosity profiles were investigated using an RVA model RVA-4 series (Newport Scientific, Warriedwood, Australia). Viscosity was recorded using the following temperature profile: holding at 50 °C for 1 min, heating from 50 to 90 at 6 °C min^{-1}, holding at a 90 °C plateau for 5 min, and then cooling down to 50 at 6 °C min^{-1} with continuous stirring at 160 rpm, and using 6, 7 and 8% flour dispersions (w/V distilled water). Six parameters were measured on the visco-amylogram: pasting temperature and pasting time (Pt), peak viscosity (PV) and peak viscosity time (PVt), hot paste viscosity (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 with the highest HPV was dispersed at 6, 7, and 8% suspension using two additional plateaux at 93 and 95 °C. From the optimal suspension-temperature couple, the incidence of a silver nitrate amylase inhibitor ($AgNO_3$ 0.002 mol L^{-1}) as per Crosbie et al. (*32*), a phosphate buffer pH 6.5, a citrate buffer pH 7 and a combination of $AgNO_3$ with phosphate or citrate buffer were investigated. All parameters were obtained in duplicate, and the mean values were calculated.

Statistical analysis and data normalization were performed on thermal and functional properties according to the analysis of the morphological, physical and chemical traits (*1*).

RESULTS/DISCUSSION

Thermal Properties. The starch onset temperatures and amylose contents of the varieties were combined (**Table 1**). Various and high onset temperatures were obtained in the 59.7−67.8 °C range, ("Bocadillo" and "Dominico", respectively). These results are consistent with some other studies (*8*, *14*, *21*). Even higher Tonset for some other varieties were earlier reported (*16*, *22*, *23*). When comparing subgroups, significant differences in onset temperature were observed between dessert bananas (63.2 °C), nonplantain cooking bananas (65.4 °C) and plantains (67.1 °C) at $p \leq 0.01$. Significant differences between subgroups imply that heat resistance is a suitable criterion for differentiating dessert and cooking bananas, even though the hybrids have a similar behavior to cooking bananas.

The amylose content fluctuated from 15.4 to 24.9% between varieties and agreed with some previous reports without any relationship established between genotypes (*8*, *18*, *26*). In the present study, "Cavendish", "Rollizo", and "FHIA 18" had the lowest amylose content, whereas "Pelipita", "Cubano Blanco", and "Cachaco" had the highest content. We found some significant differences between varieties at $p \leq 0.01$. The HSD test performed on the subgroups clearly highlighted two groups of varieties: sweet bananas (dessert and dessert hybrids) and the others (**Figure 1**).

Apart from "Guineo" and "Bocadillo" clones, the mean amylose contents were well distributed. Low to intermediate amylose contents were represented by dessert bananas (15.4−20.9%), while intermediate to high amylose levels corresponded to cooking bananas (19.7−24.9%). Dessert hybrids exhibited lower amylose contents than dessert bananas whereas cooking hybrids exhibited lower amylose contents than cooking bananas.

A clear relationship between consumption mode and starch amylose contents of bananas was demonstrated. The amylose content seems a relevant quality criterion to be use in future breeding strategies for screening and discriminating the consumption pattern of new varieties. The study based on cultivated

Table 1. Starches Physical Properties and Amylose Contents[a]

consumption modes and subgroups	Tonset (°C)	amylose %
Dessert bananas		
bocadillo	63.5 ± 0.9	20.9 ± 0.8
primitivo	65.7 ± 0.5	19.0 ± 0.8
cavendish	66.5 ± 0.1	15.7 ± 0.2
gros michel	63.2 ± 0.3	17.2 ± 0.8
rollizo	61.9 ± 0.6	1c.3 ± 1.1
tafetan morado	59.7 ± 0.6	16.6 ± 0.1
mean ± std ($n = 14$)	**63.2 ± 2.3a**	**17.4 ± 1.9a**
Dessert hybrids		
fhia 17	67.1 ± 0.6	17.1 ± 0.0
fhia 1	66.9 ± 0.7	17.9 ± 0.0
fhia 18	67.0 ± 0.1	15.4 ± 0.1
fhia 25	66.2 ± 0.6	17.5 ± 0.7
mean ± std ($n = 9$)	**66.8 ± 0.6bc**	**16.8 ± 1.1a**
Cooking hybrids		
fhia 20	66.7 ± 0.5	20.9 ± 0.5
fhia 21	65.9 ± 1.5	23.0 ± 0.8
mean ± std ($n = 10$)	**66.2 ± 1.2bc**	**22.2 ± 1.3b**
Nonplantain cooking bananas		
guineo	64.4 ± 0.4	19.7 ± 0.6
guayabo	64.8 ± 0.4	21.8 ± 0.1
hua moa	65.7 ± 0.1	22.6 ± 0.1
cachaco	65.5 ± 0.8	24.5 ± 1.5
pelipita	65.8 ± 0.7	24.9 ± 0.2
mean ± std ($n = 17$)	**65.4 ± 0.7c**	**23.4 ± 2.1b**
Plantains		
africa	67.1 ± 1.5	22.7 ± 0.4
dominico	67.8 ± 0.2	23.8 ± 0.5
dominico harton	67.7 ± 2.2	23.4 ± 1.1
harton	67.2 ± 1.3	23.2 ± 1.7
cubano blanco	66.2 ± 0.8	24.8 ± 0.8
maqueño	67.7 ± 0.2	21.8 ± 0.2
mean ± std ($n = 39$)	**67.1 ± 1.4b**	**23.5 ± 1.4b**

[a] Means followed by the same letters in the same column are not significantly different ($p \leq 0.01$).

bananas might even be improved if the analyses were carried out on clones from a core collection.

FUNCTIONAL PROPERTIES

RVA Protocol Development: Incidence of Concentration and Temperature on the RVA Profile. The flour of the "Cavendish" sample proved to be the variety with the highest hot paste viscosity. The obvious strong influence of the concentration on the pasting properties was observed (**Figure 2**).

The 8% concentration obtained higher viscosity with larger amplitudes. This phenomenon was previously described using a Brabender viscoamylograph (*9*, *10*, *26*). Nevertheless, the maximum viscosity obtained at 8% concentration is optimal under the recommendations of Newport Scientific (η < 2500 cP). The complementary study of the influence of the temperature plateau on the pasting profile showed that the 95 °C temperature plateau induced some major undesired variations of viscosity just after the peak. The 90 °C plateau induced less noise than the 93 °C plateau, which is relatively closer to the critical 96.5 °C temperature where water boils at this altitude (1100 m above sea level in Cali, Colombia). The concentration of 8% flour dry basis and the 90 °C plateau were then selected prior to the other methodological steps.

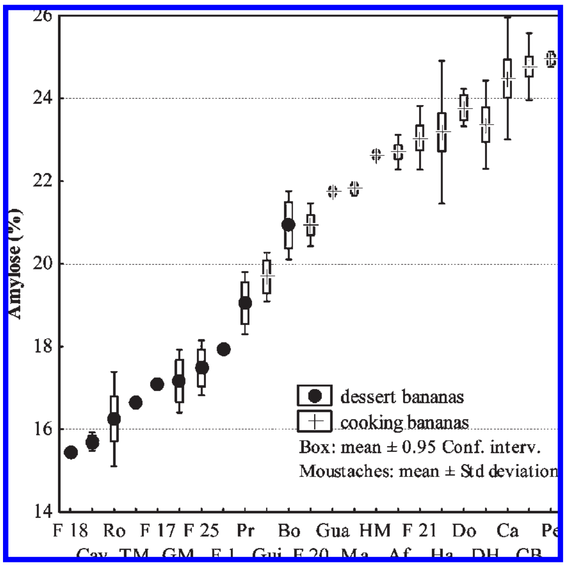

Figure 1. Mean amylose contents with standard errors and standard deviations of the banana consumption groups. F 18, FHIA 18; Cav, Cavendish; Ro, Rollizo; TM, Tafetan Morado; F 17, FHIA 17; GM, Gros Michel; F 25, FHIA 25; F 1, FHIA 1; Pr, Primitivo; Gui, Guineo; Bo, Bocadillo; F 20, FHIA 20; Gua, Guayabo; Ma, Maqueño; HM, Hua Moa; Af, Africa; F 21, FHIA 21; Ha, Harton; Do, Dominico; DH, Dominico Harton; Ca, Cachaco; CB, Cubano Blanco; Pe, Pelipita.

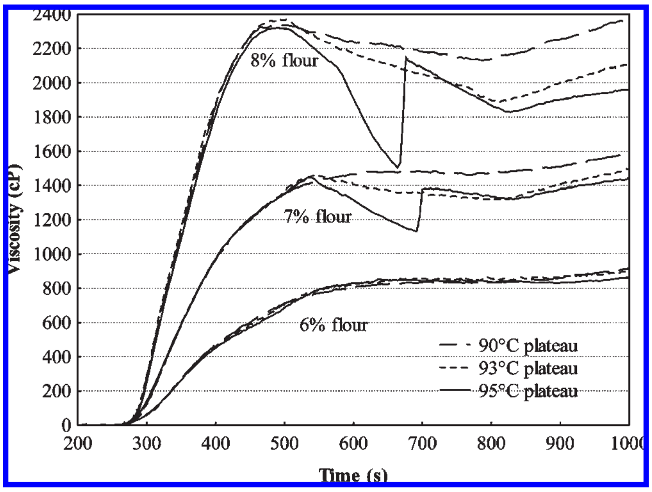

Figure 2. Cavendish banana flour RVA visco-amylograms using water with 6, 7, and 8% dry matter content and temperature plateaux 90, 93, 95 °C.

Comparison between RVA Profiles in Water and Water with Amylase Inhibitor. The complementary study of the influence of using of an amylase inhibitor showed a significant influence for the three varieties with the highest pasting temperature: "Cavendish", "FHIA 1", and "FHIA 18" (**Figure 3**). Silver nitrate does not affect the pH of the flour mixture (*33*). Nevertheless, the $AgNO_3$ had various effects on the pasting profiles of the three varieties. While some limited effects of the inhibitor were observed on "Cavendish" (small PV increase and a slight CPV decrease), a strong influence was observed for both "FHIA 1" and "FHIA 18". These results are consistent with some previous work (*32*), where the efficiency of $AgNO_3$ for amylase inactivation in Japanese ramen was studied and stressed. Here, the hypothesis of a lower amount of amylase in the "Cavendish" flour compared to hybrid flours could therefore be assumed. This hypothesis is consistent with some other

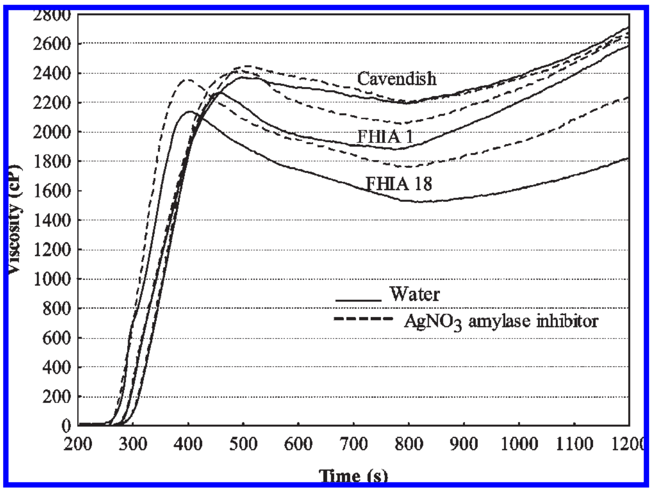

Figure 3. Comparison between Cavendish, FHIA 1, and FHIA 18 flour RVA visco-amylograms using water or $AgNO_3$ amylase inhibitor, at 8% dry matter.

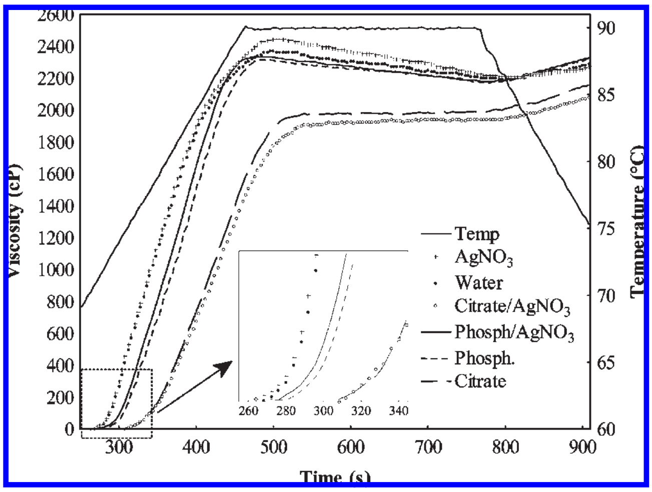

Figure 4. Cavendish banana flour RVA visco-amylograms performed with 8% dry matter up to 90 °C, using water, phosphate buffer, citrate buffer, citrate buffer with $AgNO_3$ inhibitor, phosphate buffer with $AgNO_3$ inhibitor, and $AgNO_3$ inhibitor only.

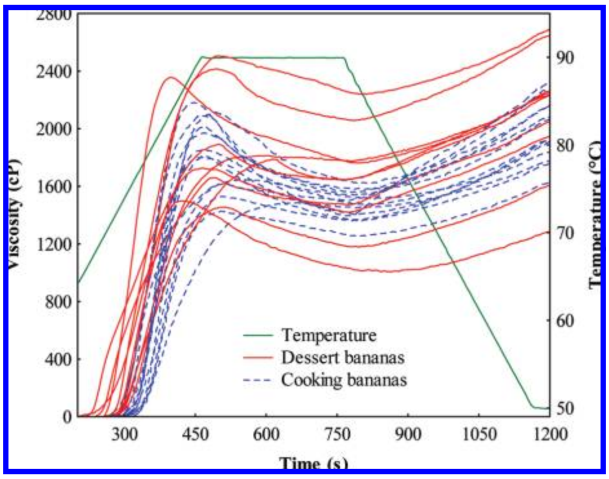

Figure 5. RVA dessert and cooking banana flour profiles at 8% dry matter content and 90 °C using $AgNO_3$ inhibitor.

work (*33*), where a large difference in PV using distilled water and $AgNO_3$ solution (0.05 mM) was obtained, and successfully combined to estimate the α-amylase content. The pasting viscosities in distilled water are also suggested as reflecting inherent resistance of the amylose to hydrolysis. Peak, hot paste, cold paste, and final viscosities were therefore significantly higher using the $AgNO_3$. The PVt of the variety "FHIA 1" was lowered with water. In addition, the Tpasting was not affected by the use of the amylase inhibitor. The latter therefore had a significant positive effect on the pasting profiles performed by RVA using banana flours at 8% concentration with the 90 °C plateau, thereby justifying its use in a future optimized protocol.

Incidence of inhibitors and buffers on RVA profiles. 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 proved to have a strong influence on the RVA profile (**Figure 4**).

As noted earlier, a significant variation in peak and cold paste viscosity was induced when using an amylase inhibitor as compared to those obtained when using water. No modification of the pasting temperature was induced. However, using of a phosphate buffer on its own or combined with $AgNO_3$ had a strong influence on the pasting temperature as can be seen in the close-up area. The lag in pasting temperature (Tpasting delayed) with the phosphate buffer was actually enhanced using the citrate buffer on its own or combined with $AgNO_3$. In addition, the phosphate buffer or combined buffer solution induced a significant decrease in PV, whereas the final viscosity was slightly enhanced compared to that obtained with the $AgNO_3$ inhibitor. The citrate buffer on its own or combined with amylase inhibitor significantly lowered the viscosity throughout the temperature pasting profile.

Diversity of Banana Flour Pasting Properties. From all these results, a standardized RVA methodology was developed, which should ensure optimal viscosities and the effectiveness of amylase inactivation using the $AgNO_3$ solution. No lag in pasting temperature is expected using such conditions with the 90 °C temperature plateau and with banana flour concentration 8%. The changes in viscosity observed during the heating and cooling stages were characteristic of flours of different varietal origins (**Figure 5**). A great pasting diversity was observed between the subgroups plantains and the other cooking bananas (blue dashed lines), with dessert bananas (red continuous lines) using the standardized defined conditions.

Large differences in the ten pasting parameters existed between the varieties. It seems that the increase in viscosity occurred earlier for dessert bananas, thus at lower temperature. It implies that dessert bananas are easier to cook than cooking bananas and their starches are less resistant to thermal treatment. Since all the individual specificities cannot be properly described and distinguished with a composite figure, the most relevant criteria underlined by statistical analysis at $p \leq 0.01$ are later detailed (**Table 2**). The least significant factors include HPV, VEP, CPV, BD, SB and CS, where few subgroups were differentiated (data not shown).

The first parameter highlighted was the pasting temperature of the flour which varies in the 66.5−77.4 °C range between varieties. The clones "Tafetan Morado" and "Dominico Harton", which exhibited the extremes starch Tonset values, also had the extreme flour Tpasting values. As suggested earlier, the comparison of the present results with other works is hazardous since various devices and concentrations were earlier used for the characterization of the varieties. Nevertheless, lower Tonset and Tpasting for starches and flours from dessert bananas (AAA) than for plantains (AAB) have been previously noted (*2*, *13*, *14*, *21*). Some differences in Tpasting were here observed between

Table 2. Functional Properties of Banana Flours[a]

consumption mode and subgroups	Tpasting (°C)	PV (cP)	CA (s)
Dessert bananas			
bocadillo	71.9 ± 0.3	1462 ± 3	236 ± 14
primitivo	72.1 ± 0.2	1896 ± 7	222 ± 8
cavendish	70.9 ± 0.3	2505 ± 56	227 ± 6
gros michel	68.7 ± 0.2	1664 ± 1	239 ± 12
rollizo	68.3 ± 2.5	1860 ± 312	246 ± 36
tafetan morado	66.5 ± 0.0	1500 ± 35	196 ± 3
mean ± std (*n* = 14)	**69.5 ± 2.4 a**	**1821 ± 368 abc**	**230 ± 25 a**
Dessert hybrids			
fhia 17	72.5 ± 0.1	1791 ± 13	330 ± 7
fhia 1	72.2 ± 0.2	2416 ± 18	213 ± 8
fhia 18	69.8 ± 0.6	2356 ± 43	136 ± 6
fhia 25	72.8 ± 0.0	1823 ± 54	273 ± 49
mean ± std (*n* = 8)	**71.8 ± 1.3 b**	**2097 ± 312 b**	**238 ± 79 a**
Cooking hybrids			
fhia 20	76.0 ± 1.5	1493 ± 365	339 ± 37
fhia 21	74.7 ± 2.0	1824 ± 487	172 ± 4
mean ± std (*n* = 8)	**75.4 ± 1.7 c**	**1658 ± 436 ab**	**255 ± 93 a**
Nonplantain cooking bananas			
guineo	71.6 ± 0.3	1622 ± 17	224 ± 8
guayabo	73.6 ± 0.1	2119 ± 30	176 ± 22
hua moa	73.4 ± 0.0	2113 ± 7	197 ± 0
cachaco	71.6 ± 1.7	2230 ± 134	163 ± 9
pelipita	75.1 ± 0.2	2013 ± 8	156 ± 2
mean ± std (*n* = 16)	**72.9 ± 1.8 b**	**2079 ± 225 b**	**177 ± 25 b**
Plantains			
africa	75.8 ± 0.5	1433 ± 5	232 ± 63
dominico	76.4 ± 3.0	1653 ± 30	237 ± 2
dominico harton	77.4 ± 1.6	1842 ± 16	161 ± 7
harton	75.7 ± 2.0	1904 ± 21	148 ± 19
cubano blanco	74.9 ± 1.2	1822 ± 12	151 ± 11
maqueño	75.2 ± 0.0	1974 ± 0	167 ± 6
mean ± std (*n* = 32)	**75.9 ± 1.8 c**	**1816 ± 157 c**	**175 ± 47 b**

[a] Means followed by the same letters in the same column are not significantly different ($p \leq 0.01$).

varieties. Moreover, while the Tonset was relevant for distinguishing plantains from other cooking bananas and also dessert bananas (without significantly differentiating dessert and FHIA cooking tetraploids), the pasting temperature analysis at subgroup level was also able to differentiate dessert FHIA hybrids (combined with nonplantain cooking bananas) from the other FHIA tetraploids (combined with plantains). The mean Tpasting of dessert bananas (69.5 °C) proved to be significantly lower than that of dessert hybrids (71.8 °C) and nonplantain cooking bananas (72.9 °C), and to a greater extend, of cooking hybrids (75.4 °C) and plantains (75.9 °C). No similar results have so far been highlighted in the literature, since no exhaustive comparison has ever been carried out between all of these subgroups.

Some relationships between PV and genotypes were also established. Restricted swelling was only observed for two plantain varieties ("Africa" and "Dominico"), whereas the other clones exhibited intermediate peak viscosities. Plantain PVs (1816 cP) proved to be significantly lower than with other cooking bananas (2079 cP) and dessert hybrids (2097 cP). No differentiation between dessert bananas PV means and those of other subgroups was shown, probably due to the great diversity of peak viscosities (1462 to 2505 cP).

The varieties "FHIA 18", "Dominico Harton", "Harton", "Cubano Blanco", "Cachaco", and "Pelipita" exhibited the lowest cooking ability. The varieties "FHIA 17", "FHIA 20", and "FHIA 25" exhibited broad peak viscosity and had the highest CA. While a relation could be suggested connecting the high Tpasting of most cooking bananas and plantains with their low cooking ability, some varieties such as 'Africa' or 'FHIA 20′ exhibited high Tpasting and CA. Complementary HSD testing conducted on CA clearly showed two varietal groups. Dessert bananas and all hybrids had significantly higher cooking ability (230−255 s) than cooking landraces (175−177 s). This result had to be brought together with the subgroups identified on amylose content. Apart from "FHIA 21" (where both amylose and cooking abilities were similar to those of cooking bananas and plantain) and "FHIA 20", which were significantly different (higher amylose content and CA), similar statistical subgroups were identified regarding amylose and cooking ability for the other clones. Plantains exhibited 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 noted (figure not shown). A similar observation was earlier reported (*13*). The author concludes that the relationship between *Musa* pasting characteristics and the amylose contents of their starch granules is less clear than with cereal starches. In addition, a substantial increase in Tpasting was shown with the rise of amylose percentage, without any strong relationship established between them.

A significant influence due to the use of flours for functional analysis could be assumed. The starch concentration is expected to fluctuate from one variety to another (*1*, *5*, *30*). A strong influence of the amylose content on the visco-amylogram could be anticipated as was shown previously with the dry matter concentration (**Figure 2**). The least significant factors (HPV, VEP, CPV, BD, SB, and CS) are assumed to be significantly influenced by the starch concentration in the flours. While the PV partially helps to distinguish banana varieties and subgroups, Tpasting not influenced by dry matter concentration (*10*, *26*) and CA proved to be the most relevant parameters for differentiating banana subgroups.

Principal Component Analysis on Thermal and Functional Properties. A PCA was performed to globally evaluate the most relevant variables. A limited number of variables (as much as possible noncorrelated and independent to each other) were selected for describing banana thermal and functional properties. In addition, the variables able to discriminate consumption subgroups were assessed. The first three components accounted for 35.3, 29.8, and 18.9% of the variation respectively (**Figure 6**). The first component was highly related to BD, PV and negatively correlated to CA, whereas the second component was highly related to Tpasting, Tonset and amylose content, already highlighted by HSD test (**Figure 6**A). As major contributions on third component, CS, PV, and SB were plotted (**Figure 6**B).

Superimposed plots of the consumption subgroups on the plans assessed the percentage of variation associated with the first and second components (**Figure 6**A), the first and third components (**Figure 6**B). Except for "Guineo" landrace, cooking bananas were mainly characterized by high BD, PV, and low CA, whereas plantains were related to intermediate BD, PV, and CA. Contrary to plantains, dessert bananas were thus mainly characterized by low Tpasting, Tonset, and amylose contents. Contrary to dessert hybrids, plantains exhibited low CS, PV, and SB (except for the atypical "Africa" landrace). Intermediate consistency, peak viscosity, and setback were shown for dessert bananas, cooking bananas, and cooking hybrids.

Synthesis on Varietal Differentiation on Physical and Functional Properties. This study pointed out that the consumption modes are often well differentiated using thermal and most functional

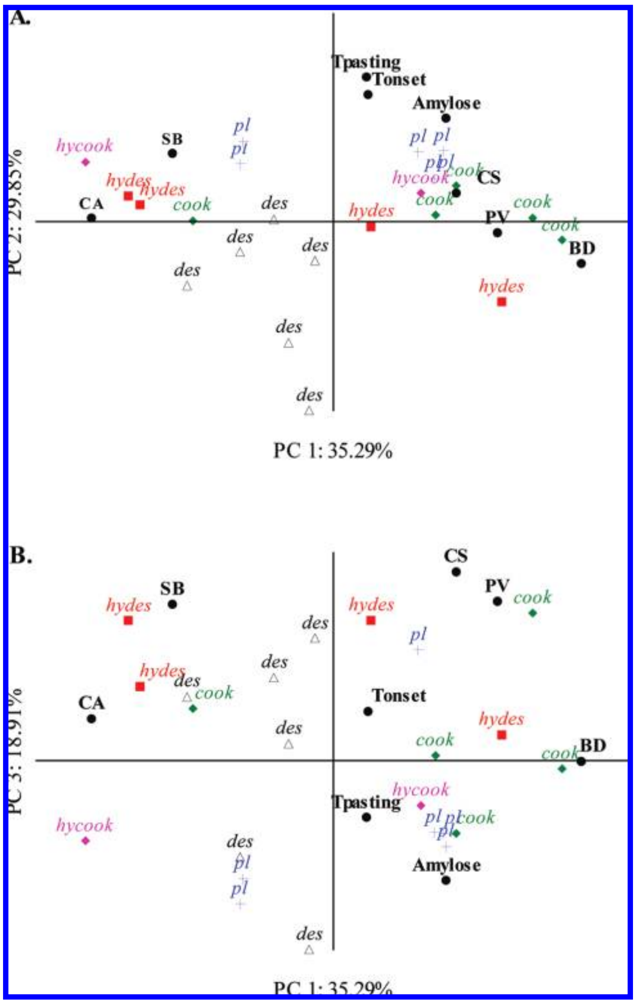

Figure 6. Principal components plots of thermal and functional variables: first and second component (A); first and third component (B); CA, cooking ability; SB, setback; Tpasting, pasting temperature; Tonset, onset temperature; Amylose, amylose %; CS, consistency; PV, peak viscosity; BD, breakdown. Superposed plotting of the banana subgroups on the first and second components (A), the first and third components (B) of principal component analysis: pl, plantain; des, dessert banana; hydes, dessert hybrid, hycook, cooking hybrid; cook, nonplantain cooking banana.

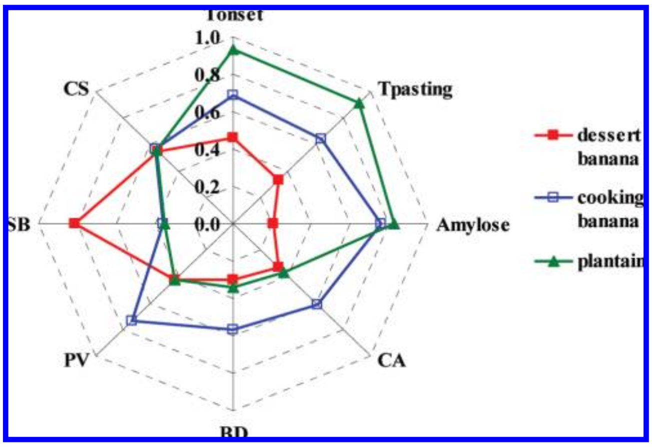

Figure 7. Radar chart of the normalized physical and functional criteria of dessert bananas, cooking bananas, and plantains. Tonset, Onset temperature (°C); Amylose, amylose content (%); Tpasting, pasting temperature; PV, peak viscosity; SB, setback; CA, cooking ability; BD, breakdown; CS, consistency.

criteria when combining HSD and PCA testing. Some parameters were shown as highly significant using the posthoc test. The complementary principal component analysis revealed that some least significant criteria were strongly contributing to variance, and thus to the differentiation of banana varieties and banana consumption subgroups. To differentiate banana genomic groups, it is suggested to determine the amylose content and onset temperature of the starches. In addition, the pasting properties of the flours determined using an optimized protocol was able to distinguish genotypes on pasting temperature and cooking ability criteria, and to a lesser extend on the peak viscosity, the breakdown, the consistency, and the setback of the banana samples.

When the relevant parameters were combined within the normalized radar chart, the synthesis of the physical and functional differentiation of 3 banana subgroups was highlighted (**Figure 7**).

On the one hand, the following normalized parameters, Tonset, Tpasting, and amylose content were higher for plantains than for dessert bananas and to a lesser extend than for cooking bananas. Plantains exhibited the highest amylose content between banana subgroups, and required a much higher temperature for hydration (pasting temperature and gelatinization temperature). The varieties “Harton”, “Dominico Harton”, “Dominico”, “Cachaco”, “Cubano Blanco”, and “Pelipita” clones with mean amylose contents between 23.2% and 24.9% mentioned as the hardest varieties to cook in water by consumers even tend to become hardened after cooking and 24 h cool storage (*2*). This phenomenon could be explained by some starch retrogradation. The “Pelipita” variety is usually consumed cooked at a ripe stage of maturity, probably to avoid hardening, as well as the variety “Cachaco” usually preferred for flour production and children’s beverages.

On the other hand, except for the CS (visually equivalent for all subgroups), the cooking ability, the breakdown and peak viscosity normalized criteria were higher for cooking bananas than for dessert landraces and plantains. The dessert bananas only exhibited a higher normalized SB criterion than both cooking bananas and plantains. After the critical pasting temperature, plantains require a shorter period to reach maximum paste viscosity under continuous shear stress than dessert bananas.

All these criteria may contribute to a better comprehension of consumer uses and the differentiation between groups and subgroups; and therefore could in future be included in some breeding strategies for the creation of suitable new clones of banana germplasms.

Further work is needed to compare varieties, genotypes, consumption modes while investigating swelling power and solubility patterns and intrinsic viscosity to estimate the differences in molecular size between genotypes, as earlier suggested (*9*, *26*). Additional work could be also focused on particle size distribution, starch granule microstructure and molecular size determination of the amylose and amylopectin by multiple-angle laser light-scattering size-exclusion chromatography (HPSECMALLS) and asymmetrical flow field-flow fractionation (A-4F).

ABBREVIATIONS USED

CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement; CIAT, International Center for Tropical Agriculture; UNIVALLE, Universidad del Valle; DSC, Differential Scanning Calorimetry; RVA, Rapid Visco analyzer; FHIA, Fundación Hondureña de investigación Agrícola; AA, AAA, AAB, ABB, AAA, AAAB, genotypes of *Musa* acuminata genome A and of *Musa* balbisiana B; Af, Africa; Bo, Bocadillo; Ca, Cachaco; Cav, Cavendish; CB, Cubano Blanco; Do, Dominico; DH, Dominico Harton; F 1, FHIA 1;

F 17, FHIA 17; F 18, FHIA 18; 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; Tonset, Onset temperature; Tpasting; Pasting temperature; PV, Peak viscosity; PVt, Peak viscosity time; HPV, Hot paste viscosity; VEP, End of plateau viscosity; CPV, Cold paste viscosity; CA, Cooking ability; BD, Breakdown; SB, Setback; CS, Consistency; ANOVA, analysis of variance; PCA, Principal Component Analysis; HSD, Honestly Significant Differences; pl, plantain; des, dessert banana; hydes, dessert hybrid, hycook, cooking hybrid; cook, non-plantain cooking banana; HPSECMALLS, multiple-angle laser light-scattering size-exclusion chromatography; A-4F, asymmetrical flow field-flow fractionation.

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LITERATURE CITED

(1) Gibert, O.; Dufour, D.; Giraldo, A.; Reynes, M.; Pain, J. P.; González, A.; Fernández, A.; Díaz, A. Differentiation between cooking bananas and dessert bananas. 1. Morphological and physical and chemical characterization of cultivated Colombian Musaceae (*Musa* sp.) in relation to consumer preferences. *J. Agric. Food Chem.* **2009**, DOI: 10.1021/jf901788x.

(2) 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; pp33.

(3) Rasper, V. Investigations on starches from major starch crops grown in Ghana I. - Hot paste viscosity and gel-forming power. *J. Sci. Food Agric.* **1969**, *20*, 165–171.

(4) Favier, J. C. Etude de la digestibilité "in vitro" de l'amidon de diverses plantes alimentaires du Sud-Cameroun: Influence des transformations technologiques sur l'amidon du manioc. *Ind. Aliment. Agric.* **1969**, *1*, 9–13.

(5) Zhang, P. Y.; Whistler, R. L.; BeMiller, J. N.; Hamaker, B. R. Banana starch: production, physicochemical properties, and digestibility - a review. *Carbohydr. Polym.* **2005**, *59*, 443–458.

(6) Patil, D. L.; Magrar, N. G. Physicochemical properties of banana fruit starch and starch components. *J. Indian Chem. Soc.* **1974**, *51*, 1004–1007.

(7) Coulibaly, S.; Nemlin, J. G.; N'Guessan Amani, G. Isolation and partial characterisation of native starches of new banana and plantain hybrids (*Musa* spp.) in comparison with that of plantain variety Orishele. *Starch/Stärke* **2006**, *58*, 360–370.

(8) 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.

(9) Eggleston, G.; Swennen, R.; Akoni, S. S. Physicochemical studies on starches isolated from plantain cultivars, plantain hybrids and cooking bananas. *Starch/Stärke* **1992**, *44*, 21–128.

(10) Lii, C. Y.; Chang, S. M.; Young, Y. L. Investigation of the physical and chemical properties of banana starches. *J. Food Sci.* **1982**, *47*, 1493–1497.

(11) Muyonga, J. H.; Ramteke, R. S.; Eipeson, W. E. Predehydration steaming changes physicochemical properties of unripe banana flour. *J. Food Process. Preservation* **2001**, *25*, 35–47.

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

(13) Steele, A. F. Characterisation of starch in Musa fruits. PhD thesis. University of Bath, **1997**; pp 187.

(14) Gnakri, D.; Champ, M.; Bouchet, B.; Colonna, P.; Delort-laval, J. Carbohydrate content and in vitro enzymatic hydrolysis of fufu starch from plantain. *Sci. Aliment.* **1996**, *16*, 297–306.

(15) Lehmann, U.; Jacobasch, G.; Schmiedl, D. Characterization of resistant starch type III from banana (*Musa* acuminata). *J. Agric. Food Chem.* **2002**, *50*, 5236–5240.

(16) Lawal, O. S.; Ogundiran, O. O.; Awokoya, K.; Ogunkunle, A. O. The low-substituted propylene oxide etherified plantain (*Musa* paradisiaca normalis) starch: Characterization and functional parameters. *Carbohydr. Polym.* **2008**, *74*, 717–724.

(17) Kayisu, K.; Hood, L. F. Molecular structure of banana starch. *J. Food Sci.* **1981**, *46*, 1894–1897.

(18) Ling, L. H.; Osman, E. M.; Fernandes, J. B.; Reilly, P. J. Physical properties of starch from Cavendish banana fruit. *Starch/Stärke* **1982**, *34*, 184–188.

(19) Siriwong, W.; Tulyathan, V.; Waiprib, Y. Isolation and physicochemical characterization of starches from different banana varieties. *J. Food Biochem.* **2003**, *27*, 471–484.

(20) Faisant, N.; Gallant, D. J.; Bouchet, B.; Champ, M. Banana starch breakdown in the human small intestine studied by electron microscopy. *Eur. J. Clin. Nutr.* **1995**, *49*, 98–104.

(21) Mendy, A. I. (**2003**). Caractérisation de pâtes de banane et de plantain vertes en vue d'élaborer une pâte à partir de farine précuite de banane verte. MSc Thesis. ENSIA-SIARC, Montpellier, 2003; pp 86.

(22) Bello-Pérez, L. A.; Agama-Acevedo, E.; Sayago-Ayerdi, S. G.; Moreno-Damian, E.; Figueroa, J. D. C. Some structural, physicochemical and functional studies of banana starches isolated from two varieties growing in Guerrero, Mexico. *Starch/Stärke* **2000**, *52*, 68–73.

(23) De la Torre-Gutiérrez, L.; Chel-Guerrero, L. A.; Betancur-Ancona, D. Functional properties of square banana (*Musa* balbisiana) starch. *Food Chem.* **2008**, *106*, 1138–1144.

(24) Nunez-Santiago, M. C.; Bello-Perez, L. A.; Tecante, A. Swelling-solubility characteristics, granule size distribution and rheological behavior of banana (*Musa* paradisiaca) starch. *Carbohydr. Polym.* **2004**, *56*, 65–75.

(25) Perez-Sira, E. E. Characterization of starch isolated from plantain (Musa paradisiaca normalis). *Starch/Stärke* **1997**, *49*, 45–49.

(26) Kayisu, K.; Hood, L. F.; Vansoest, P. J. Characterization of starch and fiber of banana fruit. *J. Food Sci.* **1981**, *46*, 1885–1890.

(27) Rodriguez-Sosa, E. J.; Cruz-Cay, J. R.; De Caloni, I. B. Amylography of plantain, cassava, and tanier flours. *J. Agric. Univ. Puerto Rico* **1983**, *67*, 303–310.

(28) Fagbemi, T. N. Effect of blanching and ripening on functional properties of plantain (Musa AAB) flour. *Plant Food Hum. Nutr.* **1999**, *54*, 199–207.

(29) Bello Pérez, L. A.; Agama Acevedo, E.; Sanchez Hernandez, L.; Paredes Lopez, O. Isolation and partial charaterization of banana starches. *J. Agric. Food Chem.* **1999**, *47*, 854–857.

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

(31) Mestres, C.; Matencio, F.; Pons, B.; Yajid, M.; Fliedel, G. A Rapid Method for the Determination of Amylose Content by Using Differential Scanning Calorimetry. *Starch/Stärke* **1996**, *48*, 2–6.

(32) Crosbie, G. B.; Ross, A. S.; Moro, T.; Chiu, P. C. Starch and protein quality requirements of Japanese alkaline noodles (Ramen). *Cereal Chem.* **1999**, *76*, 328–334.

(33) Collado, L. S.; Corke, H. Accurate prediction of sweetpotato amylase activity by flour viscosity analysis. *J. Agric. Food Chem.* **1999**, *47*, 832–835.

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