Physical and morphological characterization and evaluation of pasting curves of *Musa* spp.

Caracterización física, morfológica y evaluación de las curvas de empastamiento de musáceas (*Musa* spp.)

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Abstract

Twenty varieties of *Musa* sp. from diverse genetic compositions were analyzed: AB, BB, AAA, AAB, ABB, AAAB and AAAA. The material was acquired from the Fedeplatano germplasm bank in Chinchiná, Colombia, located at 1360 masl. The varieties were physically and morphologically characterized, and their functional flour and starch properties were identified. The analysis of the principal components (PCA) showed that plantains are differentiated by their larger size (weight, length and diameter), when compared among varieties. MB Tani, ICAFHIA 110, Saba and Bluggoe plantain subgroups showed the largest peel percentages; the other clones did not differ from each other. Plantains for cooking from the Plantain subgroup (AAB), have more dry matter; Bocadillo Chileno and hybrid dessert (except FHIA 1) have more edible proportions than other varieties. The onset temperature for flour gelatinization in the RVA ranged from 66.58°C for Bocadillo Chileno, to 75.21 °C for Mbindi. The maximum viscosity was between 441.57 and 1837.17 cP for Red Tafetan and Dwarf Cavendish; cooking facility was between 2.76 and 7.55 minutes for the Bocadillo Chileno and Gros Michel Guayabo varieties. The onset temperature for starch gelatinization ranged between 65.58°C for Gros Michel Guayabo, and 74.41°C for Red Tafetan. The maximum viscosity was between 483.24 cP and 1958.44 cP for the varieties Yangambi Km3 and Indio. The Mbindi variety cooked more easily (1.91 minutes), while FHIA 1 needed more time (9.49 minutes).

Key words: Dry matter, edible fraction, Musaceae, pasting curves, plantain, Principal Component Analysis (PCA).

Resumen

Se caracterizaron veinte variedades de musáceas de diferente composición genética: AB, BB, AAA, AAB, ABB, AAAA y AAAB, del Banco de Germoplasma existente en la hacienda Las Vegas, de Fedeplátano, Chinchiná (1360 m.s.n.m., 4° 58' N y 75° 20' O), Colombia. La caracterización incluyó propiedades físicas como peso, diámetro, longitud, materia seca y porcentaje de cáscara del fruto y propiedades funcionales como harinas y almidones. El análisis de componentes principales (ACP) mostró que las variedades de plátano se diferencian por su mayor tamao (peso, longitud y diámetro). M. B. Tani, ICAFHIA 110, Saba, y los plátanos del subgrupo Bluggoe tuvieron altos porcentajes de cáscara. Entre los demás clones no se observaron diferencian entre sí. Los plátanos de cocción del subgrupo Plantain presentaron el mayor contenido de materia seca. Bocadillo Chileno e híbridos postre (exceptuando FHIA-1), presentaron mayor contenido de fracción comestible frente a las demás variedades. La temperatura de inicio de gelatinización de las harinas en el RVA varió entre 66.58 °C para la variedad Bocadillo Chileno y 75.21 °C para Mbindi. La viscosidad máxima varió entre 441.57 y 1837.17 cP para las variedades Tafetán Rojo y Dwarf Cavendish, respectivamente. La facilidad de cocción varió entre 2.76 min en Bocadillo Chileno y 7.55 min en Gros Michel Guayabo. La temperatura de inicio de gelatinización de los almidones varió entre 65.58°C para Gros Michel Guayabo y 74.41°C en Tafetán Rojo. La variedad Yangambi Km3 presentó la viscosidad máxima a 483.24 cP e Indio a 1958.44cP. La variedad Mbindi presentó la mayor facilidad de cocción (1.91 min) mientras que FHIA-1 presentó el mayor tiempo (9.49 min).

Palabras claves: Análisis de Componentes Principales (ACP), curvas de empastamiento, fracción comestible, materia seca, Musaceae, plátano.

Introduction

Plantain and banana are typical from Southeast Asia, this crop has extended to large areas in Central America and South America where they are a staple food of the population. Most of the plantain and banana cultivars from the Musaceae family originated from two wild species: *Musa acuminata* (A) and *Musa balbisiana* (B) that by polyploidy and hybridization generated the varieties currently grown (Simmonds, 1973).

In several tropical countries agriculture is based on semi-intensive production which contributes to the diversity maintenance of the food plants and to generate income for the rural population. In Colombia, with exception of the Plantain group, 400,000 t of plantain are grown and consumed locally, which includes bananas for cooking and Bluggoe type varieties (Arcila *et al.*, 2002; Price, 1999; Lescot, 2008). Nowadays, Musas are an important carbohydrate source on Colombians' diet and are the fourth source of energy after maize, rice and wheat (FAO, 2005).

Genetic breeding programs of Musa have been directed mainly to develop varieties with resistance to pests and diseases. Strategies have been centered in agronomical aspects such as yield, organoleptic characteristics (semblance), stress tolerance, shelf life, mineral content, water absorption and mechanical resistance to damage (Bakry *et al.*, 2008). Among tetraploid species that were introduced, hybrids from the Fundación Hondureña de Investigación Agrícola (FHIA) present advantages due to their productivity and pest resistance. However, some of them are rejected by consumers because of their deficiencies in organoleptic traits (visuals, sensorial and of texture), and their low dry matter content and shelf life in green state (Dzomeku *et al.*, 2006; Arvanitoyannis and Mavromatis, 2009).

In existing bibliography there is some research in which the physical and chemical characteristics of plantain flour pastes are compared during different maturity stages (Arvanitoyannis and Mavromatis, 2009 and Aurore *et al.*, 2009), that include methodologies for proximal analysis of dessert bananas (Forster *et al.*, 2002, Da Mota *et al.*, 2000; Mustaffa *et al.*, 1998) plantains and bananas for cooking (Eggleston *et al.*, 1991; Ngalani and Tchango Tchango, 1996; Díaz *et al.*, 1999; Pacheco-Delahaye *et al.*, 2008) also during different maturation stages. However, they do not include comparisons between groups and between consumption uses. On the other hand, studies on intra-cluster variability are scarce (Mustaffa *et al.*, 1998, Jullien *et al.*, 2001).

The large biodiversity of Musa plants is an important asset in programs with objectives on getting fruits with desirable organoleptic characteristics and good nutrient quality including taste and antioxidant content. Taking the consumers requirements and demands on new markets there are nine acuminata species described, being the most consumed clones on the world: Group AA, Subgroup AAA, Group AB, Group AAB, Group ABB, Group AAAA (Aurore *et al.*, 2009).

The present study had the objective to evaluate the potential agroindustrial use of twenty Musa varieties grown in Colombia over 1300 masl using parameters such as cluster size, hands and fingers number with or without skin; physical characteristics like density, dry matter content, skin percentage and, rheological properties of starch and flour.

Materials and methods

Variety selection

Samples were taken from the Colombian Collection of Musas varieties (Table 1) from Fedeplatano located on Las Vegas farm in the town of Chinchiná (1360 masl, 4° 58' N and 75° 20' W), Caldas, Colombia. Samples consisted of a cluster of green fruits on optimal developmental stage.

Physical characterization

Weight of each cluster was determined before separating hands or fruit groups (fingers) from the raquis, then the raquis was weighted separately from the hands on a triple arm balance (Ohaus 700 series). Fruit weight was determined, with and without skin, on a precision analytical balance (± 0.0001 g), and the fruit skin was weighed separately.

Fruit and pulp length were measured with a metric tape (±0.1cm) from the peduncle till the apex. Diameter was measured in the middle part of each fruit and pulp using the circumference perimeter formula. To determine fruit and pulp density it was used the water displacement method (Dadzie and Orchard, 1996; Bainbridge *et al.*, 1996) with an analytical balance (±0.0001 g), as follows:

$$\rho_p = \frac{m_p}{m_{ad}}$$

where,
r_p= plantain density (g/ml).
m_p = plantain mass (g) with or without skin -g.
m_{ad} = mass or volume (ml) of water displaced by the plantain with or without skin.

To determine dry mass, three randomly

Table 1. Genetic classification and subgroup of evaluated Musa varieties.

Genotype and name	Genetic clasification	Subgroup
Diploid: 2n = 2x = 22		
New Poovan	AB	Sucrier
M.B. Tani	BB	Balbisiana
Triploid: 2n = %x = %%		
Guineo	AAA	Mutika
Gros Michel Guayabo	AAA	Gros Michel
Cachaco Sin Bellota	ABB	Bluggoe
Yangambi KM3	AAA	Ibota
Cachaco Espermo	ABB	Bluggoe
Mbindi	AAB	Plantain
Bocadillo Chileno	AAA	Gros Michel
Dwarf Cavendish	AAA	Cavendish
Saba	ABB	Saba
Pisang Ceylan	AAB	Mysore
Indio	AAA	Cavendish
Banano Chico	AAA	Gros Michel
África 1	AAB	Plantain
Tafetán Rojo	AAA	Red Dacca
Banano 2	AAA	Gros Michel
Tetraploid hybrids 2n=4x=44		
HIA 17	AAAA	Hybrid
ICAFHIA 110	AAAA	Hybrid
FHIA 1	AAAB	Hybrid

selected samples were peeled and cut to determine wet and dry weight at 105 °C for 48 h. Percentage of skin in fruit was calculated by the ratio between the dry weight of fruit and skin. Edible fraction (kg/plant DM) was calculated according to the following:

Fc = (*Pr* - *Prq*) . *%pulp* . *%DM* (Ferris, 1999)

where,
Pr: cluster weight.
Prq: raquis weight.
%pulp: pulp percentage.
%DM: dry matter percentage.

Characterization of the pasting curves of flours and starch

Sample preparation. To get flour, pulp was cut in slices and dried out at 50 °C for 48 h on a fluidized bed furnace (Mermmet UL40) with range 1 to 200 °C, before it was grinded and stored on a cold room (Dufour *et al.*, 2008, 2009).

For starch extraction it was used the methodology of Dufour *et al.* (2008, 2009). To the effect, a fraction of pulp from the entire cluster was blended on distilled water for one minute, and then it was strained to separate by sedimentation the starch after several washings.

Pasting curves properties. These properties were determined with a rapid viscosity analyzer RVA-4 (Newport Scientific) with a defined temperature profile: starting at 50 °C and increasing at 6 °C/min till 90 °C for 5 min and cool down till 50 °C at 6°C/min. For flours, a 8% dry based suspension was made in presence of α-amylase inhibitor (($AgNO_3$, 0.002 mol/l) and the starch with distilled water at 7% dry base concentration (Dufour *et al.*, 2008, 2009).

Variables analyzed for characterization of the pasting curves were: onset gelatinization temperature (Tpasting -°C) and time (t´pasting -min), maximum viscosity (Vmax -cP), maximum viscosity temperature (T°Vmax -°C) and time at the maximum viscosity (tVmax -min), breakdown (Vmax VPC -cP), hot paste viscosity (VPC -cP), minimum viscosity (Vmin -cP), cold paste viscosity (VPF -cP), setback (VPF Vmax -cP), cooking behavior (tVmax - tpasting -min), (Dufour *et al.*, 2008, 2009).

Data analysis

For descriptive statistical analysis of results it was used the Software SPSS v. 15.0 (SPSS, 2006) and for the principal component analysis it was used SPAD 3.5 (CISIACeresta, 1998).

Results and discussion

Physical characteristics of the fruit

The cluster average weight differed between clons, with a coefficient of variation of 43.27%. Cachaco Espermo was the variety with the lightest clusters (8 kg), while Bocadillo Chileno produced clusters with an average weight of 43 kg. Characteristics of Musa's clusters depend on genetic and agroclimatic factors and crop age, among others, showing that the morphological characteristics of these plants rely on the genotype x environment interaction (Vuylsteke, 1997) and indicates that the variety state is not restrictive for the results found in this study. On Table 2 is shown that hybrids for desserts produce the heaviest clusters with more hands and fruits, followed by the dessert plantains; in the opposite, cooking plantains showed the lightest clusters with less hands and fruits.

In Colombia, industrial varieties have large sizes, lengths and diameters. Fruits that presented the maximum values for these characteristics were from the subgroup Plantain (Africa and Mbindi) which, according to Azcón-Bieto and Talon (1996), can be modified by the environment.

In all the varieties, the fruit average length was less than 25 cm, with exception of the Plantain subgroup (Mbindi y África-1), this agrees with the findings of Dufour *et al.* (2008) and Gibert *et al.* (2009) for the subgroup Africa-1. This researcher also found that plantains of the group AAB were longer than 23 cm, however in this work it was found that the Pisang Ceylan (AAB) variety is shorter than that value.

Cooking plantains from the Plantain subgroup had a superior fruit average diameter (> 5 cm) than the other plantains and bananas studied, this agrees with findings of Dufour *et al.* (2008) and Gibert *et al.* (2009).

África-1 variety showed the highest dry

Table 2. Physical characteristics of cluster and fruits of the Musa varieties evaluated.

Type and use	Name of cluster variety	Weight (kg)	Number of hands	Number of fingers	Fruit weight (g)	Fruit lenght (cm)	Mean fruit diameter (cm)
Dessert diploid	Ney Poovan	14.4	8	101	129.0±22.9	18.2±1.7	4.1±0.2
Diploid BB	M.B. Tani	22	14	197	95.9±50.4	16.9±3.0	4.2±0.7
Dessert banana	Gros Michel Guayabo	20	8	126	135.7±29.3	16.8±2.0	4.1±0.2
	Yangambi Km3	14	8	111	136.5±21.3	19.4±1.6	4.0±0.1
	Bocadillo Chileno	43	10	191	212.2±45.2	21.6±1.7	4.5±0.3
	Dwarf Cavendish	14.2	8	104	131.7±16.5	20.9±1.8	3.8±0.1
	Indio (Primitivo)	23.9	9	154	136.6±13.7	20.8±1.5	3.9±0.1
	Banano Chico	14.25	9	105	118.9±15.9	19.3±1.8	3.7±0.1
	Tafetan Rojo	13.25	5	67	163.4±20.7	18.0±1.3	4.7±0.2
	Banano 2	20	8	137	127.3±21.8	22.6±2.1	3.8±0.7
Cooking banana	Guineo	20.5	8	137	146.8±17.1	18.5±0.6	4.7±0.2
Dessert plantain	Pisang Ceylan	24.15	13	202	102.3±23.3	17.5±1.9	3.8±0.1
Cooking plantain	Mbindi	14	7	44	304.6±75.8	25.7±2.9	5.1±0.5
	Africa 1	17.75	6	32	550.0±36.3	37.0±1.1	5.7±0.2
	Cachaco sin Bellota	10.5	6	71	142.9±22.3	17.8±1.1	4.5±0.3
	Cachaco Espermo	8	6	60	105.8±21.5	17.6±1.7	4.2±0.2
	Saba	14.25	7	76	168.7±25.9	21.5±1.6	4.9±0.2
Desert hybrids	FHIA 17	26	12	182	179.3±28.3	20.7±1.9	4.2±0.1
	ICAFHIA 110	36.5	11	175	186.9±22.4	23.9±1.6	4.3±0.2
	FHIA 1	20	9	260	130.2±25.4	18.0±1.6	4.1±0.13

weight and pulp length (335.8 g and 28.7 cm, respectively) (Table 3), while the M.B. Tani variety only weighted 42.2 g and revealed a length of 11.5 cm.

Cooking plantains from the Plantain subgroup had mean pulp diameters larger than 4 cm, while for the others this characteristic was between 2 and 4 cm (Table 3). M.B. Tani variety, with an average value of 58.44%, showed the highest skin percentage and Yangambi Km3 variety had the lowest (35.16%) (Table 3). Agroindustry searches for materials with low skin percentages to ensure high raw material yield. In Colombia, the most used plantains in industry are Dominico Harton and Harton, with skin percentages between 35 and 39% (Dufour *et al.*, 2008; Gibert *et al.*, 2009), according with this criteria, varieties such as Yangambi Km3, Guineo Mutika, Africa- 1, Tafetán Rojo, FHIA 17, Mbindi, Banano Chico, Gros Michel Guayabo, Pisang Ceylan and Dwarf Cavendish, with skin percentages between 35.16% and 37.26%, are varieties that should be studied with more detail as potential materials for agroindustrial use.

Densities

Mean densities of the fruit and pulps of each variety are included in the Table 4. The highest fruit density was observed in Banano Chico variety (1.23 g/ml) and the lowest in M.B Tani (0.83 g/ml). Bananas for desserts had densities >1 g/ml; cooking plantains from the Mbindi variety had the highest density (1.03 g/ml) and hybrid bananas for desserts had densities between 0.86 and 1.10 g/ml; for cooking bananas the density was 0.95 g/ml and for dessert plantains was 0.98 g/ml.

The highest pulp density was found in Banano Chico (1.36 g/ml), and the lowest in M.B. Tani (0.77 g/ml). M.B. Tani density is affected by seed presence on the pulp.

A lower density means lower porosity on the skin or pulp, meaning that it has less open spaces and when it is submerged in water it tends to precipitate to the bottom of the con-

Table 3. Pulp characteristics and skin percentage of the Musa varieties evaluated.

Type and use	Variety name	Pulp weight (g)	Pulp lenght (cm)	Mean pulp diameter (cm)	Skin (%)
Dessert diploid	Ney Poovan	71.6±13.4	13.5±1.6	3.1±0.1	41.2±1.2
Diploid BB	M.B. Tani	42.2±31.3	11.5±2.7	3.0±0.7	58.4±9.4
Dessert bananas	Gros Michel Guayabo	82.0±19.8	14.3±1.6	3.2±0.2	37.1±1.7
	Yangambi Km3	89.8±11.5	15.5±1.3	3.2±0.1	35.2±1.8
	Bocadillo Chileno	119.6±25.9	17.9±2.1	3.4±0.2	40.6±1.7
	Dwarf Cavendish	78.8±11.1	16.9±1.4	2.9±0.1	37.3±2.0
	Indio (Primitivo)	71.1±7	17.3±1.2	2.8±0.1	44.9±2.0
	Banano Chico	73.3±10.6	14.9±1.2	3.0±0.1	36.7±1.6
	Tafetan Rojo	99.8±12.8	15.1±0.9	3.8±0.2	36.3±1.1
	Banano 2	62.7±8.0	18.7±1.8	2.6±0.1	51.4±3.3
Cooking bananas	Guineo	82.1±12.8	12.5±1.8	3.7±0.2	35.3±3.1
Dessert plantain	Pisang Ceylan	63.2±13.3	12.8±1.8	3.1±0.2	37.2±5.7
Cooking plantains	Mbindi	215.0±57.9	21.3±2.9	4.1±0.4	36.4±1.8
	Africa 1	335.8±27.1	28.7±0.9	4.6±0.2	36.2±1.5
	Cachaco sin Bellota	71.3±11.4	13.4±1.2	3.4±0.2	47.2±2.1
	Cachaco Espermo	50.0±13.6	12.5±1.9	2.9±0.2	52.9±4.0
	Saba	76.75±12.24	14.7±1.70	3.45±0.16	52.3±3.9
Dessert hybrids	FHIA 17	110.1±16.7	17.6±2.4	3.4±0.1	36.3±1.19
	ICAFHIA 110	90.4±11.1	18.5±1.1	3.1±0.1	49.5±1.0
	FHIA 1	78.3±14.7	14.5±2.0	3.2±0.1	41.4±4.4

tainer; the opposite happens with materials with larger porosity, some spaces are empty or full of air and when submerged in water, the first ones are filled up with water letting them float (Lucas *et al.*, 2010) affecting cooking processes in water and/or oil because the product is not totally submerged.

Dry matter and edible fraction

Mbindi variety showed the highest fruit DM (40.02%), followed by the Africa-1 variety (36.76%). Subgroup varieties such as Bluggoe, Cachaco Espermo, Cachaco sin Bellota and Saba had DM percentages of 35.08, 34.83, and 31.85%, respectively. The fry industry searches for raw materials with high DM content since during the process water is replaced by oil, therefore with less water the material absorbs less oil and the time for the process is reduced (Lemaire, 1997).

Bocadillo Chileno variety presented the highest edible fraction per cluster (5.99 g of DM). DM and edible fraction results found in this study agree with data from Dufour *et al.* (2008) and Gibert *et al.* (2009) and, although the values of those variables are not the same in both studies, the performance was similar. Additionally, it is known that the DM content is associated with consumption uses; therefore dessert bananas have lower contents than cooking plantains.

In the analysis of variance, significant differences were found ($P < 0.005$) between the varieties in all the parameters evaluated, therefore, it is necessary to analyze and describe the morphological characters and physico-chemical properties of the varieties in order to find correlations between pulp characteristics and consumers preferences, that determine fruit acceptance or rejection.

Viscoamylographs of starches and flours

Viscoamylographs of starches.

On figure 1 and Table 5 are presented the

Table 4. Density, dry matter and edible fraction of the Musa varieties evaluated.

Type and use	Variety name	Group	Subgroup	Fruit density (g/ml)	Pulp density (g/ml)	Edible fraction (MS, kg)	Dry matter (DM)
Dessert diploitre	Ney Poovan	AB	Sucrier	0.98±0.11	1.01±0.12	2.31	31.85±0.65
Diploid BB	M.B. Tani	BB	Balbisiana	0.85±0.07	0.77±0.08	1.73	21.24±1.22
Dessert postre	Gros Michel Guayabo	AAA	Gros Michel	1.16±0.11	1.02±0.10	3.35	28.98±1.54
	Yangambi Km3	AAA	Ibota	1.02±0.06	1.04±0.12	2.79	33.25±0.85
	Bocadillo Chileno	AAA	Gros Michel	1.01±0.04	1.28±0.21	5.99	26.64±0.31
	Dwarf Cavendish	AAA	Cavendish	1.0±0.08	1.32±0.14	2.32	28.90±0.99
	INDIO (Primitivo)	AAA	Cavendish	0.95±0.07	1.05±0.20	3.43	29.73±2.47
	Banano Chico	AAA	Gros Michel	1.22±0.12	1.36±0.21	2.37	33.02±2.52
	Tafetan Rojo	AAA	Red Dacca	1.05±0.06	1.08±0.12	1.87	24.87±0.60
	Banano 2	AAA	Gros Michel	1.12±0.12	1.16±0.32	2.68	29.33±0.76
Cooking bananas	Guineo	AAA	Mutika	0.95±0.06	1.07±0.18	2.95	25.26±0.64
Dessert plantain	Pisang Ceylan	AAB	Mysore	0.98±0.12	1.12±0.19	4.33	31.34±2.03
Cooking	Mbindi	AAB	Plantain	1.04±0.03	1.13±0.05	3.84	40.02±1.10
	Africa 1	AAB	Plantain	1.02±0.05	1.13±0.07	3.64	36.76±1.24
	Cachaco sin Bellota	ABB	Bluggoe	1.03±0.03	0.88±0.11	1.58	34.82±0.29
	Cachaco Espermo	ABB	Bluggoe	0.95±0.04	0.79±0.09	1.23	35.07±0.61
	Saba	ABB	Saba	0.92±0.04	0.91±0.14	1.87	31.84±1.14
Dessert	FHIA 17	AAAA	Hybrid	0.95±0.06	0.99±0.10	4.66	22.44±0.96
	ICAFHIA 110	AAAA	Hybrid	0.86±0.04	0.99±0.15	4.83	28.61±2.34
	FHIA 1	AAAB	Hybrid	1.1±0.13	1.3±0.22	2.92	27.52±1.03

pasting curves and functional properties of the starch from the studied varieties. According to the consumption use the following functional properties were found:

Gelatinization temperature.

Average onset gelatinization temperature for starch from dessert bananas was 65.58 and 74.41 °C for Gros Michel Guayabo and Tafetan Rojo, respectively, the other varieties in this group had values close to 70 °C. Among cooking plantains, Africa-1 had the lowest value (69.35 °C) and Cachaco sin Bellota the highest (73.22 °C), for the others the temperature was above 70 °C. Among hybrid bananas dessert, FHIA-1 variety showed the lowest value (66.99 °C) and ICAFHIA 110 had the highest (70.34 °C). Cooking bananas had an onset gelanization temperature of 72.47 °C and dessert plantain of 69.11 °C. The samples above indicate that to start gelatinization cooking plantains require more energy than the other Musa varieties studied. A higher onset gelatinization temperature of native starch reflects a higher internal stability of the starch granules, associated normally with larger semi-crystalline areas and high amylose content (Imberty, 1988). Gelatinization temperatures, low among different clones, are explained by the fact that the starch granule rapidly absorbs water due to weakening of the attraction forces between molecules (amylose/amylopectine), phenomenon associated, possibly, with lower amounts of amylase and larger crystalline regions in the granule that require lower heating temperature.

Viscosity.

Among the dessert bananas, Yangambi Km3 variety showed the lowest maximum viscosity (483.24 cP) during the cooking process, whereas the clon Indio had the highest maximum viscosity (1958.44 cP). Starch from Ney Poovan and Tafetan Rojo did not reach maximum viscosities over 1000 cP. In cooking plantains, Africa-1 variety had the highest maximum viscosity (1849.54 cP), whereas for the clon Saba was the lowest (978.56 cP). The other varieties of this group showed values over 1000 cP. ICAFHIA 110 variety presented a lower maximum viscosity (1025.40 cP) than the

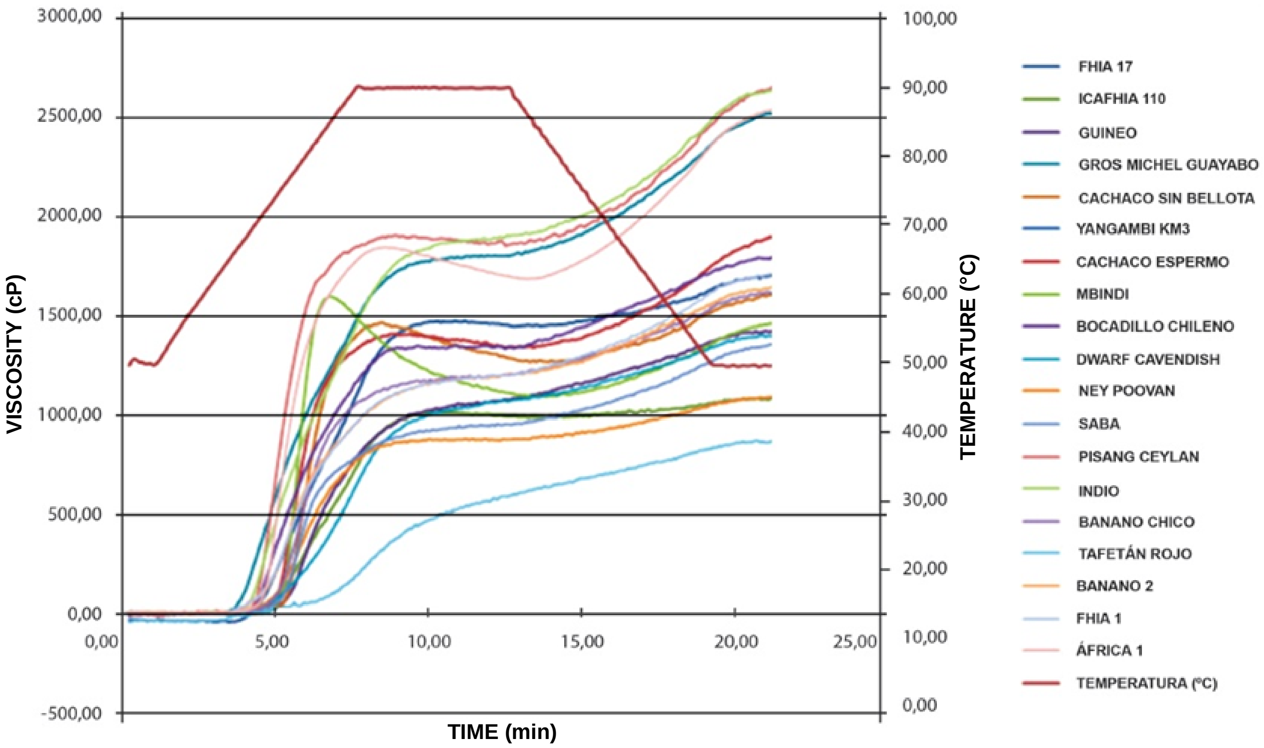

Figure 1. Viscoamylograph of starches from the varieties of Musa evaluated.

Table 5. Functional properties of the starch of the evaluated varieties.

Variety	Group	T°pasting (°C)	Vmax (cP)	Breakdown (cP)	VPF (cP)	Setback (cP)	Cooking time (min)
FHIA 17	AAAA	68.31	1505	256.5	1668	419.5	7.09
ICAFHIA 110	AAAA	70.34	1025	180.5	1068	223	6.16
Guineo	AAA	72.47	1082	0	1358	276.5	8.18
Gros Michel Guayabo	AAA	65.58	1832	0	2364	532	9.66
Cachaco Sin Bellota	ABB	73.82	1463	194	1512	243	3.47
Yangambi Km3	AAA	73.77	483	98.5	544	159	7.05
Cachaco Espermo	ABB	71.08	1409	66.5	1753	410	4.37
Mbindi	AAB	73.00	1558	518	1304	263.5	1.91
Bocadillo Chileno	AAA	69.38	1471	15.93	1798	342.93	7.94
Dwarf Cavendish	AAA	70.37	1101	0	1378	277.5	8.86
Ney Poovan	AB	70.25	891	0	1069	177.5	8.78
Saba	ABB	72.29	978	0	1276	297.5	8.64
Pisang Ceylan	AAB	69.11	1876	43.5	2444	611.5	6.1
INDIO (Primitive)	AAA	67.07	1958	0	2513	555	8.61
Banano Chico	AAA	69.63	1177	0	1483	306	8.96
África 1	AAB	69.35	1849	165	2356	672	4.41
Tafetan Rojo	AAA	74.41	637	0	854	216	8.25
Banano 2	AAA	66.75	1222	0	1584	361	9.45
FHIA 1	AAAB	66.99	1223	0	1597	374	9.49

other dessert hybrid bananas; while for FHIA 17 the highest value was obtained (1504.91 cP); cooking banana showed a value of 1081.86 cP and dessert plantain 1875.93 cP.

Differences between maximum viscosities are explained by the relation between the amylose/amylopectin content in the starch from the different varieties and the granule size (Gordon, 1990). For their maximum viscosity, FHIA 17 (1504.91 cP), Gros Michel Guayabo (1831.68 cP), Cachaco sin bellota (1462.96 cP), Cachaco Espermo (1409.24 cP), Mbindi (1558.52 cP), Bocadillo Chileno (1471.16 cP), Pisang Ceylan (1875.93 cP), Indio (1958.44 cP), and África-1 (1849.54 cP) varieties, showed promising properties for the agroindustry searching to improve stability in products such as sauces and soups.

Breakdown (Vmax VPC).

Dessert bananas had breakdown between 0 and 98.50 cP, Gros Michel Guayabo, Dwarf Cavendish, Ney Poovan, Indio, Banano Chico, Tafetán Rojo and Banano-2 did not have reduction in viscosity and were the varieties with the most stable starch during cooking, their breakdown was 0. Yangambi Km3 had the highest breakdown. Mbindi was the cooking plantain with more breakdown (518 cP) and the clon Saba was the most stable (0 cP). Among the dessert hybrid bananas starch, FHIA-1 was the most stable (0 cP); whereas the FHIA 17 showed the highest breakdown (265.50 cP). Cooking banana breakdown was 0 and cooking plantain was 43.50 cP.

Starches.

The less recommended varieties for processes involving mechanical stirring are FHIA 17 (256.5 cP), ICAFHIA 110 (180.5 cP), Cachaco Sin Bellota (194 cP), Yangambi Km3 (98.5 cP), Pisang Ceylan (43.5 cP), África 1 (165 cP) and Mbindi (518 cP). Differences in breakdown are due to the amylopectin presence in the starch, this is a polymer that is rapidly solubilize on aqueous medium and gives viscoelastic stability to the pasting curve when it is subjected to extreme temperature changes (Wang *et al.*, 2003). These results suggest a great capacity for the starch granules to swollen in the varieties evaluated and a low stability when cooked. From this, it can be inferred that the granules are very fragile and are easily destroyed as the system losses viscosity. This fragility depends on granule size; thus, larger granules are easily destroy since they are more susceptible to fracture by thermic or mechanical forces, indicating that bonding forces among starch granules are not stable (Zobel, 1988).

Setback (VPF - Vmax).

For this property, Yangambi Km3 showed the lowest value among dessert bananas (159 cP), whereas clone Indio had the highest (555 cP). Among cooking plantains, Cachaco sin Bellota (243 cP) and Mbindi (263.50 cP) had the lowes setback; in the opposite, Africa-1 had the highest (672 cP). Among dessert hybrid bananas, ICAFHIA 110 showed a setback of 223 cP and FHIA 17 of 419.50 cP. Cooking banana had a setback of 276.50 cP and dessert plantain 611.50 cP.

Ease of cooking.

Among the dessert bananas, the lowest cooking time was observed for Yangambi Km3 (7.05 min) whereas for Banano 2 the time was the longest (9.45 min). Dwarf Cavendish, Ney Poovan, Indio, Banano Chico and Tafetán Rojo clons had cooking times between 8 and 9 min. Among the cooking plantains, Mbindi had the shortest cooking time (1.91 min) and Saba had the longest (8.64 min), for the rest of clones in this group values were between 3 and 4.5 min.

Dessert hybrid bananas had times longer than 6 min, being ICAFHIA 110 the one with the shortest time (6.16 min) and FHIA-1 the one with the longest (9.49 min). Cooking plantain had a cooking time of 8.18 min and dessert plantain of 6.10 min. Similarly to the cooking time of flours, starches had cooking times close to 5 min, for example, Mbindi and Cachaco sin Bellota had similar results (3.47 min) useful for the food industry, and Africa-1 (4.41 min). These differences in cooking behavior are due to the starch granules that are occupying a larger superficial area in the solution, while the starch granules with smaller superficial area in the solution directly impact on a shorter time in relation to the ease of paste cooking (Gunaratne and Hoover, 2002).

The strong differences in pasting curves between starches are notorious due to the genetics of each variety. Gel formation relies on the association of polymers, especially from the amylose fraction present in the molecules, on granule size and form. Boyer and Shannon (1987) indicate that starches with high amylose content had higher gelatinization temperatures than those high in amylopectin. Wurzburg (1986) considers that amylose had a good capacity to form hydrogen bonds, reducing its water affinity and requiring high energy to incorporate this molecule in its structure. This can explain, in part, the onset gelatinization temperatures and the low viscosity curves observed in Figure 1 and Figure 2 for starches and flours.

Viscosity fall showed by some varieties when temperature is constant, is possibly due to the orientation of the soluble starch molecules that goes in the direction of the system stirring originating a reduction in viscosity, phenomenon known as shear thinning (Hoseney *et al.*, 1986). Viscosity increments during the cooling period indicates a tendency of several components of the hot paste like swollen granules, fragments of swollen granules, molecules of coloidal starch that are molecularly disperse, to associate or retrogress while the paste temperature decreases (Singh *et al.*, 2003).

Viscoamylographs of flours.

Pasting curves and functional properties of the flours from the hand 2 of each cluster are shown in Figure 2 and Table 6.

Dessert bananas had very varying onset gelatinization temperatures; the lowest average was for Bocadillo Chileno (66.58 ± 0.13 °C) and the highest for Yangambi Km3 (74.71 ± 0.06 °C). Except for the latest one and Banano Chico, this group had gelatinization temperatures under 70 °C, different to the cooking plantains with values between 70.35 °C for Saba and 75.21 °C for Mbindi. Cooking plantain had a gelatinization temperature of 73.62 °C and for dessert plantain was 69.22 °C (Table 6).

As it is known, at lower gelatinization temperatures, less energy is required to start the swelling of the starch granules present in the flours. According to the results of this study, varieties with lower onset gelatinization temperatures are dessert bananas, among them Bocadillo Chileno, meaning that they require less time to gelatinize starches, for cooking and softening.

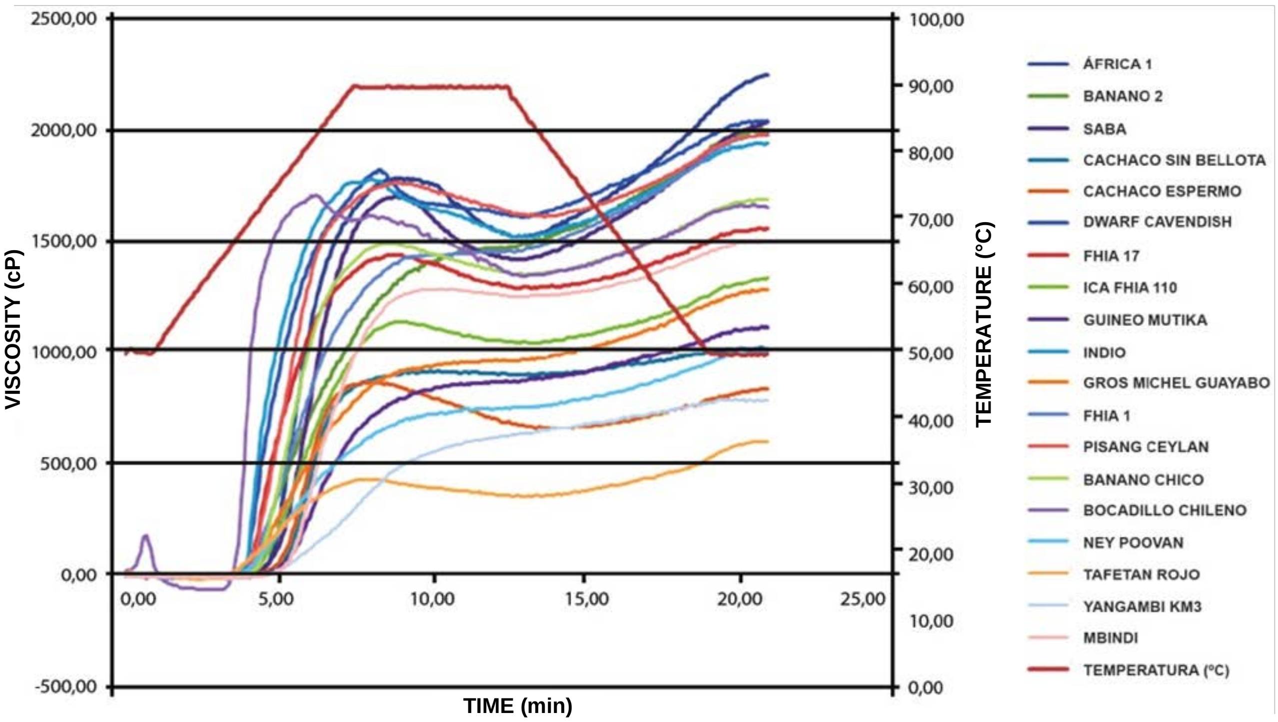

Figure 2. Viscoamylograph of flours from the varieties of Musa evaluated.

According to the maximum viscosity reached, flours from varieties such as Dwarf Cavendish, África1, Pisang Ceylan, FHIA 17, Bocadillo Chileno, Saba, Indio, Banano 2, can be considered promissing as thickeners for soups, compotes and sauces, among others.

Breakdown (Vmax - VPC) is associated with mechanical fragmentation, thus, to higher instability the higher will be the exposition to gel fragmentation for mechanical causes; this is due to the fragility for destroying granules that is reflected in viscosity losses in the system that depends on granule size. Larger granules are more easily destroyed because they are more suceptible to breakdown by thermical or mechanical forces (Zobel, 1988; Dufour *et al.*, 2008, 2009). Flours from FHIA 17, Cachaco Espermo, Bocadillo Chileno, Dwarf Cavendish, Saba, Pisang Ceylan, Indio, Banano Chico and África-1 had the particular characteristic of higher susceptibility to this kind of breakdown when compared to other varieties.

Viscosity after cooling (VPF) is an important factor for selecting materials that keep suitable viscosities in each productive process; increments in paste viscosity at the end of the pasting curve are associated with its cooling, retrogression processes and amylose content in the starches. Retrogression phenomenon is influenced by various factors related to amylose, among them: the content, length and dispersion state of this compound chains (molecules) (Gunaratne and Hoover, 2002). Tafetan Rojo, among other dessert bananas, presented the lowest value of this parameter (531 cP), whereas Dwarf Cavendish had the highest (1977 cP). Cachaco Espermo cooking plantain had the lowest cold paste viscosity (792 cP) and Africa-1 the highest (2083 cP), ICAFHIA 110 had the lowest value among dessert hybrids (1261 cP) and FHIA-1 had the highest (1893 cP), for cooking banana was 1066 cP and for dessert plantain was 1908.42 cP.

Setback (VPF - Vmax) is observed with the increment in viscosity during the cooling period because the hydrogen bonds between amylose and amylopectin are restored, generating a gel consistency as result of heating loss and retro-

Table 6. Functional properties of flours from the varieties of Musa evaluated.

Variety	Group	T°pasting	V max	Breakdown	VPF	Setback	Cooking
FHIA 17	AAAA	68.93	1448	156.5	1504	212.0	4.86
ICAFHIA 110	AAAA	70.50	1147	69.5	1261	183.0	4.77
Guineo	AAA	73.62	875	0	1066	191.5	6.88
Gros Michel Guayabo	AAA	68.60	970	0	1223	253.5	7.55
Cachaco Sin Bellota	ABB	73.18	927	19	1005	97.5	5.53
Yangambi Km3	AAA	74.71	628	0	780	153.6	7.15
Cachaco Espermo	ABB	72.85	877	211.5	792	126.5	3.37
Mbindi	AAB	75.21	1296	40.5	1455	199	5.58
Bocadillo Chileno	AAA	66.58	1721	315.5	1625	219.5	2.76
Dwarf Cavendish	AAA	68.1	1837	222.5	1977	362.5	4.64
Ney Poovan	AB	68.56	757	0	958	201.5	7.43
Saba	ABB	70.35	1712	287	1904	479	4.78
Pisang Ceylan	AAB	69.22	1773	110	1908	245.5	5.18
Indio (Primitivo)	AAA	68.40	1824	238.5	1874	289	3.92
Banano Chico	AAA	70.47	1501	107	1631	237.5	4.58
Africa 1	AAB	71.31	1794	268	2083	557.0	4.67
Tafetán Rojo	AAA	66.68	441	61.5	531	151.5	4.59
Banano 2	AAA	69.5	1532	75.5	1931	474.5	6.64
FHIA 1	AAAB	68.53	1465	0	1893	428.5	6.69

gression process. Tafetan Rojo showed the lowest setback among dessert plantains (151.50 cP), whereas Africa-1 had the highest (557 cP) among cooking plantains; ICAFHIA 110 had the lowest value (183 cP) and FHIA-1 had the highest (428.50 cP); for cooking banana was 191.50 cP and for dessert plantain 245.50 cP.

Ease of cooking indicates the industrial use of a flour. Since the energy demand to gelatinize is lower, it is require having shorter times than 5 min, cooking time estimated for other flour sources like wheat. According to this criterion, FHIA 17 (4.86 min), ICAFHIA 110 (4.77min), Cachaco Espermo (3.37 min), Bocadillo Chileno (2.76 min), Dwarf Cavendish (4.64 min), Saba (4.78 min), Indio (3.92 min), Banano Chico (4.58 min), África 1 (4.67 min) and Tafetán Rojo (4.59 min) could be of interest for several agroindustrial processes.

In the analysis of variance or Anova highly significant differences were found ($P < 0.005$) for all the evaluated parameters, indicating that the functional properties of starches and flours differ according to the plant material of origin.

Principal component analysis

According to this analysis, fruit weight is the most representative variable among the ones studied; this is due to the association of this trait with fruit development and size. Each variety has a different genetic conformation and diverse crop factors. Variables associated with component 1 were related between them, they are affected by fruit development and formation, characteristics mainly affected by agroclimatic factors.

In the principal component analysis, 68.99% of the varieties were grouped in two components (Figure 3). In the bottom left group are the África-1(17) and Mbindi(8) clones from the Plantain subgroup with larger sizes and weights. In the top right group is included M.B. Tani(9) which has a high skin percentage, the same happens with the group below the previous one composed by Bluggoe(5 and 7), Saba(12) and ICAFHIA 110(2). Varieties in the largest group had similar fruit physical and morphological characteristics, thus, this are not useful parameters to establish differences among clones. Banano Chico(16) is on a group associated with fruit and pulp densities.

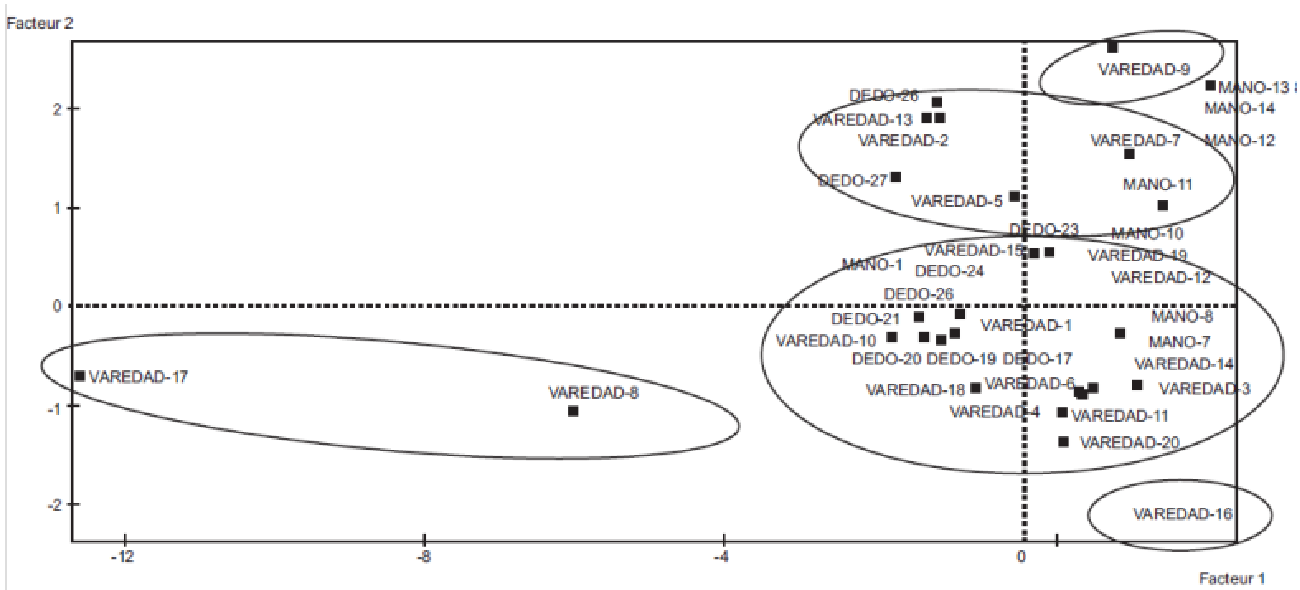

Figure 3. Grouping of Musa varieties for their physical and morphological characteristics.
In the bottom left is the group with varieties differentiated by superior weight and sizes. In the top right group is included M.B. Tani (9) which has a high skin percentage, the same happens with the group below the previous one composed by Bluggoe(5 and 7), Saba(12) and ICAFHIA 110(2).

Conclusions

- ICAFHIA 110 and Bocadillo Chileno had the heaviest clusters. Africa-1, despite of having a small cluster, had high weight and is an alternative source to the traditional Dominico Harton crop. Similarly, FHIA, Pisang Ceylan and Bocadillo Chileno have high number of fruits being of interest for agroindustry.
- Physical and morphological characteristics of Musas vary according to their location in the cluster, larger fruits are found in the bottom hands. Dry matter is the most homogeneous parameter along the cluster. All the morphological and physical traits evaluated had highly significant differences confirming the large varietal diversity of Musas. Varieties from the Plantain subgroup, Mbindi and Africa-1 with fruit diameters of 5.11 and 5.74 cm, respectively, are outstanding plantains among the musaceaes.
- Yangambi Km3, Guineo Mutika, África 1, Tafetán Rojo, FHIA 17, Mbindi, Banano Chico, Gros Michel Guayabo, Pisang Ceylan and Dwarf Cavendish, with skin percentages between 35.16% and 37.26%, are in the range of varieties normally used in agroindustry. The other varieties have a skin percentage larger than 40.58% making them less profitable generating high residues volumes.
- Plantain subgroup varieties have dry matter percentages close to 40% and, Bocadillo Chileno, ICAFHIA 110, Pisang Ceylán and FHIA 17 have edible fractions higher than 4 kg.
- Gelatinization temperature of flours in the RVA was around 66.58 °C and 75.21 °C for Bocadillo Chileno and Mbindi, respectively. Maximum viscosity varied between 441.57 and 1837.17 cP for Tafetán Rojo and Dwarf Cavendish. Cooking times for flours varied between 2.76 and 7.55 min for Bocadillo Chileno and Gros Michel Guayabo varieties.
- Gelatinization temperature for starches from bananas, plantains and dessert hybrids is lower than the one of cooking plantains and cooking bananas. Maximum viscosity is lower in dessert banana and plantains, followed by dessert hybrids bananas, plantains and cooking bananas. Starch from cooking plantain is easier to cook than dessert plantains, dessert hybrid bananas and cooking plantains; dessert bananas have the longest cooking times. Starch from the cooking plantains demands more energy for the onset of gelatinization than dessert plantains, however, these plantains have lower values for ease of cooking than the other studied varieties.
- In the evaluation of the functional properties of flours, FHIA 17, Dwarf Cavendish, África-1, Saba, and Bocadillo Chileno, had the best behaviors during the hydrothermal treatment in the maximum viscosity, breakdown and ease of cooking variables. Bocadillo Chileno and Cachaco Espermo showed the best results for consistency, indicating a low susceptibility to retrogression processes and syneresis.
- Starches with highest susceptibility to fragmentation by mechanical stirring were FHIA 17 (256.5 cP), ICAFHIA 110 (180.5 cP), Cachaco Sin Bellota (194 cP), Yangambi Km3 (98.5 cP), Pisang Ceylán (43.5 cP) and África-1 (165 cP). This varieties also showed lower susceptibility to retrogression and syneresis and, high values for maximum viscosity. Additional to these varieties, Mbindi and Cachaco Espermo, had better ease of cooking than the other studied varieties.

In following postharvesting studies for Musas' fruits, it is recommended to take notice of the fruit location in the cluster when measuring physical and morphological parameters, opposite to the starch pasting curves evaluation where the measured parameters did not show any difference among the hands of the same evaluated cluster.

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