Physiological attributes of banana and plantain cultivars of the Colombian Musaceae Collection

Atributos fisiológicos de cultivares de plátano y banano de la Colección Colombiana de Musáceas

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ABSTRACT

The Colombian Musaceae Collection (CMC) contains 140 banana and plantain cultivars. For this study, twelve cultivars were selected when they were in the initial flowering stage and the physiological attributes of the plants and some components of the bunches were studied. Similar cultivar groups were determined in terms of the evaluated attributes with the use of a multivariate statistical analysis for principal components and grouping analysis. With 89.35% explanation of the total variance by the first five components, the variables fresh weight of the bunches, fresh weight of the fruit, number of fruits, specific leaf area, total dry weight of the plant, dry weight of the corms, and percentage of dry weight of the bunches represented the majority of the differentiation of the cultivars. This study allowed for the evaluation and comparison of the principal promising banana and plantain cultivars for use as basic tools in selection programs of the Musaceae germplasm in terms of agronomic and productive behaviors.

Key words: plant genetic resources, plant physiology, yield components, biomass, leaf area, fruits.

RESUMEN

La Colección Colombiana de Musáceas (CCM) cuenta con 140 cultivares de plátanos y bananos. Para este trabajo se seleccionaron doce cultivares cuando se encontraban en la etapa inicial de floración y se estudiaron los atributos fisiológicos de la planta y algunos componentes del racimo. A través de un análisis estadístico multivariado por componentes principales y análisis de agrupamientos, se determinaron grupos de cultivares similares en cuanto a los atributos evaluados. Con una representación del 89,35% de la varianza total explicada para los primeros cinco componentes se identificó que las variables peso fresco del racimo, peso fresco total del fruto, número de frutos, área foliar específica, peso seco total de la planta, peso seco del cormo y porcentaje de peso seco del racimo fueron las que presentaron mayor discriminación de los cultivares. El estudio permitió evaluar y comparar los principales cultivares promisorios de plátano y banano para utilizarlos como herramienta básica en los programas de selección de germoplasma de musáceas relacionadas con el comportamiento agronómico y productivo.

Palabras clave: recursos genéticos vegetales, fisiología de plantas, componentes del rendimiento, biomasa, área foliar, frutas.

Introduction

Bananas (*Musa* AAA Simmonds) and plantains (*Musa* AAB, ABB Simmonds) are the principal basic food for millions of people in the countries of tropic zones and are considered, in terms of total production value, the fourth important global food, after rice, wheat, and milk (Heslop-Harrison and Schwarzacher, 2007). The total production of these crops exceeds 106 million t year^{-1}. They are grown in more than 120 developing countries and are the basic food for 400 million people (Perea *et al*., 2010; FAOSTAT, 2011). The edible banana and plantain species originated from interspecific crosses of the wild species *Musa acuminata* Colla (Genoma A) and *Musa balbisiana* Colla (Genoma B), of which the latter presents less variability (Nadal-Medina *et al.,* 2009; Agrawal *et al*., 2010). In order of economic importance, there are the triploid cultivars AAA, AAB and ABB, the diploids AA and AB, and the tetraploids AAAA, AAAB and AABB (Nadal-Medina *et al.,* 2009), which are indistinctive in their genome and are considered important nutritional sources for the Latin-American population and in some African countries (Orellana *et al*., 2002). In Colombia, the plantain is mainly produced in the departments of Antioquia, Boyaca, Caldas, Cauca, Cundinamarca, Huila, Nariño, Quindio, Risaralda, Santander, Tolima, Valle del Cauca and Arauca. The cultivated area is equivalent to 23% of the permanent species and has 590,000 ha set aside for its cultivation (Hoyos *et al.,* 2008).

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In general, the production of edible Musaceae is threatened by a series of pests and diseases of economic importance, especially due to low quality cultivars (Belalcázar *et al*., 1998). Since 1990, there has been an attempt to strengthen research on these crops, principally focusing on the maintenance of germplasm banks and genetic breeding with conventional and nonconventional methods. The Colombian Musaceae Collection (CMC), under field conditions, previously located in the Experimental Center El Agrado (Montenegro, Quindio) and currently located in the Palmira Research Center (Palmira, Valle), contains 140 diploid (AA, BB, AB), triploid (AAA, AAB, ABB) and tetraploid (AAAA, AAAB, AABB, ABBB) cultivars, all of which have been characterized by morphological, agronomic, and molecular methods. The CMC, under *in vitro* conditions, is found in the Tibaitata Research Center (Mosquera, Cundinamarca) and contains 145 clonal materials, the majority of which come from the CMC established in the field (Giraldo *et al*., 2011). During recent years, plant breeding has implemented the use of morphological and molecular characteristics in order to register and protect some collections of agricultural interest (Nadal-Medina *et al.,* 2009; Giraldo *et al*., 2011). The Musaceae breeding programs that are being developed in the world are seeking new cultivars with allometric relationship can be derived and used to assess biomass production and for developing banana growth models, which can help breeders and agronomists to further exploit the crop's potential (Nyombi *et al*., 2009).

The morphological classification of the bananas and plantains was based on 117 descriptors of morphological characterization and 27 descriptors of morphological evaluation, such as height and color of the pseudostem, nature of the leaves, color, form, and position of the stigma, type and orientation of the bunch, length of the peduncle, form, size, number, and curvature of the fruit and presence of seeds (IPGRI-INIBAP/CIRAD, 1996). With these descriptors, the use of morphological descriptors with high heritability was sought in order to ensure high stability in different environments (Belalcázar *et al*., 1998).

When studying the growth and development of large crops such as banana, these types of measurements are laborious and time consuming. An alternative to these measurements is the generation and use of empirical relationships, relating changes in biomass to thermal or physiological time or to simple measurable morphological traits (Niklas, 2005). Physiological variables, such as specific leaf area (SLA), which expresses the mass per unit of foliar area (White and Montes-R., 2005), or the relative thickness of the leaves, are very sensitive to external and environmental factors (Ayala and Gómez, 2000; Santamaría *et al*., 2000; Pérez *et al*., 2004). Through the use of evaluations for the banana and plantain cultivar characterization it was possible to broaden the possibilities of selecting promising clones within the CMC.

The present study aimed to evaluate and compare the principal physiological attributes that are present in promising banana and plantains clones for use as a basic tool in selection programs of the Musaceae germplasm related to agronomic and productive behaviors.

Materials and methods

Musaceae collections exist around the world at altitudes below 1,000 m a.s.l.; however, the CMC, which was used in the present study, is located at 1,350 m a.s.l. with unique ecological altitude conditions in the Experimental Center "El Agrado" in the municipality of Montenegro, Quindio department (Colombia), at 4°28' N, 75° 49' W with an average annual temperature of 22°C, annual precipitation of 2,100 mm and relative humidity of 78%. The soil of the experiment field had a sandy loam texture, 6.0 pH and 5.7% organic material. Twelve diploid, triploid and tetraploid materials were used (Tab. 1), considered promising due to their general characteristics of the bunches and fruits. Due to the lack of plants per cultivar in the CMC, only three plants per material were evaluated, selected when they were in the initial flowering stage, corresponding to the apical appearance of the inflorescence or floral bud. When the plants reached the bunch harvest stage, data for height, pseudostem perimeter at 1.0 m, number, length, and width in the functional leaves, total foliar area, specific leaf area (SLA, leaf area: leaf mass), and chlorophyll content (CHL) of the leaves were taken. The leaf area (LA) of each leaf was calculated with the formula LAF= L x A x 0.80246, where L is the length of the leaf and A is the width of the middle part. In each bunch, the weight, number of hands, and length, weight, and number of the fruits of the 1, 3, and 5 hands were registered.

During the harvest, the components of the bunches were registered: weight, number of hands, number of fruits, and weight and length of the fruits; along with the physiological variables of the plants: height, leaf area, and chlorophyll in leaf 3 (the chlorophyll concentration was determined with the ethanol extraction method using 1.3 cm^2 foliar discs (Wintermans and De Mots, 1965), SLA and dry weight.

TABLE 1. Banana and plantain cultivars of the evaluated Colombian Musaceae Collection (CMC).

Common name	Genome	Type
Bocadillo	AA	Banana
Pisang Mas	AA	Banana
Gross Michel coco	AAA	Banana
Cachaco	ABB	Plantain
Pelipita	ABB	Plantain
Dominico	AAB	Plantain
Dominico-Harton	AAB	Plantain
Africa 1	AAB	Plantain
Orishelle	AAB	Plantain
FHIA-01	AAAB	Banana
FHIA-03	AABB	Plantain
FHIA-21	AAAB	Plantain

The generated data were processed through the use of the SAS® software, version 9.0. Multivariate statistics of the principal components was applied, which generated characteristic vectors associated with the principal components, composed of the coefficients of all of the studied variables. In the selection of the variables, those that presented coefficients of a high absolute value were considered important due to a higher contribution to differentiation of the cultivars (Chávez, 2003). The variables with a negative coefficient meant that they were characterized in a sense contrary to the relationship with the positive variables and vice versa. Through the conglomerate analysis with a hierarchical method connected to the mean and the criteria of variation maximization between the groups and minimization within them, a dendrogram was generated using a Pearson correlation distance that measured the degree of lineal association between two objects (until the two object points were proportional) and where the transverse of this coefficient varied between -1.0 and 1.0 (Hidalgo, 2003).

Results and discussion

Physiological variation analysis

The principal components analysis (Tab. 2), which included 18 quantitative variables in order to differentiate the 12 banana and plantain genotypes, demonstrated that the first five components possessed a characteristic value (λ) over 1, being the more important ones in this study, representing 89.35% of the total variance. The first principal component contributed 32.58% of the total variance, while the distribution of the coefficients of the first fitted vector indicated that the physiological variables fresh weight of the bunches (FWB) and total dry weight of the plant (TDWPL) were the variables that provided more positive contribution to this component due to their high coefficients, 0.376 and 0.380, respectively; followed by the dry weight of the pseudostem (DWPSEU) and the dry weight of the leaves (DWL). On the other hand, the percentage of dry weight of the corm (PDWCOR) was the variable that contributed the most negatively (Tab. 2). These results suggest that the first principal component allows for distinguishing the materials

TABLE 2. Variation represented by the coefficients of the physiological characteristics in the associated characteristic vectors in the five principal components of the 12 banana and plantain cultivars from the Colombian Musaceae Collection (CMC).

Variables	Principal components				
	1	2	3	4	5
Height, HEI	0.127	0.247	0.268	-0.341	0.036
Fresh weight of the bunches, FWB	**0.376**	-0.023	-0.167	0.076	-0.241
Number of hands, NH	0.253	-0.307	-0.038	0.207	-0.158
Number of fruits, NF	0.165	**-0.397**	-0.117	0.029	-0.074
Total fresh weight of the fruits, FWF	0.065	**0.444**	-0.105	0.179	0.095
External length of the fruits, ELF	0.057	0.390	-0.077	-0.004	0.255
Average fruit weight, AFW	0.270	0.348	-0.156	-0.003	-0.147
Total leaf area, TLA	0.304	-0.206	0.038	0.037	0.216
Chlorophyll, CHL	0.274	-0.039	-0.047	0.250	0.463
Total dry weight of the corm, TDWCOR	0.004	0.018	0.335	**0.523**	-0.145
Dry weight leaf, DWL	0.321	-0.079	0.250	-0.148	-0.212
Specific foliar area, SLA	0.165	-0.218	-0.074	0.031	**0.602**
Dry weight of the pseudostem, DWPSEU	0.354	0.099	0.269	-0.054	-0.068
Total dry weight of the plants, TDWPL	**0.380**	0.083	0.110	0.089	-0.217
Percentage dry weight corm, PDWCOR	-0.257	-0.025	0.274	0.423	-0.053
Percentage dry weight pseudostem, PDWPSEU	0.142	0.090	**0.454**	-0.218	0.242
Percentage dry weight leaves, PTDWL	-0.085	-0.286	0.056	**-0.448**	-0.021
Percentage dry weight bunches, PDWB	0.167	0.089	**-0.537**	-0.029	-0.094
Contribution to variance (%)	32.58	24.88	14.72	11.01	6.16

that have a high FWB and high total dry biomass and low values of PDWCOR. Similarly, the positive contribution of the PDWPSEU and the DWL negatively affected the dry weight of the corms.

The number of hands (NH), average fruit weight (FW), SLA and CHL also positively contributed to the first component, but at a lower proportion than the previously mentioned variables, leading to the conclusion that the materials with a high biomass and that produce heavy bunches tend to have a high number of hands, a high average fruit weight, and present a high SLA and CHL concentration. The number of fruits per bunch and nutritional quality of the fruits are important horticultural and breeding selection indices in *Musa* improvement programs (Ndukwe *et al*., 2012). Any crop management practice should aim to maintain the physiological processes of the plants in an active condition so that these plants can produce more biomass with the least destructive process. Higher photosynthetic activity is a good indication of physiologically efficient plants in bananas. This primarily depends upon the leaf chlorophyll content. The chlorophyll content in leaves indicates the efficiency of photosynthesis, where the solar energy is converted into chemical energy (Kuttimani *et al*., 2013).

The second component explained 24.88% of the total variance (Tab. 2). The descriptors with a high positive effect on the component included those related to the fruit, such as the total fresh weight of the fruit (FWF), the external length of the fruit (ELF), and the average fruit weight (AFW). On the other hand, the variables that presented a high incidence of negative values included the number of fruits (NF) and number of hands (NH). With this component, the banana and plantains can be differentiated by larger fruits with their fresh weights and lengths but with a lower number of fruits and hands. Although the variables were selected to be mutually independent and non-correlated as much as possible, some morphological variables, such as bunch and hand weights, seemed to exhibit a similarly weighted contribution to the explanation of the variation (Gibert *et al*., 2013).

The third component contributed 14.72% of the total variance (Tab. 2). The coefficients of the third fitted vector suggested that the contributing factors included the percentage of dry weight of the pseudostem (PDWPSEU) and the total dry weight of the corm (TDWCOR). As a consequence, this component allowed for the differentiation of the genotypes with plants with higher heights and larger pseudostems and corms, while the majority of the other variables had notably negative contributions. Thereby, the percentage of dry weight of the bunches favored the production of plants with small bunches. The fourth component explained 11.01% of the total variance. The variable with the most contribution was total dry weight of the corm (TDWCOR), while the variable with the most negative effect was the percentage of total dry weight of the leaves (PTDWL), a behavior that allowed for the differentiation of the samples through larger corm sizes and lower leaf biomass. The fifth and last component explained 6.16% of the total variance (Tab. 2) and, contrary to the above components, it positively contributed to the variables of SLA and CHL and negatively contributed to the majority of the other variables.

In general, the results demonstrated that, in the banana and plantain genotypes, the variables related to biomass were more important and more discriminating than the variables that described the fruit, which were more important and discriminating than the variables that described the SLA and CHL. Among the variable related to biomass, the total dry weight of the plants and the fresh weight of the bunches of the first component reached first and second place, respectively. Therefore, they were the more representative ones among the 18 analyzed quantitative characteristics for the differentiation of the studied cultivars, followed by the fruit quality variables total fresh weight of the fruit and number of fruits in terms of importance, with a behavior mainly dependent on the genotype. The dry matter content was confirmed as being an essential attribute for differentiating between groups, subgroups and genotypes (Gibert *et al*., 2013).

Cluster analysis of the cultivars

The dendrogram obtained with the Pearson distance correlation and the connected mean algorithm (Fig. 1) demonstrated a distance with a range of 0 and 1 because the R^2 was graphed, indicating that the association of the cultivars with the $R^2 = 0$ distance was completely distant and, with $R^2 = 1$, they were similar materials, considering the data of the 18 analyzed quantitative variables. Two sample groups appeared at the Pearson correlation distance of 0.75 units, with the differentiation principally based on the variables of fresh weight of the bunches and the total dry weight of the plants. Group 1, comprised of the cultivars FHIA-03, Pelipita and Gross Michel coco, presented the highest mean value for the variable of fresh weight of the bunches (35.0 kg), notably so in the cultivars FHIA-03 (39.0 kg) and Pelipita (37.8 kg), as compared to the general average of the 12 evaluated materials (21.4 kg). However, the FHIA-01 hybrid, coming from sub-group 2B, obtained the highest registered average weight for this variable (41.7 kg), contrary to results obtained by Belalcázar *et al*. (1998)

for the hybrids FHIA-01 and FHIA-03 in conditions of the coffee region, with bunch weights below 28.0 kg. Nevertheless, the Pelipita clone had one of the higher weights, reaching 32.0 and 39.6 kg in two production cycles. Group 2 registered the highest total fruit weight with an average of 233.1 g, with a notably high value from sub-group 2A, as confirmed by the Africa 1 material which obtained a total fruit weight of 445.3 g.

The total fresh weight of the fruit for group 1, while not the highest, represented the highest fresh weight of the bunches, which indicated a high number of fruits per bunch (Tab. 3). For Gibert *et al.* (2009), hand weight, finger weight and finger density appeared to be the most relevant morphological traits contributing to the differentiation between the consumption subgroups of banana. The complementary characterization of bunch spatial dimensions (length, girth) highlighted within-bunch variability. Thus, landraces with high productivity and low variability can be expected to exhibit a great potential for industrial application (Gibert *et al.*, 2013).

In the variable of total dry weight of the plants, group 1 registered the highest value, with a notably high average of 24.2 kg in the Pelipita material, followed by the FHIA-01 hybrid with 21.1 kg. These two genotypes together with

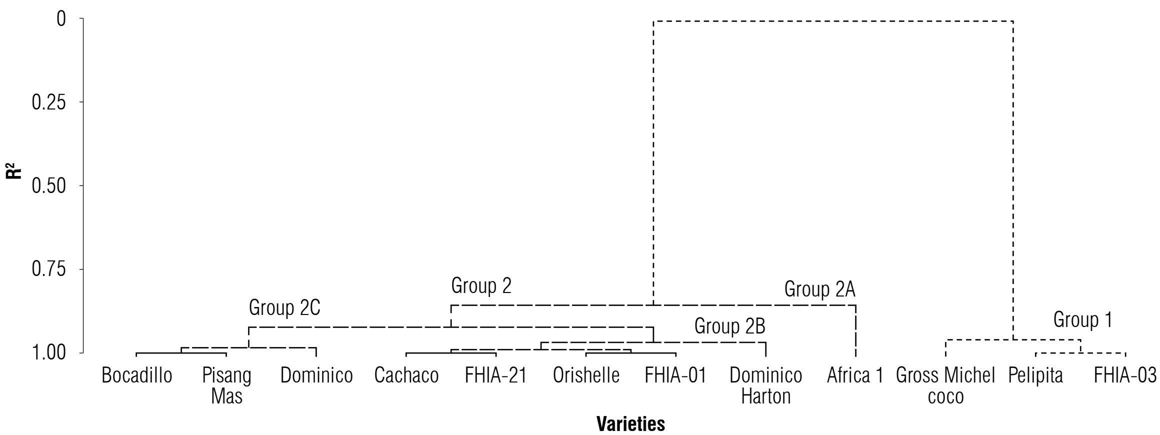

FIGURE 1. Dendrogram of the 12 banana and plantain cultivars generated from 18 quantitative variables.

TABLE 3. Behavior of the banana and plantain cultivars by groups of similarity for the set of studied quantitative physiological variables.

Group	Cultivar	Fresh weight of the bunches (kg)	No. fruits	Fresh weight of the fruits (g)	Dry weight of the corm (kg)	Specific leaf area ($m^2 g^{-1}$)	Dry weight of the plants (kg)	DWB/TDWP (%)
1	FHIA-03	39.0	39	180.3	2.7	0.3	18.0	38.0
	Pelipita	37.8	38	231.1	2.1	0.2	24.2	38.6
	Gross Michel coco	28.3	180	126.8	3.0	0.6	18.7	28.9
	Average	35.0	86	179.4	2.6	0.4	20.3	35.1
2A	Africa 1	16.6	42	445.3	1.6	0.2	11.7	46.8
	Average	16.6	42	445.3	1.6	0.2	11.7	46.8
2B	Dominico-Hartón	11.3	62	291.2	3.3	0.2	12.1	23.8
	FHIA-01	41.7	163	228.3	2.8	0.2	21.2	37.7
	Orishelle	15.0	49	306.9	3.8	0.3	19.2	15.5
	FHIA-21	25.9	137	302.9	2.0	0.3	16.1	31.6
	Cachaco	11.9	104	219.3	2.1	0.2	12.8	21.9
	Average	21.2	103	269.7	2.8	0.2	16.3	26.1
2C	Dominico	17.4	103	173.2	5.2	0.3	16.3	30.1
	Pisang Mas	3.2	135	75.1	3.5	0.2	8.5	11.5
	Bocadillo	8.1	154	55.8	8.1	0.3	6.4	32.9
	Average	9.6	131	101.4	5.6	0.3	10.4	24.8
Group 2	Average	16.8	105	233.1	3.6	0.2	13.8	28.0
General average		**21.4**	**100**	**219.7**	**3.4**	**0.3**	**15.4**	**29.8**

DWB/TDWP, bunch dry weight/plant dry weight.

FHIA-03 were characterized by presenting the higher fresh weights of the bunches, as confirmed by the percentage of dry weight in said organ, distributed as dry material, with respect to the general average weight of the plants (Tab. 3).

Group 2 of Fig. 1 registered the highest average value for the variable dry weight of the corm, resulting in sub-group 2C with 5.6 kg; of this sub-group, the cultivars Bocadillo and Dominico presented the higher average values of 8.1 kg and 5.2 kg, respectively. The FHIA-01 hybrid, as in the FHIA-03 hybrid and Pelipita cultivar, obtained the higher values for fresh weight of the bunches. In contrast, they registered a low value for the dry weight of the corm with respect to the other cultivars; inferring that a large-sized corm does not necessarily indicate bunches of an equal proportion or vice versa.

For the SLA, the values were similar for all of the cultivars with a general average of 0.3 $m^2 g^{-1}$, with a notable result for group 1 with the variety Gross Michel coco 0.6 $m^2 g^{-1}$, a value that indicates that the leaves were slightly thicker and possessed more square centimeters of area per units of weight with respect to the others banana and plantain cultivars (Tab. 3).

The distribution of dry material in the bunches with respect to the plant (DWB/TDWP) presented the highest value in group 1 (35.1%). However, the Africa 1 material from sub-group 2A presented the highest individual value (46.8%). The diploid cultivar Bocadillo, which presented the lowest plant dry weight (6.4 kg), obtained a percentage of dry material distribution (32.9%) above the average of its group (28.0%) and the general average (29.8%) (Tab. 3).

The distribution of dry material (algometric ratio) is explained as a plant distributing assimilates to each of its organs. The dry material of the bunches represented 45.28% of the total aerial dry material of the plantain plants. For this reason, the pseudostem and root structures had to be sufficient sources to support the bunches (Cháves *et al.*, 2009). To achieve this, before flowering, plants direct half or more of the dry material towards the pseudostem and the leaves because the area in this part of the plant is highly capable of supporting large bunches; in order to produce this massive structure, plants produce dry material at a high rate, as seen among the tropical perennial cultivars (Rodríguez *et al.* 2012). At harvest, more than 80% of the dry material is in the rhizome (10%), pseudostem (32%), and bunch (44%) and less than 20% is in the leaves 44% (Cayón, 2004; Cháves *et al.*, 2009).

Among the plants, there are differences for the delivery of dry material. Therefore, it is important to know the method, such as the produced biomass distributed among the organs of the plant in order to compare the growth of each organ with respect to the growth of the total plant (Lacointe, 2000) and establish the physiological differences between the genotypes of a species.

Conclusions

The banana and plantain cultivars of the evaluated CMC, which includes diploid, triploid, and tetraploid materials, had a significant aggregated value from the dry biomass and fruit physiological parameters; notably the distribution of dry material in the bunches with respect to the plant (DWB/TDWP). The group 1 plantains Pelipita and FHIA-03 and banana Gros Michel coco reached values of 35.1% on average for the group. However, the Africa 1 material from group 2 demonstrated the highest individual value with 46.8%. Of the biomass and fruit physiological parameters, the variables related to biomass were the ones that contributed more to the differentiation of the genotypes through the contribution of a high percentage of the total accumulated variance of the studied variables. This study allowed for the evaluation and comparison of the principal promising banana and plantain clones for use as a basic tool in the selection programs of Musaceae germplasm related to agronomic and productive behaviors.

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