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Gas exchange and leaf area requirement in tall 'Prata' banana

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Abstract

The objective of this study was to evaluate the gas exchange and leaf area requirement for yield of six tall 'Prata' banana genotypes, under semi-arid conditions. The genotypes 'Pacovan' (AAB), 'Pacovan Ken' (AAAB), 'Preciosa' (AAAB), 'Japira' (AAAB), 'PV79-34' (AAAB) and 'Garantida' (AAAB) (four tetraploid hybrids and one triploid cultivar) were evaluated in two cycles, arranged in a completely randomized design in a factorial scheme, with five replicates and four usable plants per plot. For the physiological characteristics, a 6 x 12 x 2 factorial arrangement was adopted, with six genotypes, 12 evaluation periods and two reading times in each period, arranged in a completely randomized design. Of the 12 phytotechnical characteristics measured, seven were influenced by the interaction between the factors cultivar and cycle. Internal CO_2 concentration, net photosynthesis rate, instantaneous water use efficiency, carboxylation efficiency and quantum efficiency of photosynthesis recorded in banana leaves are higher in the morning, favored by higher stomatal conductance and lower leaf temperature resulting from the meteorological conditions, while transpiration and intrinsic water use efficiency increase in the afternoon. The hybrid 'PV79-34' has higher yield and production efficiency per unit of leaf area, associated with high transpiration, compared to the tall 'Prata' banana cultivars

Keywords: agronomic traits, genotypes, *Musa* spp., photosynthesis, water use efficiency

Introduction

In Brazil, 'Prata' banana cultivars are the most widespread, including 'Prata-Anã' and 'Pacovan', although the latter has a greater presence in the Northeast region. 'Pacovan' has problems with its tall stature and susceptibility to lodging, pseudostem breakage and diseases such as Fusarium wilt and Sigatokas (Rodrigues Filho et al., 2014).

In general, there is an inverse relationship between stature and yield in banana and regardless of the genomic group, shorter genotypes were more productive than taller genotypes (Donato et al., 2006). The effects of wind are more intense on taller cultivars, as the plant is more subject to undermining and rupture of roots, which reduces the absorption of water and nutrients, pseudostem breakage and lodging, to greater laceration of the leaf blade, which can reduce photosynthesis rates (Donato et al., 2021), and to acceleration of senescence and loss of leaves (Magalhães et al., 2020), which can leave the plant with insufficient leaf area to meet the functional requirement for economic yield.

In any case, environmental conditions that favor the reduction of leaf area affect photosynthesis and can reduce yield. Under these conditions, certain cultivars may have at flowering an insufficient amount of leaves to ensure economic yield. Thus, these cultivars would not have adequate environmental adaptation to these conditions, which can be verified by the evaluation of gas exchange and leaf area to yield ratio, because it is recommended to use cultivars with lower leaf area requirement per unit quantity of banana produced, which may suggest higher photosynthetic efficiency. This understanding is crucial for tall cultivars, more subject to the deleterious effects of wind.

Studies were conducted with tall 'Prata' cultivars (Azevedo et al., 2010; Rodrigues Filho et al., 2014), limited

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to agronomic characters. The objective was to evaluate the gas exchange and leaf area requirement for yield of tall 'Prata' banana genotypes.

Material And Methods

The experiment was set up in the area of the Federal Institute of Bahia, Campus of Guanambi, Bahia, Brazil, on May 11, 2010, and conducted until February 12, 2012. Physiological and phytotechnical readings were taken between November 2010 and October 2011. The soil, whose original classification is Latossolo Vermelho-Amarelo which corresponds to Oxisol (Santos et al., 2018), before the crop was planted, showed high fertility, improved by anthropic actions previously performed on the site (**Table 1**). The climate is hot and dry semi-arid, with an average annual temperature of 25.9 °C and average annual precipitation of 664.7 mm, referring to the average of the last 39 years.

Planting was carried out on 05/11/2010 with micropropagated seedlings at spacing of 3.0 x 2.5 m (equivalent to 1,333 plants ha^{-1}) and, along with the cultural practices, followed the recommendations for the crop. The plants were irrigated by microsprinkler, with Netafim® pressure-compensating emitters, with flow rate of 120 L h^{-1}, wetted diameter of 7.4 m, red nozzle of 1.57 mm, spacing of 6 m between lateral lines and 5 m between emitters. In addition to irrigation, banana plants received, by precipitation, 1,260.6 mm of water during the entire experimental period.

Table 1. Means of the chemical attributes of two composite samples of soil from the experimental area, before planting, Guanambi, BA, Brazil

Characteristics	0.0-0.20m	Standard deviation	0.20-0.40 m	Standard deviation
pH (H_2O)	7.60	0.14	7.60	0.57
P (mg dm^{-3})	318.15	157.47	185.80	21.78
K^+ (mg dm^{-3})	567.50	45.96	512.50	154.86
Na^+ ($cmol_c$ dm^{-3})	0.20	0.00	0.15	0.07
Ca^{2+} ($cmol_c$ dm^{-3})	3.45	0.49	2.90	0.00
Mg^{2+} ($cmol_c$ dm^{-3})	1.70	0.28	1.30	0.00
Al^{3+} ($cmol_c$ dm^{-3})	0.00	0.00	0.00	0.00
H^++Al^{3+}($cmol_c$$dm^{-3}$)	0.90	0.00	0.95	0.07
S.B.[1] ($cmol_c$ dm^{-3})	6.75	0.92	5.65	0.35
t [2] ($cmol_c$ dm^{-3})	6.75	0.92	5.65	0.35
T [3] ($cmol_c$ dm^{-3})	7.65	0.92	6.65	0.21
V[4] (%)	88.00	1.41	85.00	1.41
m[5] (%)	0.00	0.00	0.00	0.00
OM[6] (g dm^{-3})	13.50	21.0	10.00	14.00
B (mg dm^{-3})	0.85	0.07	0.75	0.07
Cu^{++} (mg dm^{-3})	1.05	0.21	0.85	0.21
Fe^{++} (mg dm^{-3})	11.85	2.33	11.35	3.46
Mn^{++} (mg dm^{-3})	48.95	3.75	40.70	11.60
Zn^{++} (mg dm^{-3})	24.25	4.31	13.30	2.40
Prem[7] (mg L^{-3})	42.15	0.92	41.40	3.68
EC[8] (dS m^{-1})	1.70	0.00	1.95	0.21

[1]Sum of bases; [2]Effective cation exchange capacity (effective CEC); [3]CEC at pH 7.0; [4]Base saturation; [5]Aluminum saturation; [6]Soil organic matter; [7]Remaining phosphorus; [8]Electrical conductivity. pH in water; OM - Colorimetry; P, K, Na, Cu, Fe, Mn, Zn - Mehlich-1 extractant; Ca, Mg and Al - 1 mol L^{-1} KCl extractant; H + Al - pH SMP; B - Hot water.

Irrigation was performed considering the reference evapotranspiration (ETo) determined daily by the Penman-Monteith method and the data collected from a Vantage Pro Integrated Sensor automatic weather station (Davis Instruments, Hayward, CA, USA) installed 100 m away from the experimental area. The crop coefficients for determining crop evapotranspiration (ETc) were defined based on the phenological stages of the crop, according to (Coelho et al., 2015).

The experimental design used was arranged in a completely randomized design, CRD, with 12 treatments resulting from the combination, in factorial, of six genotypes of tall 'Prata' banana with two production cycles. The evaluated genotypes were: 'Pacovan' (AAB), its hybrids 'Pacovan Ken', 'Preciosa', 'Japira', 'PV79-34' (AAAB), in addition to the hybrid 'Garantida' (AAAB), derived from 'Prata São Tomé', with five replicates and four usable plants per plot.

Regarding phytotechnical aspects, 12 characteristics were evaluated: mass of bunch (MB), mass of hands (MH) and mass of rachis (MRA), expressed in kg; number of hands (NH) and number of fruits (NFR); number of leaves at flowering (NLF) and at harvest (NLH); length (LL3) and width (WL3) of the third leaf, in cm; total leaf area (TLA) at flowering and at harvest, in m², estimated by the Eq.1 (Zucoloto et al., 2008)

$$TLA = 0.5187\ (L \times W \times N) + 9603.5 \qquad (1)$$

where:

L and W - respectively length and width of the third leaf;

0.5187 - correction factor;

N - number of active leaves of the plant at flowering and at harvest;

LAI - leaf area index,at flowering and at harvest, in m^2 m^{-2};

LAF/MB - ratio between leaf area at flowering and mass of bunch, in m^2 kg^{-1};

LAF/MH - ratio between leaf area at flowering and mass of hands, in m^2 kg^{-1};

LAF/NH - ratio between leaf area at flowering and number of hands, in m^2 per hand;

LAH/MB - ratio between leaf area at harvest and mass of bunch, in m^2 kg^{-1};

LAH/MH - ratio between leaf area at harvest and mass of hands, in m^2 kg^{-1};

LAH/NH - ratio between leaf area at harvest and number of hands, in m^2 per hand;

LAF/NFR - ratio between leaf area at flowering and number of fruits, in m^2 per fruit; and,

LAH/NFR - ratio between leaf area at harvest and number of fruits, in m^2 per fruit.

Ten physiological parameters were also evaluated: incident radiation on the leaf (Q_{Leaf}) expressed in μmol photons m^{-2} s^{-1}; internal CO_2 concentration (C_i), in μmol CO_2 mol^{-1}; leaf temperature (T_{Leaf}), in °C; stomatal conductance (g_s), in mol H_2O m^{-2} s^{-1}; transpiration (E), in mmol H_2O m^{-2} s^{-1}; net photosynthesis (A), in μmol CO_2 m^{-2} s^{-1}; instantaneous water use efficiency (A/E), in μmol CO_2 m^{-2} s^{-1} $mmol^{-1}$ H_2O m^{-2} s^{-1}; carboxylation efficiency (A/C_i), in μmol CO_2 m^{-2} s^{-1} $μmol^{-1}$ CO_2 mol^{-1}; quantum or photochemical efficiency of photosynthesis (A/Q_{Leaf}), in μmol CO_2 m^{-2} s^{-1} $μmol^{-1}$ photons m^{-2} s^{-1}; and intrinsic water use efficiency (A/g_s), in μmol CO_2 m^{-2} s^{-1} mol^{-1} H_2O m^{-2} s^{-1}.

Gas exchange in the banana plants was evaluated using the third or fourth leaf, counting from the apex to the base (Arantes et al., 2018), using an LCpro+ ® Portable Photosynthesis System (ADC BioScientific Limited, UK) infrared gas analyzer (IRGA), with ambient temperature and irradiance and airflow of 200 mL min^{-1}, under natural light (without IRGA programming), always with the radiation shield facing the sun. 12 monthly evaluations were carried out, encompassing the period from November 2010 to October 2011, at two reading times, 8:00 and 14:00 h.

For statistical analyses of the data of the evaluated characteristics, the following procedure was adopted: a) For phytotechnical characteristics, there was a total of 12 treatments, formed by the combination in factorial of six genotypes and two production cycles, arranged in a randomized block design (RBD). The data showed normality by the Lilliefors test and were subjected to analysis of variance (ANOVA) at 0.05 significance level. In cases of significant interactions between the factors genotypes and cycles, these interactions were decomposed, with the comparison of genotypes within the cycles by the Skott-Knott criterion ($p \leq 0.05$) and the comparison of cycles within genotypes by the F test ($p \leq 0.05$). In the absence of interactions, the effects of the main factors were studied with the comparison of means between genotypes by the Skott-Knott criterion ($p \leq 0.05$) and the comparison of means between cycles by the F test ($p \leq 0.05$), using the statistical program SISVAR - UFLA, version 5.6. b). Regarding the physiological parameters, the adopted arrangement was in factorial scheme, 6 x 12 x 2, referring to the six genotypes, 12 evaluation periods (months) and two reading times (8:00 and 14:00 h) in each period. The treatments were arranged in RBD. The data were subjected to the Lilliefors test and did not show normality, that is, they did not have normal distribution, so nonparametric Wilcoxon test (for paired samples), evaluation times, and Kruskal-Wallis test (for independent samples), cultivars and evaluation times were applied, considering p value ≤ 0.05 as statistically significant. These analyses were performed using the statistical program SAEG - UFV, version 9.1.

Results and Discussion

All phytotechnical characteristics measured in the study showed normal distribution and, therefore, were subjected to analysis of variance (**Table 2**).

Table 2. Summary of the analyses of variance, with the respective mean squares, means and coefficients of variation of phytotechnical characteristics evaluated at flowering and at harvest in two production cycles, in tall 'Prata' banana plants. Guanambi, BA, Brazil

	Sources of variation				Means	CV (%)
	Genotypes (A)	Cycles (B)	Interaction (AxB)	Residual		
Degrees of freedom	5	1	5	48		
MB	82.09**	71.59**	6.95 ns	3.99	17.89kg	11.16
MH	64.58**	39.19**	4.60 ns	3.36	15.52kg	11.82
NH	7.64**	2.08**	0.54 ns	0.23	7.9 unit	6.1
NFR	1605.14**	1898.43**	247.07**	66.95	113.37 unit	7.22
LAF/MB	0.10**	0.006ns	0.02 ns	0.02	0.78 m^2 kg^{-1}	20.33
LAH/MB	1.065**	0.00019ns	0.013*	0.009	0.52 m^2 kg^{-1}	18.58
LAF/MH	0.015**	0.0014ns	0.037 ns	0.043	0.90 m^2 kg^{-1}	20.79
LAH/MH	1.092**	0.0003ns	0.017 ns	0.012	0.60 m^2 kg^{-1}	18.52
LAF/NH	0.375**	0.878**	0.125 ns	0.078	1.73m^2 per hand	16.19
LAH/NH	0.265**	0.485**	0.091*	0.032	1.16m^2 per hand	15.46
LAF/NFR	0.0013**	0.0081**	0.0009*	0.0003	0.12m^2 per hand	16.20
LAH/NFR	0.0010**	0.0043**	0.0006**	0.0001	0.08m^2 per hand	15.74

The analysis of variance showed that the characteristics number of fruits (NFR), ratio between leaf area at flowering and number of fruits (LAF/NFR) and ratios between leaf area at harvest and mass of bunch (LAH/MB), number of hands (LAH/NH) and number of fruits (LAH/NFR), measured in tall 'Prata' banana plants, were significantly influenced ($p \leq 0.05$) by the interaction between the factors genotype and cycle. Mass of bunch (MB), mass of hands (MH), number of hands (NH) and ratio between leaf area at flowering and number of hands (LAF/NH) varied independently with genotypes and cycles ($p \leq 0.05$), while the ratios between leaf area at flowering and mass of bunch (LAF/MB) and mass of hands (LAF/MH), as well as the ratio between leaf area at harvest and mass of hands (LAH/MH) varied independently only with genotypes.

Regarding the NFR produced by the banana plants, the genotype 'PV79-34' had the highest means, while the lowest values were observed in 'Garantida', in the two production cycles (**Table 3**). (Azevedo et al., 2010) also found a higher number of fruits for 'PV79-34' in Sebastião Laranjeiras, BA, a region with characteristics similar to those of the present study, but with lower wind speed.

Table 3. Phytotechnical characteristics evaluated at flowering and at harvest, in two production cycles, in genotypes of tall 'Prata' banana. Guanambi, BA, Brazil

	Characteristics									
	NFR (unit)		LAH/MB (m^2 kg^{-1})		LAH/NH (m^2 per hand)		LAF/NFR (m^2 per fruit)		LAH/NFR (m^2 per fruit)	
Genotypes	1st cycle	2nd cycle	1st cycle	2nd cycle	1st cycle	2nd cycle	1st cycle	2nd cycle	1st cycle	2nd cycle
Garantida	87.80 Cb	101.05 Ba	0.63 Aa	0.56 Ab	1.34 Aa	0.90 Bb	0.14 Ba	0.11 Ab	0.10 Aa	0.07 Bb
Japira	105.20 Ba	114.47 Aa	0.49 Ba	0.54 Aa	1.28 Aa	1.16 Aa	0.13 Ba	0.12 Aa	0.09 Ba	0.08 Aa
PV79-34	135.75 Aa	131.73 Aa	0.35 CB	0.44 Ba	0.87 Ba	0.91 Ba	0.10 Ca	0.10 Aa	0.06 Ca	0.06 Ba
Pacovan Ken	104.70 Bb	124.53 Aa	0.64 Aa	0.58 Aa	1.52 Aa	1.20 Ab	0.16 Aa	0.10 Ab	0.11 Aa	0.08 Ab
Preciosa	99.40 Bb	122.85 Aa	0.49 Ba	0.45Ba	1.24 Aa	0.96 Bb	0.14 Ba	0.11 Ab	0.09 Ba	0.06 Bb
Pacovan	113.60 Ba	119.32 Aa	0.49 Ba	0.55 Aa	1.25 Aa	1.28 Aa	0.13 Ba	0.13 Aa	0.09 Ba	0.09 Aa
CV (%)	7.22		18.59		15.46		16.20		15.74	
Mean	113.37		0.52		1.16		0.12		0.08	

†Means followed by the same uppercase letters in the columns for genotypes belong to the same grouping by the Scott-Knott criterion at 0.05 significance level, and means followed by the same lowercase letters in the rows for cycles do not differ from each other by the F test at 0.05 significance level; NFR - Number of fruits; LAH/MB - Ratio between leaf area at harvest and mass of bunch; LAH/NH - Ratio between leaf area at harvest and number of hands; LAF/NFR - Ratio between leaf area at flowering and number of fruits; LAH/NFR - Ratio between leaf area at harvest and number of fruits; CV - Coefficient of Variation.

The lowest values for LAH/MB were observed in the genotype 'PV79-34' in the first cycle (0.35 m^2 kg^{-1}) and in 'PV79-34' (0.44 m^2 kg^{-1}), followed by 'Preciosa' (0.45 m^2 kg^{-1}) in the second cycle. On the other hand, the highest values were observed in 'Garantida' and 'Pacovan Ken', which formed the same grouping in the first cycle, while 'Pacovan Ken', 'Pacovan', 'Japira' and 'Garantida' were grouped in the second cycle (Table 3).

The lowest values for LAH/NH were observed in 'PV79-34' in the first cycle and in the group formed by 'Garantida', 'PV79-34' and 'Preciosa' in the second cycle (Table 3). In the first cycle, the genotypes 'Pacovan Ken', 'Garantida', 'Japira', 'Pacovan' and 'Preciosa' were grouped together, with the highest values, while in the second cycle, this group was formed by 'Pacovan', 'Pacovan Ken' and 'Japira'.

For LAH/NFR, 'PV79-34' had the lowest means in the first cycle, while in the second cycle it formed a group with 'Garantida' and 'Preciosa'. The group formed by the cultivars 'Pacovan Ken' and 'Garantida' had the highest values for LAH/NFR in the first cycle. In general, the analysis of interactions between genotypes and cycles (Table 3) indicate that the hybrid 'PV79-34' has higher production efficiency, because it showed higher yield, represented by the number of fruits, corroborating (Azevedo et al., 2010), and requires smaller leaf area for yield, expressed by mass of bunch, number of hands and number of fruits, which attests to greater environmental adaptability for conditions that contribute to reduction of leaf area, such as predominance of winds (Donato et al., 2021) and pathogens that cause leaf diseases.

For LAF/NFR, the lowest values were recorded in 'PV79-34', while the cultivar 'Pacovan Ken' had the highest values, and the others formed an intermediate group (Table 3). In the second cycle, the genotypes were similar, forming a single group for this variable. It is worth pointing out that the cultivar 'PV79-34' recorded not only the lowest values for LAF/NFR in the first cycle, but also low values for LAH/MB, LAH/NH and LAH/NFR in both cycles (Table 3), which attests to its higher production efficiency when compared to the other tall 'Prata' banana cultivars studied. This is crucial for cultivation in regions with high wind speed (Donato et al., 2021).

Despite the higher yield and production efficiency per leaf area unit of the hybrid 'PV79-34', compared to the tall 'Prata' banana cultivars studied (Table 3 and **Table 4**), in addition to its shorter stature, higher vigor and higher yield (Azevedo et al., 2010), as well as resistance to yellow Sigatoka, this banana hybrid is susceptible to the fungus *Fusarium oxyporum* f. sp. *cubense*, which causes

Table 4. Phytotechnical characteristics evaluated at flowering and at harvest in tall 'prata' banana plants. Guanambi, ba, Brazil

genotypes	characteristics						
	mb (kg)	mh (kg)	nh (unit)	laf/mb (m^2 kg^{-1})	laf/mh (m^2 kg^{-1})	lah/mh (m^2 kg^{-1})	laf/nh (m^2 per hand)
garantida	13.24 d	11.19 c	7.07 c	0.90 a	1.06 a	0.70 a	1.66 b
japira	17.92 c	15.70 b	7.53 b	0.76 a	0.86 a	0.59 b	1.77 a
pv79-34	21.85 a	18.77 a	9.57 a	0.61 b	0.71 b	0.46 c	1.39 b
pacovan ken	17.13 c	14.92 b	7.68 b	0.88 a	1.01 a	0.70 a	1.94 a
preciosa	17.91 c	15.40 b	7.55 b	0.76 a	0.87 a	0.54 b	1.77 a
pacovan	19.63 b	17.11 a	8.02 b	0.76 a	0.88 a	0.60 b	1.86 a
cv (%)	11.16	11.82	6.10	20.33	20.79	18.52	16.19
mean	17.89	15.12	7.90	0.78	0.90	0.60	1.73

[1]means followed by the same letter in the columns belong to the same grouping by the scott-knott criterion at 0.05 significance level. mb - mass of bunch; mh - mass of hands; nh - number of hands; laf/mb - ratio between leaf area at flowering and mass of bunch; laf/mh - ratio between leaf area at flowering and mass of hands; lah/mh - ratio between leaf area at harvest and mass of hands; laf/nh - ratio between leaf area at flowering and number of hands; cv - coefficient of variation.

fusariosis (Rodrigues Filho et al., 2014). These aspects make it difficult for researchers to indicate or recommend the hybrid for plantations in the region by banana growers.

The tall 'Prata' banana plants had higher mass of bunch, mass of hands and ratio between leaf area at flowering and number of hands in the first cycle, compared to the second cycle, with a percentage variation of 13, 11 and 14.9%, respectively (**Figure 1**.). Increase in yield in the second cycle would be expected, which does not occur in tall varieties, as they are greatly influenced by the high wind speed in this region (Rodrigues Filho et al., 2014).

The data of physiological characteristics did not show normal distribution and were, therefore, subjected to nonparametric analyses (**Table 5**, **Table 6** and **Table 7**). It was possible to observe, through the Kruskal-Wallis test

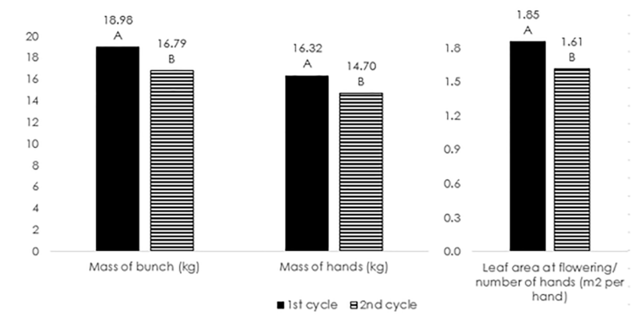

Figure 1. Phytotechnical characteristics evaluated at flowering and at harvest in two production cycles, in tall 'Prata' banana plants. Guanambi, BA, Brazil.

Table 5. Physiological characteristics evaluated in the third leaf of tall 'Prata' banana plants. Guanambi, BA, Brazil

Genotypes	Characteristics		
	T_{Leaf} (°C)	E (mmol H_2O m^{-2} s^{-1})	A/E ((μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1}) $^{-1}$)
Japira	35.9 C	5.5 B	3.4 A
Garantida	37.0 BC	6.3 AB	3.0 AB
PV79-34	38.0 AB	7.0 A	2.6 BC
Preciosa	38.1 AB	6.6 A	2.6 BC
Pacovan	38.1 AB	6.9 A	2.6 BC
Pacovan Ken	38.6 A	6.7 A	2.5 C
Mean	37.6	6.5	2.8
CV (%)	10.54	36.64	41.77

Means followed by uppercase letters in columns for genotypes do not differ significantly by Kruskal-Wallis test at 0.05 significance level. T_{Leaf} - Leaf temperature; E - Transpiration; A/E - Instantaneous water use efficiency; CV - Coefficient of variation

at 0.05 significance level, significant variations among the tall 'Prata' banana genotypes for leaf temperature (T_{Leaf}), transpiration (E) and instantaneous water use efficiency (A/E) (Table 5) and between evaluation periods (months) for incident radiation on the leaf (Q_{Leaf}), leaf temperature (T_{Leaf}), internal CO_2 concentration (C_i), transpiration (E), stomatal conductance (g_s), net photosynthesis (A), instantaneous water use efficiency (A/E), quantum or photochemical efficiency of photosynthesis (A/Q_{Leaf}), carboxylation efficiency (A/C_i) and intrinsic water use efficiency (A/g_s) (Table 5). In addition, for these same variables, except Q_{Leaf}, variation between reading times was found by Wilcoxon test at 0.05 significance level (Table 6).

The cultivar 'Pacovan Ken' had the highest T_{Leaf}, 38.6 °C, while 'Japira' had the lowest value, 35.9 °C (Table 5). According to Table 6, there was an increase in T_{Leaf} from 34.9 °C, recorded at 8:00 h, to 40.3 °C at 14:00 h, due to the increase in air temperature, which caused an increase of E, from 5.9 to 7.16 mmol H_2O m^{-2} s^{-1}, and a decrease in A/E, from 3.6 to 2.0 µmol CO_2 m^{-2} s^{-1} $mmol^{-1}$ H_2O m^{-2} s^{-1}. This

Table 6. Physiological characteristics evaluated in the third leaf of tall 'Prata' banana plants, in different periods. Guanambi, BA, Brazil

Char.	Month / year												Mean	CV (%)
	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun	Jul	Aug	Sep	Oct		
Q_{Leaf}	1417 B	1155 CD	1542 AB	1614 A	1408 B	1095 CD	1323 C	1530 AB	1323 C	1422 B	1020 D	945 D	1288	37.76
T_{Leaf}	40.6 A	39.8 A	40.4 A	38.1 AB	38.2 AB	37.7 AB	37.3 B	35.3 C	36.9 BC	34.2 C	36.3 BC	37.1 B	37.6	10.54
C_i	205.8 C	216.4 BC	215.7 BC	217.0 BC	210.3 C	227.3 AB	223.4 AB	220.6 B	217.7 BC	212.5 BC	211.8 BC	231.7 A	218.6	8.33
E	8.6 A	6.6 BC	8.5 A	5.1 C	6.1 BC	6.2 BC	4.7 C	6.4 BC	6.3 BC	5.8 BC	6.4 B	6.9 B	6.5	36.64
g_s	0.3 B	0.2 BC	0.4 AB	0.2 C	0.3 B	0.4 A	0.3 BC	0.4 AB	0.3 B	0.4 AB	0.4 AB	0.4 AB	0.3	52.63
A	18.0 AB	15.1 B	18.1 AB	12.5 B	16.1 B	19.1 AB	12.9 B	18.9 AB	16.1 B	20.2 A	19.4 AB	18.5 AB	17.2	35.46
A/E	2.2 C	2.4 BC	2.3 C	2.8 BC	2.7 BC	3.4 AB	2.6 BC	3.1 AB	2.6 BC	3.75 A	2.9 AB	2.8 B	2.8	41.77
A/Q_{Leaf}	0.013 C	0.015 BC	0.012 CD	0.008 D	0.013 C	0.021 B	0.012 CD	0.013 C	0.013 C	0.014 BC	0.053 A	0.040 A	0.020	154.92
A/C_i	0.087 B	0.072 C	0.084 B	0.059 D	0.077 C	0.085 B	0.058 D	0.086 C	0.073 C	0.09 A	0.0914 A	0.080 BC	0.079	3612
A/g_s	54.7 AB	59.2 A	45.9 BC	55.5 AB	53.9 AB	40.3 C	52.5 AB	48.4 B	51.6 AB	53.15 AB	45.0 BC	50.6 B	50.6	25.49

Means followed by uppercase letters in columns for months do not differ significantly by the Kruskal-Wallis test at 0.05 significance level. Char. – characteristics; Q_{Leaf} - Incident radiation on the leaf (μmol photons $m^{-2} s^{-1}$); T_{Leaf} - leaf temperature (°C); C_i - Internal CO_2 concentration (μmol CO_2 mol^{-1}); E – Transpiration (mmol H_2O $m^{-2} s^{-1}$); g_s - Stomatal conductance (mol H_2O $m^{-2} s^{-1}$); A - Net photosynthesis (μmol CO_2 $m^{-2} s^{-1}$); A/E - Instantaneous water use efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(mmol H_2O $m^{-2} s^{-1}$)$^{-1}$); A/Q_{Leaf} - quantum or photochemical efficiency of photosynthesis ((μmol CO_2 $m^{-2} s^{-1}$)(μmol photons $m^{-2} s^{-1}$)$^{-1}$); A/Ci - carboxylation efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(μmol CO_2 mol^{-1})$^{-1}$); A/g_s - Intrinsic water use efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(mol H_2O $m^{-2} s^{-1}$)$^{-1}$); CV - Coefficient of variation.

Table 7. Physiological characteristics evaluated in the third leaf of tall 'Prata' banana plants, at different times. Guanambi, BA, Brazil

Char.	Times		Mean	CV	Δ (08:00-14:00)
	08:00 h	14:00 h		(%)	(%)
T_{Leaf}	34.9 B	40.3 A	37.6	10.54	15.23
C_i	221.5 A	215.7 B	218.6	8.33	-2.59
E	5.9 B	7.1 A	6.5	36.64	20.54
g_s	0.4 A	0.2 B	0.3	53.42	-41.67
A	20.6 A	13.8 B	17.2	35.46	-33.04
A/E	3.6 A	2.0 B	2.8	41.77	-45.50
A/C_i	0.02 A	0.02 B	0.020	154.92	-4.76
A/Q_{Leaf}	0.09 A	0.06 B	0.079	36.12	-32.29
A/g_s	47.1 B	54.2 A	50.6	25.49	14.98

Means followed by the letter A had higher values and means followed by the letter B had lower values, and differ significantly at 0.01 and 0.05 significance levels by the Wilcoxon test. Char. – characteristics; T_{Leaf} - Leaf temperature (°C); C_i - Internal CO_2 concentration (μmol CO_2 mol^{-1}); E - Transpiration (mmol H_2O $m^{-2} s^{-1}$); g_s - Stomatal conductance (mol H_2O $m^{-2} s^{-1}$); A - Net photosynthesis (μmol CO_2 $m^{-2} s^{-1}$); A/E - Instantaneous water use efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(mmol H_2O $m^{-2} s^{-1}$)$^{-1}$); A/Q_{Leaf} - Quantum or photochemical efficiency of photosynthesis (μmol CO_2 $m^{-2} s^{-1}$)(μmol photons $m^{-2} s^{-1}$)$^{-1}$); A/C_i - Carboxylation efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(μmol CO_2 mol^{-1})$^{-1}$); A/g_s - Intrinsic water use efficiency ((μmol CO_2 $m^{-2} s^{-1}$)(mol H_2O $m^{-2} s^{-1}$)$^{-1}$); Δ(08:00-14:00), represents the percentage variation of the physiological variable, when compared to the measurements performed at 08:00 and 14:00 h; (-) - Represents decreases; and, (+) - Represents increases. CV - Coefficient of variation.

mechanism is performed by the banana favored by the moisture in the soil from irrigation and aims at cooling the plant to reduce thermal stress (Arantes et al., 2018), even under lower g_s.

Transpiration (E) was higher in four genotypes, namely 'PV79-34', 'Pacovan', 'Pacovan Ken' and 'Preciosa', and lower in the cultivar 'Japira' (Table 5). November (2010) and January (2011) were the months that led the cultivars to show the highest values for E, while the lowest means were verified in February and May 2011 (Table 6). It was observed that the banana plants showed the highest means of E in the afternoon, at 14:00 h and the lowest means at 8:00 h (Table 7).

The cultivar 'Japira' was the most efficient for water use (A/E), compared to 'Pacovan Ken', 'Pacovan', 'Preciosa' and 'PV79-34' (Table 6). The highest means for A/E were recorded in the banana plants in August (2011), with 3.7 ((μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$), while the lowest means were found in November (2010) and January (2011) (Table 6). The highest rate of A/E was observed in the morning, at 8:00 h, while the lowest rate was observed at 14 hours (Table 7).

Despite the lower water use efficiency, indicating higher water consumption per mol of fixed carbon, the high transpiration rate of the hybrid 'PV79-34' (Table 6) suggests greater cell turgor, defense against thermal stress, and is associated with its higher vigor (Azevedo et al., 2010), which corroborates the higher yield and production efficiency per leaf area unit discussed previously. However, (Ramos et al., 2018) recorded higher yield in the 'Maçã' cultivar with higher photosynthetic rate and higher A/E. The best way to obtain maximum A/E values is by establishing a good ratio between maximum CO_2 absorption and minimal H_2O loss, which is obtained when the stomata are partially closed, promoting better use of water by the plant; however, open stomata may contribute to higher yield.

The banana plants showed significant variation in A/E between the months (Table 6) and times evaluated (Table 7). In April, they showed the highest value for A/E, 5.3 μmol CO_2 m^{-2} s^{-1} $mmol^{-1}$$H_2O$ m^{-2} s^{-1}, similar to that recorded in September, while the lowest value was observed in July, 2.5 μmol CO_2 m^{-2} s^{-1} $mmol^{-1}$ H_2O m^{-2} s^{-1}, similar to those recorded in February, March, August and October (Table 6). Between reading times, A/E decreased 34.58% from 8:00 to 14:00 h, indicating a strong reduction in the photosynthesis rate, due to the increase in transpiration (Table 5), corroborating the results found by (Arantes et al., 2016), (Ramos et al., 2018) and (Coelho et al., 2019).

The physiological behavior of banana varies with climatic conditions. In the semi-arid region of Bahia, the seasons are well defined, with hot and rainy summer and cold and dry winter. In the spring, November and December, with higher precipitation and higher humidity, associated with high air temperatures and high VPDair, the Q_{Leaf} of the banana plants showed intermediate values, 1.417 and 1.155 μmol photons m^{-2} s^{-1}, respectively, while the T_{Leaf} showed higher values, 40.6 and 39.8 °C, respectively (Table 6). According to (Turner et al., 2007), the photosynthetically active radiation recommended for banana is between 1.500 and 2.000 μmol photons m^{-2} s^{-1}, with drastic reduction of photosynthesis when it is below 1.000 μmol photons m^{-2} s^{-1}.

The association of climatic conditions in November and December caused the banana plants to show a similar physiological behavior, except for transpiration (E), which had higher values in November (8.6 mmol H_2O m^{-2} s^{-1}) and lower values in December (6.9 mmol H_2O m^{-2} s^{-1}).

In summer, months with records of minimum precipitation higher than 50 mm, high air temperatures and relative humidity and lower VPDair, the highest mean of Q_{Leaf} was recorded in the banana plants in February, 1,614 μmol photons m^{-2} s^{-1}, while the lowest mean was found in March, 1,408 μmol photons m^{-2} s^{-1} (Table 6). This period was characterized by the record of the highest values of T_{Leaf} and lowest values of C_i. Despite the similarities, compared by the Kruskal-Walli's test, between A/E, A/Q_{Leaf} and A, the latter showed a percentage variation of 45.12% from the lowest absolute value in February (12.5 μmol CO_2 m^{-2} s^{-1}) to the highest value in January (18.1 μmol CO_2 m^{-2} s^{-1}). Transpiration rates were higher in January (8.6 mmol H_2O m^{-2} s^{-1}), while A/g_s was lower ((45.9 μmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1})$^{-1}$). The banana plants showed lower g_s (0.2 mol H_2O m^{-2} s^{-1}) in February compared to the other months of the season.

In autumn, with precipitation recorded only in May, intermediate air relative humidity and temperatures and lower VPDair, the Q_{Leaf} recorded in June was higher (1,530 μmol photons m^{-2} s^{-1}) compared to the other months of the season, while leaf temperature was lower (35.3 °C). Despite the similarities indicated by the statistical test for C_i, E, A, A/E and A/Q_{Leaf}, the parameter g_s was higher in April (0.49 mol H_2O m^{-2} s^{-1}) and lower in May (0.30 mol H_2O m^{-2} s^{-1}), month that the banana plants also had lower carboxylation efficiency ((0.058 μmol CO_2 m^{-2} s^{-1})(μmol CO_2 mol^{-1})$^{-1}$) and higher intrinsic water use efficiency ((52.5 μmol CO_2 m^{-2} s^{-1})(mol H_2O m^{-2} s^{-1}) $^{-1}$).

In the period comprising the winter, characterized by the absence of precipitation, mild temperatures and lower relative humidity and intermediate values of VPDair, the banana plants showed similar values of T_{Leaf}, C_i, E and g_s. A and A/E rates were highest in August ((20.2 μmol CO_2 m^{-2} s^{-1}) and (3.7 μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$), respectively, and lowest in July ((16.1 μmol CO_2 m^{-2} s^{-1}) and ((2.6 μmol CO_2 m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$), respectively. The A/Q_{Leaf} recorded in the banana plants was highest in September ((0.053 μmol CO_2 m^{-2} s^{-1}) (μmol photons m^{-2} s^{-1})$^{-1}$), while A/g_s was lowest ((45.0 μmol CO_2 m^{-2} s^{-1}) (mol H_2O m^{-2} s^{-1})$^{-1}$). Measurements of A/C_i in the banana plants in winter recorded highest values in August and September, 0.095 ((μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 mol^{-1})$^{-1}$) and 0.091 ((μmol CO_2 m^{-2} s^{-1}) (μmol CO_2 mol^{-1})$^{-1}$), respectively.

The gas exchange measured in the tall 'Prata' banana plants differed between reading times (Table 7). Radiation quality, higher relative humidity and lower air temperature, as well as lower VPDair at 8:00 h, compared to 14:00 h, allowed greater thermal comfort for the banana plants, which showed lower values of leaf temperature, 34.9 and 40.3 °C, respectively, higher C_i, probably due to higher g_s, higher rates of A, which shows the higher interference of g_s and translates into a value 41.67% higher at 8:00 h, differently from the lower rates of E, which point to lower interference of g_s, and higher A/E, A/Q_{Leaf} and A/C_i. Environmental conditions in the afternoon required 20.54% higher transpiration rates in the banana plants, for maintenance of water status and turgor pressure, as well as for cooling (Marques et al., 2018; Rodrigues Filho et al., 2020). Associated with the reduction of around 33.04% in the net photosynthesis rate, the water use efficiency was lower in this period, with a reduction of 45.40%. The decrease in photosynthesis in this case is more associated with the stomatal factor, because the reduction in carboxylation efficiency was only 4.76%, unlike the results reported by (Donato et al., 2021), who found a decrease of 47.05% in A/C_i, when the temperature increased by 10.2 °C, ranging from 30.2 °C, a temperature close to optimal for photosynthesis in the banana crop (Robinson & Saúco, 2012), at 8:00 h to 40.4 °C at 14:00 h, which points to another enzymatic problem, with increase in oxygenase activity in RuBisCO, while in the present study the leaf temperature ranged from 34.9 to 40.3 °C.

Also associated with this, the morning period favors the photosynthetic process due to the predominance, at 8:00 h, of radiation with wavelength within the red and far-red range, with better effect on photosynthesis, while the predominant radiation from 10:00 h can cause photoinhibition, because of the higher energy (Donato et al., 2021).

It is recurrent in the local semi-arid region to record increase in temperature combined with low relative humidity, conditions that result in high vapor pressure deficit in the atmosphere, observed mainly in the months of September, October and February (Donato et al., 2015; 2021). These conditions cause the increase in evapotranspiration demand, affecting all metabolic and physiological processes of the plant, which is proven by variations in the physiological characteristics of banana plants influenced by evaluation periods (Table 6) and reading times (Table 7).

The amount of carbon dioxide (CO_2) in the environment determines the internal concentration of this gas in the plant, which in turn moves from the most to the least concentrated medium, by diffusion, regulated by the opening and closing of the stomata, being also a factor that influences stomatal closure (Arantes et al., 2016). The photosynthesis is favored by higher C_i, whereas low values can alter the activity of the RuBisCO enzyme from carboxylase to oxygenase, causing increased photorespiration and decreased net photosynthesis.

Water relations and gas exchange are directly related because the movement of opening and closing of stomata is the main mechanism of control of gas exchange in higher plants, which are influenced by climatic conditions (Taiz et al., 2017). Thus, the recorded values may be associated with the oscillations in accumulated solar radiation and air temperature, as well as variations in relative air humidity and precipitation along the experimental period. Transpiration and drought avoidance pattern varies with genotype (Eyland et al., 2022), photosynthesis rates can increase with changes in planting density and arrangement (Barrera-Violeth et al., 2020), and transpiration rates and leaf temperature can be maintained with changes irrigation shift and irrigation system settings as they influence changes in leaf angle (Lage et al., 2020). These changes in management improve canopy environmental conditions, gas exchange and water relations

A high photosynthesis rate, in most cases, is due to the increase in g_s, which allows greater absorption and consequent fixation of carbon dioxide (Taiz et al., 2017), justifying the values of photosynthesis recorded in the morning in the present study, because the temperature was already out of the optimal range for photosynthesis in banana (Robisnon & Galán Saúco, 2012). Although (Eyland et al., 2021) argue that the dominant photosynthesis limiting factor was the diffusional limitation associated with gs kinetics, under diurnally fluctuating light conditions the impact of gs speediness on A and intrinsic water use efficiency depended on time of day, with a setback in kinetics during the afternoon. According to (Gago et al., 2020), leaf photosynthesis is dependent on CO_2 availability at the carboxylation sites and is, therefore, strongly influenced by g_s. A/g_s showed a slight increase of 6.35% from 8:00 to 14:00 h, illustrating a gain in photosynthetic efficiency with the reduction of g_s and being little affected by temperature.

A/Q_{Leaf} is a characteristic that assesses plant efficiency in converting sunlight into energy (ATP). In the present study, the A/Q_{Leaf} recorded in banana leaves at the different times decreased by 32.22% from 8:00 to 14:00 h (Table 7).

Conclusions

1. The internal CO_2 concentration, net photosynthesis rate, instantaneous water use efficiency, carboxylation efficiency and quantum efficiency of photosynthesis, recorded in the banana leaves, are higher in the morning, favored by the higher stomatal conductance and lower leaf temperature resulting from the meteorological conditions, while transpiration and intrinsic water use efficiency increase in the afternoon period.
2. The hybrid 'PV79-34' has higher yield and production efficiency per leaf area unit, associated with high transpiration, compared to the tall 'Prata' banana cultivars studied.

References

Arantes, A.M., Donato, S.L.R., Siqueira, D.L., Coelho, E.F., Silva, T.S. 2016. Gas exchange in different varieties of banana prata in semi-arid environment. *Revista Brasileira de Fruticultura* 38: e-600.

Arantes, A.M., Donato, S.L.R., Siqueira, D.L., Coelho, E.F. 2018. Gas exchange in 'Pome' banana plants grown under different irrigation systems. *Engenharia Agrícola* 38: 197-207.

Azevedo, V.F., Donato, S.L.R., Arantes, A.M., Maia, V.M., Silva, S.O. 2010. Avaliação de bananeiras tipo Prata, de porte alto, no Semiárido. *Ciência e Agrotecnologia* 34: 1372-1380.

Barrera-Violeth, J.L., Cartagena-Valenzuela, J.R., Nanclares-Gómez, O.A. 2020. Estimation of physiological parameters on high density plantations and population arrangements of *Musa* AAA Simmonds. *Revista Colombiana de Ciencias Hortícolas* 14: 342-354.

Coelho, E.F., Santos, M.R., Donato, S.L.R, Cruz, J.L., Oliveira, P.M., Castricini, A. 2019. Soil-water-plant relationship and fruit yield under partial root-zone drying irrigation on banana crop. *Scientia Agricola* 76: 362-367.

Coelho, E.F., Silva, A.J.P., Donato, S.L.R., Santana Júnior, E.B., Oliveira, P.M. 2015. Sistemas de irrigação localizada e manejo de água em bananeira. *Informe Agropecuário* 36: 62-73.

Donato, S.L.R., Brito, C.F.B., Fonseca, V.A., Sônego, M., Marques, P.R.R., Santos, M.R., Arantes, A.M., Lichtemberg, L.A. 2021. Aspectos da ecofisiologia, fenologia e produção: In: Donato, SL.R., Borém, A., Rodrigues, M.G.V. *Banana: do plantio à colheita*. Epamig, Belo Horizonte, Brasil. 235 p.

Donato, S.L.R., Coelho, E.F., Santos, M.R., Arantes, A.M., Rodrigues, M.G.V. 2015. Eficiência de uso da água em bananeira. *Informe Agropecuário* 36: 46-61.

Donato, S.L.R., Silva, S.O., Lucca Filho, O.A., Lima, M.B., Domingues, H., Alves, J.S. 2006. Correlações entre caracteres da planta e do cacho em bananeira (*Musa* spp.). *Ciência e Agrotecnologia* 30: 21-30.

Eyland, D., Luchaire, N., Cabrera-Bosquet, L., Parent, B., Janssens, S.B., Swnnem, R., Welcker, C., Tardieu, F., Carpentier, S.C. 2022. High□throughput phenotyping reveals differential transpiration behaviour within the banana wild relatives highlighting diversity in drought tolerance. *Plant Cell Environ* 45: 1647-1663.

Eyland, D., Wesemael, J., Lawson, T., Carpentier, S.C. 2021. The impact of slow stomatal kinetics on photosynthesis and water use efficiency under fluctuating light. *Plant Physiology* 186: 998-1012.

Gago, J., Daloso, D.M, Carriquí, M., Nada, L.M, Morales, M., Araujo, W.L., Nunes-Nesi, A., Perera-Castro, A., Clemente-Moreno, M.J., Flexas, J. 2020. The photosynthesis game is in the inter-play: mechanisms underlying CO_2 diffusion in leaves. *Environmental and Experimental Botany* 178: 1-15.

Lage, G.G.A., Souza, J.A.A., Cotrim, C.E., Donato, S.L.R., Arantes, A.M. 2020. Physiological and productive characteristics of the banana 'Prata-Anã' subjected to different irrigation intervals and emitter heights. *Acta Scientiarum-Agronomy* 42: e44000.

Magalhães, D.B., Donato, S.L.R., Santos, M.R., Brito, C.F.B., Fonseca, V.A., Souza, B.S. 2020. Yield of 'Prata-Anã' banana plants under water deficit and high plant density. *Revista Brasileira de Fruticultura* 42: e046.

Marques, P.R.R., Donato, S.L.R., São José, A.R., Arantes, A.M., Rosa, R.C.C. 2018. Gas exchange and yield of Prata-type banana plants with fertilizer sources for organic management. *African Journal of Agricultural Research* 13: 272-280.

Ramos, A.G.O., Donato, S.L.R., Arantes, A.M., Coelho Filho, M.A., Rodrigues, M.G.V. 2018. Evaluation of gas exchanges and production of genotypes of Maçã banana type cultivated in the semi-arid region of Bahia. *Revista Brasileira de Fruticultura* 40: e-500.

Robinson, J.C., Saúco, V.G. 2012. *Plátanos y bananos*. Mundi- Prensa, Madri, España. 321 p.

Rodrigues Filho, V.A., Donato, S.L.R., Arantes, A.M., Coelho Filho, M.A., Lima. M.B. 2020. Growth, yield and gas exchange of 'D'Angola' plantain under different planting densities. *Revista Brasileira de Engenharia Agrícola e Ambiental* 24: 490-496.

Rodrigues Filho, V.A., Donato, S.L.R., Silva, T.S., Amorim, E.P. 2014. Características agronômicas e ocorrência de mal-do-Panamá em bananeiras tipo Pacovan. *Revista Brasileira de Fruticultura* 36: 515-519.

Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.Á., Lumbreras, J.F., Coelho, M.R., Almeida, J.A., Araújo Filho, J.C., Oliveira, J.B., Cunha, T.J.F. 2018. *Sistema brasileiro de classificação de solos*. Embrapa, Brasília, Brasil. 356 p.

Taiz, L., Zeiger, E., Moller, I., Murphy, A. 2017. *Fisiologia e desenvolvimento vegetal*. Artmed, Porto Alegre, Brasil. 858 p.

Turner, D.W., Fortescue, J.A., Thomas, D.S. 2007. Environmental physiology of the bananas (*Musa* spp.). *Brazilian Journal Plant Physiology* 19: 463-484.

Zucoloto, M., Lima, J. S.S., Coelho, R.I. 2008. Modelo matemático para estimativa da área foliar total de bananeira 'Prata-Anã'. *Revista Brasileira de Fruticultura* 30: 1152-1154.

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