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Morphophysiological characteristics of arabic coffee

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ABSTRACT: The understanding of the behavior of each cultivar under adverse climatic conditions is important in the choice of plants that best fit the region to be inserted. Due to the large number of cultivars available on the market it makes it difficult for producers to choose which material to plant. In view of the above, this study aimed to know the morphophysiological characteristics of coffee. The experimental design was in randomized blocks with 10 treatments, that is, arabic coffee varieties: Catuai IAC62; Catuai IAC99; Ouro IAC4397; Tupi RN IAC1669-13; Obatã IAC1669-20; Mundo Novo IAC379-24; Mundo Novo IAC 388-17-2; Mundo Novo SH3 Faz São José; Bourbon IACJ15 and Icatu IAC 2944-11 and with four replications totaling 40 plots, where each plot was composed of seven plants. The Mundo Novo IAC 388-17-2 coffee variety shows higher yield in the seventh year of cultivation. Variety of Bourbon IACJ15 coffee presented water use efficiency (EUW) which did not reflect in higher productivity. The Catuai V IAC99 arabica coffee variety stood out in the internal morphology of the leaves. The thickness of the adaxial and abaxial epidermis (TADE and TABE) and the CO_2 assimilation rate (A) showed negative correlations with the productivity of processed coffee bags.
Keywords: *Coffea arabica*; plant morphology; plant physiology; varieties.

Características morfofisiológicas do café arábico

RESUMO: O entendimento do comportamento de cada cultivar sob condições climáticas adversas é importante na escolha das plantas que melhor se adaptam à região a ser inserida. Devido ao grande número de cultivares disponíveis no mercado, torna-se difícil para o produtor escolher qual material plantar. Diante do exposto, este estudo teve como objetivo conhecer as características morfofisiológicas do café. O delineamento experimental foi em blocos casualizados com 10 tratamentos, ou seja, variedades de café arábico: Catuai IAC62; Catuai IAC99; Ouro IAC4397; Tupi RN IAC1669-13; Obatã IAC1669-20; Mundo Novo IAC379-24; Mundo Novo IAC 388-17-2; Mundo Novo SH3 Faz São José; Bourbon IACJ15 e Icatu IAC 2944-11 e com quatro repetições totalizando 40 parcelas, sendo cada parcela composta por sete plantas. A variedade de café Mundo Novo IAC 388-17-2 apresenta maior produtividade no sétimo ano de cultivo. A variedade de café Bourbon IACJ15 apresentou eficiência no uso de água (EUW) o que não refletiu em maior produtividade. A variedade de café arábica Catuai V IAC99 se destacou na morfologia interna das folhas. A espessura da epiderme adaxial e abaxial (TADE e TABE) e a taxa de assimilação de CO_2 (A) apresentaram correlações negativas com a produtividade das sacas de café beneficiado.
Keywords: *Coffea arabica*; morfologia vegetal; fisiologia vegetal; variedades.

1. INTRODUCTION

Brazil is one of the world's largest producers of coffee (*Coffea Arabica* L.), reaching about 30% of world production, with approximately 2 million hectares planted in 2014 (AGRIANUAL, 2015). Only in the New High Paulista region coffee cultivation was present in five thousand hectares and approximately 65 thousand tons of grain were produced (SANTOS et al., 2015). The national coffee park is made up of 84% of the Coffea arabica species, accounting for 2.7% of the total value of Brazilian exports (PINOTTI et al., 2009). The importance of the coffee crop is evident, mainly because of the extension of the cultivated area, the use of labor, the generation of income in the properties, the foreign exchange in the export (RENA et al., 1986).

As coffee cultivation presents an enormous variability of climate, spacing, variety and nutritional, phytosanitary and cultural management, it is recommended that it be carefully applied and even analyzed under the aspect of seedling survival (SANTINATO et al., 2008). The understanding of the behavior of each cultivar under adverse climatic conditions is important in the choice of plants that best fit the region to be inserted. Due to the large number of cultivars available on the market it makes it difficult for producers to choose which material to plant.

Research that evaluates the physiological aspects together with the agronomic aspects of coffee help in the discovery of cultivars with characteristics of tolerance to environmental stresses, pathogens, among others, in addition to assisting in the exploration of a greater number of genotypes in coffee breeding programs (QUEIROZ-VOLTAN et al., 2014).

Leaf anatomy is directly influenced by environmental factors, with the status of water in the plant being one of the most important factors of leaf growth; therefore, leaf morphology is a fundamental issue for agricultural production (CASTRO et al., 2009). In view of the above, this study aimed to know the morphophysiological characteristics of coffee.

2. MATERIAL AND METHODS

2.1. Characteristics of the experimental area

In April of 2011 an experiment was installed in the Paulista Agribusiness Technology Agency, Regional Paulista Regional Camp, located in the municipality of Adamantina, State of São Paulo, with the following geographic coordinates: 21°40'24.024 "S and 51°8'31.088" W, with an approximate altitude of 420 m. The climate of the region is characterized as Aw according to Köppen and Geiger, with rainy summer and dry winter, with an average temperature of 22.1°C and a rainfall of 1204 mm per year.

The soil of the area was classified as Argissolo vermelho-amarelo distrófico (EMBRAPA, 2013) with good drainage and presented the chemical attributes according to Table 1.

Dolomitic limestone was applied in total area and the planting was carried out after 15 days of its application, the fertilization of planting was according to Raij et al. (1996).

2.2. Experimental design

The experimental design was in randomized blocks with 10 treatments, that is, arabic coffee varieties: Catuai IAC62; Catuai IAC99; Ouro IAC4397; Tupi RN IAC1669-13; Obatã IAC1669-20; Mundo Novo IAC379-24; Mundo Novo IAC 388-17-2; Mundo Novo SH3; Bourbon IACJ15 and Icatu IAC 2944-11 and with four replications totaling 40 plots, where each plot was composed of three plants. The planting spacing of the seedlings was 0.90 x 3.0 m, making 3703 seedlings per hectare.

Table 1: Chemical attributes of the soil of the area of experiment in moment of the planting.
Tabela 1: Atributos químicos do solo da área de experimento no momento do plantio.

pH	OM	P	K	Ca	Mg	H+Al	Al	SB	CEC	V%	m%
$CaCl_2$	g dm^{-3}	mg dm^{-3}	-----	-----	-----	-----	$mmol_c$ dm^{-3}	-----	-----	-----	-----
4.6	12.0	26.0	2.9	8.0	4.0	20.0	1.0	14.9	34.9	43.0	6.0

OM: organic matter; SB: Sum of bases; CEC: Cation exchange capacity; V%: Base saturation; m%: Aluminum saturation.

2.3. Parameters evaluated

2.3.1. Yield of grains benefited

After seven years after planting coffee, the yield of grains benefited, where the fruits were harvested in cherry stage in seven plants of each plot and later, the conversion to the productivity in bags of 60 kg of coffee benefited per hectare was carried out, where the following formula was used described by Mendes (1994):

$$\mathrm{YGB} = \frac{\left[\left(\frac{\mathrm{kg}}{\mathrm{plant}} * 0{,}2\right) * \mathrm{n^{o}}\frac{\mathrm{plant}}{\mathrm{ha}}\right]}{60\mathrm{kg}} \quad (01)$$

where: YGB= Yield of grains benefited in bags of 60kg.

2.3.2. Gas Exchange Parameters

After seven years the following parameters were determined, gas exchange was evaluated via non-destructive analyses using a portable gas exchange device (Infra-Red Gas Analyzer − IRGA, brand ADC BioScientific Ltd, model LC-Pro). The following parameters were determined: CO_2 assimilation rate expressed by area (A – µmol CO_2 m^{-2} s^{-1}), transpiration (E – mmol H_2O m^{-2} s^{-1}), stomatal conductance (gs – mol H_2O m^{-2} s^{-1}), and internal CO_2 concentration in the substomatal chamber (Ci – µmol mol^{-1}) and use of water (EUW), determined by the formula: EUW = A/E (µmol CO_2 m^{-2} s^{-1} / mmol H_2O m^{-2} s^{-1}). The initial conditions imposed for the measurements were 1000 µmol m^{-2} s^{-1} of photosynthetically active radiation (PAR), provided by LED lamps, 380 ppm of CO_2, and a chamber temperature of 28 °C.

2.3.3. Leaf morphology

After seven years the following parameters were determined, a leaf fragment was collected from each evaluated plant, the first fully expanded leaf from a branch in the central median region of the plant's crown was chosen.,. The samples were transported to Laboratory of Vegetal Morphophysiology and Forages at College of Agricultural and Technological Sciences – São Paulo State University. The collected material was immersed in F.A.A. 70 (formaldehyde 37%, acetic acid and 70% ethanol in the ratio of 1.0:1.0:18.0 – V/V). Twenty-four hours after, the fragments were washed and stored in 70% ethanol until the date of the analyzes, as described by Kraus and Arduim (1997). All fragments of plant tissues were treated with the pertinent procedures for dehydration, diaphanization, inclusion and embedding. By using a microtome Leica that contains steel razors, eight-µm transversal sections were done in each embedded fragment.

The first transversal sections without damage caused by cut of plants tissues was chosen for preparation of the histological slides. These sections were fixed with patches (albumin), were tinted with safranin with a 1% ratio, and were set in microscope and glass slides wih Entellan® patch (KRAUS and ARDUIN, 1997).

All slides were observed with an Olympus optical microscope; model BX 43, with a attached camera in order to perform the photographs of the cuts. Pictures were used to measure anatomic parameters through the software cellSens Standart that was calibrated with a microscopic ruler in the same gains.

By using transversal sections, the following ultrastructural variables were measured: Phloem Diameter of Leaf (PDL); Xylem Diameter of Leaf (XDL); thickness of adaxial epidermis (TADE) and thickness of abaxial epidermis (TABE) and Thickness of Palisade Parenchyma (PP). Ten measurements were done for all characteristics in each microscope slide. Plots were represented by average value obtained on each characteristic.

2.4. Statistical analysis

In all of the datasets considered, the normality of the data was analyzed using the Anderson-Darling test and homoscedasticity was analyzed with the variance equation test (or Levene's test). The results were subjected to statistical analysis using Assistat 7.7 static software (SILVA and AZEVEDO, 2016) system for Windows 7.0. The means were compared using the Scott-Knott test ($p<0.05$) (BANZATTO and KRONKA, 2013), by using.

3. RESULTS

It was observed that the productivity of arabica coffee varieties showed significant differences. The varieties Mundo Novo IAC 388-17-2 showed the highest yield of processed grains, as shown in Table 2.

The evaluation of photosynthesis levels for Arabica coffee varieties (Table 2) indicated that Mundo IAC 388-17-2 (0.65 mmol CO_2 m^{-2} s^{-1}), Mundo Novo SH3 (0.82 mmol CO_2 m^{-2} s^{-1}) and Icatu IAC 2944-11 (0.87 mmol CO_2 m^{-2} s^{-1}) had the lowest values observed. It is noted that there was excessive variation in the results evaluated in this characteristic.

It was observed that the internal CO_2 concentration varied according to the Arabica coffee varieties in the seventh year after planting (Table 2). The varieties Catuai IAC99 (237.66 µmol mol^{-1}) and Bourbon IACJ15 (218.75 µmol mol^{-1}) had the worst results, differing statistically from the other varieties.

Analyzing the transpiration of coffee varieties in the seventh after planting, it is noted that Mundo Novo IAC 388-17-2 (2.44 mmol CO_2 m^{-2} s^{-1}) had prominence and higher result of this variable when compared to the varieties Obatã IAC 1669-20 (1.36 mmol CO_2 m^{-2} s^{-1}), Catuai IAC99 (1.06 mmol CO_2 m^{-2} s^{-1}), Bourbon IACJ15 (0.62 mmol CO_2 m^{-2} s^{-1}) and Icatu IAC 2944-11 (0.55 mmol CO_2 m^{-2} s^{-1}) as shown in Table 3.

Table 2. Average values of yield of grains benefited (YGB); rate of photosynthesis (A) and internal CO_2 concentration in the substomatal chamber (Ci) of arabica coffee varieties.
Tabela 2. Valores médios de rendimento dos grãos beneficiados (YGB); taxa de fotossíntese (A) e concentração interna de CO_2 na câmara subestomática (Ci) de variedades de café arábica

	YGB (bags of 60kg)	A (µmol CO_2 m^{-2} s^{-1})	Ci (µmol mol^{-1})
Catuai IAC62	21.98d	2.19a	321.25a
Catuai IAC99	20.09d	1.82a	237.66b
Ouro IAC4397	21.22d	1.83a	326.41a
Tupi RN IAC1669-13	22.66d	1.52a	300.33a
Obatã IAC1669-20	24.35d	2.02a	280.91a
Mundo Novo IAC379-24	34.61c	2.51a	294.75a
Mundo Novo IAC 388-17-2	58.66a	0.65b	294.66a
Mundo Novo SH3	32.46c	0.82b	351.41a
Bourbon IACJ15	46.19b	2.02a	218.75b
Icatu IAC 2944-11	40.80b	0.87b	377.83a
AO	32.30	1.62	300.40
CV (%)	22.18	27.54	27.93
p value	<0.0001	0.0164	0.0003

AO: Average overall; CV: coefficient of variation.

Table 3. Average values of transpiration (E); stomata conductance (gs) and efficient use of water (EUW) of arabica coffee varieties.
Tabela 3. Valores médios de transpiração (E); condutância estomática (gs) e uso eficiente de água (EUW) de variedades de café arábica.

	E (mmol H_2O m^{-2} s^{-1})	Gs (mol H_2O m^{-2} s^{-1})	EUW
Catuai IAC62	1.85a	0.05a	2.17b
Catuai IAC99	1.06c	0.02c	1.79b
Ouro IAC4397	1.89a	0.04a	1.09b
Tupi RN IAC1669-13	1.54b	0.03b	1.43b
Obatã IAC1669-20	1.36b	0.03b	1.02b
Mundo Novo IAC379-24	1.54b	0.03b	1.43b
Mundo Novo IAC 388-17-2	2.44a	0.05a	2.14b
Mundo Novo SH3	2.14a	0.03b	0.44b
Bourbon IACJ15	0.62c	0.01d	5.78a
Icatu IAC 2944-11	0.55c	0.01d	1.95b
AO	1.50	0.03	1.92
CV (%)	52.45	40.74	153.05
p value	<0.0001	<0.0001	0.0039

AO: Average overall; CV: coefficient of variation.

According to stomatal conductance averages, the varieties Catuai IAC 62 (0.05 mmol CO_2 m^{-2} s^{-1}); Mundo Novo IAC 388-17-2 (0.05 mmol CO_2 m^{-2} s^{-1}) and Ouro IAC4397 (0.04 mmol CO_2 m^{-2} s^{-1}) had superior results standing out when comparing with the varieties Catuai IAC99 (0.02 mmol CO_2 m^{-2} s^{-1}), Bourbon IACJ15 (0.01 mmol CO_2 m^{-2} s^{-1}), and IAC 2944-11 (0.01 mmol CO_2 m^{-2} s^{-1}) that had low values of this characteristic.

For efficient water use, the Bourbon IACJ15 variety had the highest result, standing out mainly when compared to the Mundo Novo SH3 variety that presented the lowest value of this trait. It is worth mentioning that the high variation coefficient of the parameter efficient water use, occurred due to the application of the formula that in some cases the average values of some plants were negative, indicating that the plant had closed stomata.

According to the results obtained (Table 4) of phloem diameter, the varieties Catuai IAC62 (7.40) and Tupi RN IAC1669-13 (6.54) presented the best values, differing statistically from the other cultivars.

The variety Catuaí Vermelho IAC99 stood out in terms of thickness of adaxial epidermis and thickness of abaxial epidermis.

Analyzing the palisade parenchyma thickness of coffee cultivars, it was observed that the varieties IAC4397, Mundo Novo IAC379-24 and Mundo Novo SH3 presented the lowest results for this variable, being characterized as cultivars that have low thickness of this parenchyma.

Figure 1 shows the internal leaf morphology of coffee plant cultivars, where all the main.

Figure 2 shows the correlogram between the variables evaluated in the Arabica coffee varieties.

Table 4 shows the significant linear regressions after Pearson's correlation analysis. It is worth noting the positive correlations between the rate of CO_2 assimilation (A) with stomatal conductance (gs) and efficient water use (EUW) and negatively with the yields of benefited grains (YGB). A positive correlation was observed between the xylem diameter of the leaves (XDL) with the efficient use of water (EUW).

Table 4. Average values of phloem diameter of leaf (PDL); xylem diameter of leaf (XDL); thickness of adaxial epidermis (TADE); thickness of abaxial epidermis (TABE) and thickness of palisade parenchyma (PP) of arabica coffee varieties.
Tabela 4. Valores médios do diâmetro foliar do floema (PDL); diâmetro do xilema da folha (XDL); espessura da epiderme adaxial (TADE); espessura da epiderme abaxial (TABE) e espessura do parênquima em paliçada (PP) de variedades de café arábica.

	PDL (µm)	XDL (µm)	TADE (µm)	TABE (µm)	PP (µm)
Catuai A IAC62	7.40a	12.30a	24.55c	16.39b	38.95a
Catuai V IAC99	5.82b	12.93a	29.12a	18.30a	43.98a
Ouro A IAC4397	5.57b	12.68a	26.06b	16.11b	35.15b
Tupi RN IAC1669-13	6.54a	11.96a	25.13c	15.64c	43.17a
Obatã V IAC1669-20	5.72b	12.17a	28.02a	14.68c	39.78a
Mundo Novo IAC379-24	5.69b	11.63b	22.76c	14.06c	35.47b
Mundo Novo IAC 388-17-2	5.33b	11.05b	24.63c	15.44c	39.25a
Mundo Novo SH3	5.34b	11.12b	27.38b	14.80c	37.39b
Bourbon A IACJ15	5.49b	13.27a	27.06b	13.98c	41.46a
Icatu Amarelo IAC2944-11	5.68b	9.93b	24.19c	14.57c	40.11a
AO:	5.86	11.91	25.89	15.40	39.47
CV%:	31.28	24.75	13.74	23.92	20.27
p value	0.0006	0.0009	<0.0001	0.0004	0.0002

AO: Average overall; CV: coefficient of variation.

Table 5. Matrix of significant linear regressions of Pearson's significant interactions of the variables analyzed in Arabica coffee varieties.
Tabela 5. Matriz de regressões lineares significativas das interações significativas de Pearson com as variáveis analisadas nas variedades de café Arábica.

	Y = βo + βi	p value	R^2
A	ci = y = 316.725374 - 9.28721405A	0.0156	0.0447
	gs = 0.03047777 + 0.00222655A	0.0104	0.0546
	EUW = 0.81264382 + 0.63532586A	<0.0001	0.1950
	YGB = 34.4246494 - 1.20554625A	0.0305	0.0351
ci	EUW = 4.48081086 - 0.00849324ci	0.0023	0.0672
E	gs = 0.00609816 + 0.01882156E	<0.0001	0.7630
	EUW = 3.80820229 - 1.24979977E	<0.0001	0.1476
Gs	EUW = 3.13032152 - 34.9177823gs	0.0104	0.0535
XDL	EUW = -1.5058922 + 0.29039981XDL	0.0020	0.0725
TABE	YGB = 43.0950005 - 0.69946628TABE	0.0310	0.0388
TADE	YAB = 50.2769198 - 0.68814269TADE	0.0499	0.0150

4. DISCUSSION

Table 2 shows the variation in yield of the cultivars analyzed in this research. This phenomenon can be explained by the ability of the coffee culture, when the production is proportional to the number of knots or buds formed in the previous growing season, with high yields alternating with low yields (NOGUEIRA and TRUGO, 2003). This is an important characteristic for the genetic improvement of plants, as it seeks to develop varieties with higher yields and with little temporal variation. Varieties like Catuai amarelo IAC62, Catuai vermelho IAC99 and Ouro IAC4397 are undesirable in the coffee market from the productive point of view, as they presented low yield.

Plant transpiration is a component of the energy balance that determines leaf temperature, according to anatomical factors of the leaves, environmental factors and biological factors that determine the number and distribution of stomata (LEUZINGER et al., 2010). According to Nunes et al. (1968), the increase in leaf temperature may contribute to a certain reduction in the values of stomatal conductance and liquid photosynthesis rates, however, in this research, the influence of increased breathing was not observed causing a decrease in stomatal conductance.

Low stomatal conductance values lead to less CO_2 inflow into the chloroplasts causing reductions in photosynthetic rates. The decrease in stomatal conductance (gs) indicates that photosynthesis would not be restricted by stomatal closure, nor by the concentration of CO_2 within the sub-stomatal chamber, but by other biochemical factors that would be making it difficult to reduce the CO_2 there (Marur and Faria, 2008). The functioning of the stomata constitutes a physiological compromise because, when opened, they allow the assimilation of CO_2 and the loss of H_2O. Closing, it reduces the entry of CO_2 to the rubisco carboxylation sites inside the chloroplasts and conserves H_2O, reducing the risk of dehydration (TATAGIBA et al., 2015).

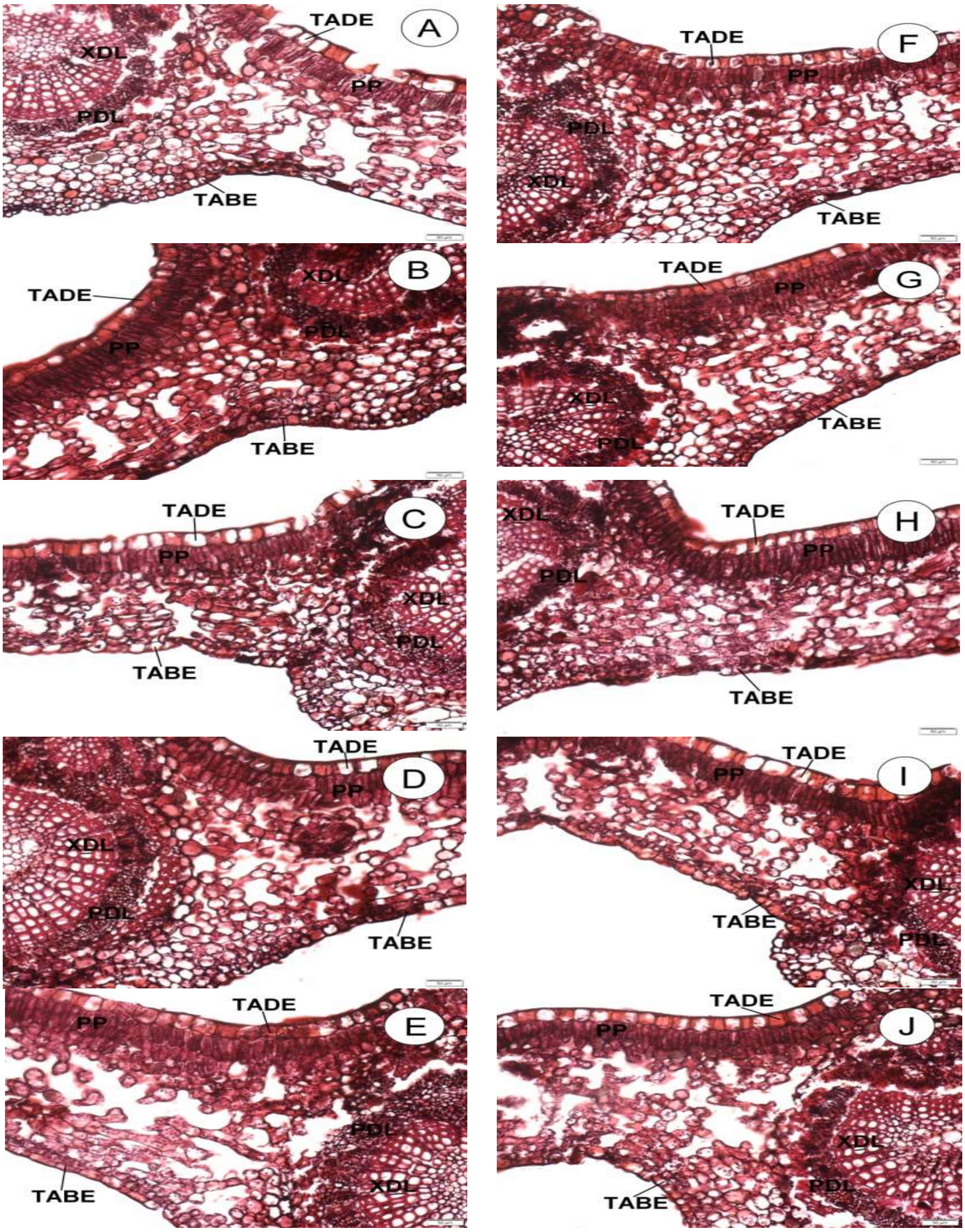

Figure 1. Internal leaf morphology of arabica coffee varieties. A: Catuai A IAC62; B: Catuai V IAC99; C: Ouro A IAC4397; D: Tupi RN IAC1669-13; E: Obatã V IAC1669-20; F: Mundo Novo IAC379-24; G: Mundo Novo IAC 388-17-2; H: Mundo Novo SH3 Faz São José; I: Bourbon A IACJ15 and J: Icatu Amarelo IAC 2944-11.
Figura 1. Morfologia interna da folha de variedades de café arábica. A: Catuai A IAC62; B: Catuai V IAC99; C: Ouro A IAC4397; D: Tupi RN IAC1669-13; E: Obatã V IAC1669-20; F: Mundo Novo IAC379-24; G: Mundo Novo IAC 388-17-2; H: Mundo Novo SH3 Faz São José; I: Bourbon A IACJ15 e J: Icatu Amarelo IAC 2944-11.

Among the physiological characteristics, which can be explored in breeding programs, the efficiency of water use stands out for nematode tolerance in conditions of water deficiency (SILVA et al., 2013). According to the results obtained with respect to the aforementioned variable, the Bourbon IACJ15 variety is promising for future breeding programs aimed at tolerance to nematode attack. The efficiency of water use corresponds to the amount of carbon fixed during photosynthesis for each water molecule lost during this process, therefore, the control of stomatal opening and closing is important to avoid excessive loss of water in transpiration, allowing the use of CO_2 accumulated in sub-stomatal chambers and reducing water loss under water deficit conditions (TAIZ et al., 2017). This trait of plants is a variable of relevant importance, as it reflects the ability of the crop to tolerate conditions of low rainfall and irregular distribution, as well as water accumulation (PERAZZO et al., 2013).

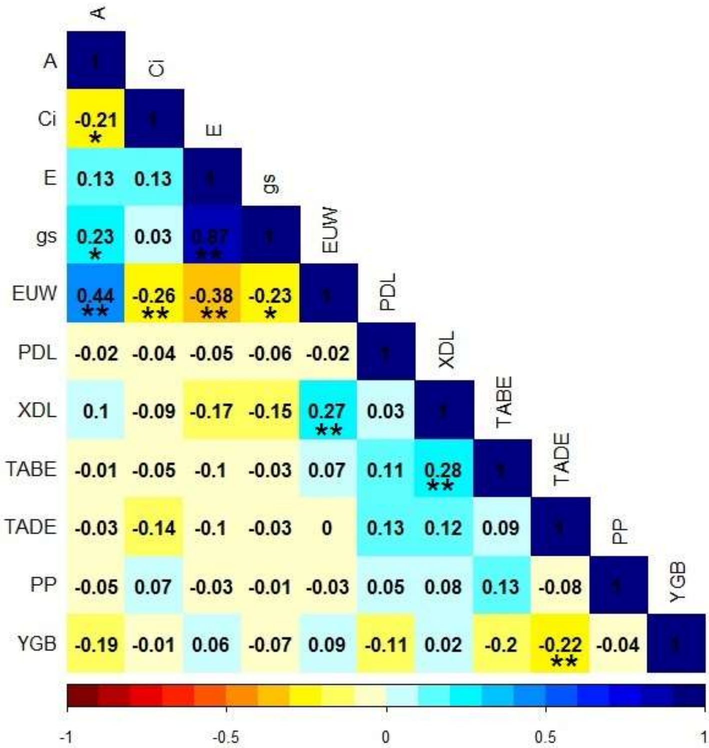

Figure 2: Pearson's correlations between the variables evaluated in Arabica coffee varieties.; A: rate of photosynthesis; Ci: internal CO_2 concentration in the substomatal chamber; E: Transpiration; gs: Stomata conductance; EUW: Efficient use of water. PDL: phloem diameter of leaf; XDL: xylem diameter of leaf; TADE: thickness of adaxial epidermis; TABE: thickness of abaxial epidermis; PP: thickness of palisade parenchyma (PP) and YGB: yield of grains benefited.
Figura 2: Correlações de Pearson entre as variáveis avaliadas nas variedades de café arábica. A: taxa de fotossíntese; Ci: concentração interna de CO_2 na câmara subestomática; E: Transpiração; gs: condutância estomática; EUW: Uso eficiente da água. PDL: diâmetro do floema da folha; XDL: diâmetro do xilema da folha; TADE: espessura da epiderme adaxial; TABE: espessura da epiderme abaxial; PP: espessura do parênquima paliçádico (PP) e YGB: rendimento de grãos beneficiado.

The efficiency of water use in plants is directly related to the functioning of the stomatal apparatus, since it corresponds to the ratio between the amount of CO_2 assimilated and the amount of water transpired by the plant. In the case of C3 plants, as is the coffee plant, stomatal resistance causes a decrease in the photosynthetic rate due to the high CO_2 compensation point for this group of plants (TAIZ et al., 2017).

Regarding the results of the phloem diameter, changes in phloem in terms of diameter, quantity, vessel area and other factors significantly influence photosynthesis, growth and development. When the plant has a more evolved xylem or in greater numbers, the supply of unprocessed sap supplied to the leaves of the plant canopies becomes more efficient, which does not compromise its physiological parameters. Thus, phloem also starts to perform more efficiently its distribution of sap elaborated to the other parts of the plant, thus being able to guarantee greater productivity (Castro et al., 2009).

Carvalho et al. (2001) evaluating the morphological aspects of Catuai Vermelho showed greater thickness of the leaves of Catuaí Vermelho with greater values of thickness of the epidermis and palisade and lacunous parenchyma. The authors found that the thickness of the abaxial and adaxial epidermis, and the palisade and lacunous parenchyma, contributed to the greater total leaf thickness. The data corroborate with that obtained in this research since this cultivar obtained the highest values of thickness of adaxial epidermis, thickness of abaxial epidermis and thickness of palisade parenchyma.

The greater thickness of the palisade parenchyma, which is a tissue rich in chloroplasts and the main tissue related to photosynthesis, can therefore favor the growth and development of plants (CASTRO et al., 2009). The higher values for the palisade parenchyma can give a greater photosynthetic capacity to the genotypes that exhibit them, being a favorable factor in conditions of high incident radiation (RIBEIRO et al., 2012).

The results of the positive correlations between the rate of CO_2 assimilation (A) with stomatal conductance (gs) and efficient water use (EUW) and negatively with the yields of benefited grains (YGB) were already expected, because with the increase in the CO_2 assimilation rate, the stomatal conductance (gs) increased, which implied a greater opening of the stomatal cleft and thus provided a greater gas exchange, thus increasing the efficient use of water (EUW), as it required less amount of water to fix more CO_2. Therefore, when a lower CO_2 assimilation rate occurs, it reduces the grain yield (BELLASIO et al., 2017).

A positive correlation between the xylem diameter of the leaves (XDL) with the efficient use of water (EUW) which was already expected, because with the increase in the diameter of the vessels, there is a greater transport and availability of unprocessed sap for the leaves (Pfautsch et al., 2015; Brodersen, 2016). It is clear that the thickness of the epidermis (TABE and TADE) had a negative influence on the production of processed grains (YGB) demonstrating that with a greater thickness it can influence the passage of light beams until reaching the chloroplasts present in the palisade parenchyma (PP), o may have caused a lower rate of photosynthesis than, consequently, yield, as this correlation between AxYGB was also observed as mentioned previously.

5. CONCLUSIONS

The Arabica coffee variety Mundo Novo IAC 388-17-2 shows higher productivity of grain bags benefited in the seventh year of cultivation.

Variety of Bourbon IACJ15 coffee presented water use efficiency (EUW) which did not reflect in higher productivity.

The Catuai V IAC99 arabica coffee variety stood out in the internal morphology of the leaves.

The thickness of the adaxial and abaxial epidermis (TADE and TABE) and the CO_2 assimilation rate (A) showed negative correlations with the productivity of processed coffee bags.

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