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Agronomic performance, postharvest and indirect selection of *Coffea arabica* L. cultivars for high-temperature regions

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ABSTRACT: This study aim was to evaluate the agronomic performance and the postharvest of small-sized *Coffea arabica* cultivars and to indicate the best agronomic variable for indirect selecting genotypes for cultivation in high-temperature regions. The experiment was conducted during the 2014/15 harvest, employing the randomized blocks experimental design, with four replicates. The treatments consisted of 17 small-sized coffee cultivars. The evaluated attributes were growth, yield and postharvest of the coffee cultivars. Considering their morphological attributes, the cultivars Obatã IAC 1669-20, Catuaí Amarelo IAC 62, Obatã Amarelo IAC 4739 and IPR 99 were superior to the others. As for yield, the cultivars Obatã IAC 1669-20 (51.90 bags ha^{-1}), Catuaí Amarelo IAC 62 (48.05 bags ha^{-1}) and Catuaí Vermelho IAC 99 (47.63 bags ha^{-1}) were superior. In the post-harvest evaluations, the cultivar Tupi IAC 125 (Tupi RN) had the best results. Due to their better agronomic performance, the cultivars Obatã IAC 1669-20 and Catuaí Amarelo IAC 62 are thus recommended for high-temperature regions. Plant height tends to be the best agronomic variable for indirect selecting more adapted cultivars for high-temperature regions.

Key words: adaptation; cultivar competition; plant height; vegetative growth

Desempenho agronômico, pós-colheita e seleção indireta de cultivares de *Coffea arabica* L. para regiões de temperaturas elevadas

RESUMO: Objetivou-se avaliar o desempenho agronômico e a pós-colheita de cultivares de café arábica de porte baixo e indicar a melhor variável agronômica para seleção indireta de genótipos para cultivo em regiões de temperaturas elevadas. O experimento foi realizado na safra 2014/15, utilizando-se o delineamento experimental de blocos casualizados, com quatro repetições. Os tratamentos foram constituídos por 17 cultivares de café de porte baixo. Avaliou-se os atributos de crescimento, rendimento e pós colheita das cultivares de café. Considerando os atributos morfológicos, as cultivares Obatã IAC 1669-20, Catuaí Amarelo IAC 62, Obatã Amarelo IAC 4739 e IPR 99 apresentaram-se superior às demais. Quanto à produtividade, as cultivares Obatã IAC 1669-20 (51,90 sc ha^{-1}), Catuaí Amarelo IAC 62 (48,05 sc ha^{-1}) e Catuaí Vermelho IAC 99 (47,63 sc ha^{-1}) foram superiores. Nas avaliações de pós-colheita a cultivar Tupi IAC 125 (Tupi RN) obteve os melhores resultados. Devido ao melhor desempenho agronômico, recomenda-se as cultivares Obatã IAC 1669-20 e Catuaí Amarelo IAC 62 para regiões de temperaturas elevadas. A altura de planta tende a ser a melhor variável agronômica para a seleção indireta de cultivares mais adaptadas em regiões de temperaturas elevadas.

Palavras-chave: adaptação; competição de cultivares; altura de plantas; crescimento vegetativo

Introduction

The global average temperature has been increasing in these last decades, having the possibility of increasing from 3.4 to 6.2 °C until year 2100 (Beckage et al., 2018). This increasing temperatures prospect has direct effects on the global climate and, consequently, on agriculture. Several studies point out that with the increasing temperature, suitable regions for cultivating different cultures will be considered as marginal or even unsuitable, while others now considered as marginal due to their low temperatures will thus become suitable (Craparo et al., 2015; Rahn et al. 2018).

With this in mind, some crops more sensitive to high temperatures, such as the Arabica coffee (*Coffea arabica* L.), will be also more affected. Increasing only 1 °C in the minimum daily temperature can reduce the productive potential of the Arabica coffee by approximately 2.5 bags ha^{-1} $year^{-1}$ (150 kg ha^{-1}) (Craparo et al., 2015). This can directly interfere in the economic scenario of several regions and even whole countries, since coffee plants are cultivated in over 70 countries and have a production of more than 100 million bags (USDA, 2019). Moreover, this crop employs more than 26 million people worldwide, thus having the potential of socially affecting several countries (Ico, 2019).

Within the *Coffea arabica* L. species, there are several cultivars around the world that are recommended and adapted for each production system. In Brazil alone, approximately 131 Arabica coffee cultivars are registered and available for producers (Mapa, 2020). Yet, little is known about the agronomic performance and the adaptability of these genotypes in high-temperature regions, as they may behave in an atypical manner, thus having a reduced yield due to the varied environmental conditions, scaling in losses for the producer (Paiva et al., 2010; Martins et al., 2016; Machado et al., 2017).

This exposes the lack of studies and experiments on the matter, since the edaphoclimatic conditions significantly influence the morphological attributes and the yield of the plants. Furthermore, studies on the agronomic performance of Arabica coffee cultivars in high-temperature regions may assist, technicians and breeders alike, in selecting the most adapted genotypes, minimizing both the economic and social impacts that climate change may cause in the coffee growing. In addition, it is noteworthy that searching for increasingly productive cultivars is the focus of coffee breeding programs, which makes studying their response pattern in different environmental conditions and growing regions a necessity (Ferreira et al., 2013; Teixeira et al., 2015).

Since the attributes from crop growth can be highly correlated with the yield (Freitas et al., 2007; Carvalho et al., 2010; Teixeira et al., 2013), indirect selecting better-adapted genotypes can be done through monitoring the plant growth. Therefore, superior genotypes can be selected quickly for more advanced stages in the breeding programs, thus gaining more time for releasing new cultivars. Moreover, in the short term, the evaluation of growth attributes may be held for selecting commercial cultivars more adapted to regions of higher temperature climates, guaranteeing greater yield and economic return to the producers (Teixeira et al., 2015).

The hypotheses in the present study are that (i) there are commercial cultivars better adapted for cultivation in high-temperature regions and that (ii) it is possible selecting cultivars more adapted to these same regions from the plant growth attributes. This study aimed to evaluate the agronomic performance and the postharvest of small-sized *Coffea arabica* L. and to indicate the best agronomic variable for indirect selecting genotypes for cultivation in high-temperature regions.

Materials and Methods

The experiment was conducted at the São Paulo State Univeristy (Unesp), School of Agricultural and Veterinary Studies, Jaboticabal, SP, during the 2014/15 agricultural harvest. The experimental area was located close to the latitude coordinates of 21°14’31.19”S and longitude 48°17’51.90”W, at an altitude of 565 m. The region climate, as according to the Köppen classification, is of the Aw type – subtropical with winter drought (Alvares et al., 2013). The region has also average annual temperature of 22.2 ºC, relative humidity of 70.8% and precipitation of 1,416 mm (1971-2014), with 80% of the total rainy season concentrated between the months of October and March.

The soil in the experimental area was classified as a “Latossolo Vermelho Eutrófico” (Oxisol), with a clayey texture (Embrapa, 2013). On table 1 are the soil chemical attributes before the experiment plantation, conducted in April 2013, determined in the layers of 0.00-0.20 m and 0.20-0.40 m.

The soil was prepared in a conventional way, by scarification, plowing and harrowing. The basic fertilization was performed in the planting furrow, at 0.40 m depth, according to the interpretation of the chemical analysis of the soil and the recommendations of Raij et al. (1996), using 20 L m^{-1} tanned corral manure, 15 g of P_2O_5 m^{-1} (85 g of Yorin Master) and 10 g of K_2O m^{-1} (17 g of KCl).

The seedlings were produced in a system composed of tubes with artificial substrate, planted in April 2013, having 5 pairs of leaves at the time. A drip irrigation system was employed in the experimental area, equipped with self-

Table 1. Soil chemical attributes in the experimental area prior to implanting the cultivars of small-sized Arabica coffee.

Layer (m)	pH ($CaCl_2$)	O.M. (g dm^{-3})	P resin (mg dm^{-3})	K	Ca	Mg	H+Al	SB	T	V (%)
				($mmol_c$ dm^{-3})						
0.00-0.20	5.5	14	48	1.7	27	16	20	44.7	64.7	69
0.20-0.40	5.3	14	44	2.1	20	14	22	36.1	58.1	62

O.M. – organic matter; SB – sum of bases; T – cation exchange capacity; V – base saturation.

compensating emitters spaced 0.50 m apart each other that were manually operated and had a single irrigation line under the surface in each coffee row, with service pressure of 100 kPa (10 mca) and flow rate of 1.6 L h^{-1}.

The experimental design employed was the randomized blocks, with four replicates. Treatments were composed of the following17 small-sized Arabica coffee cultivars: Catuaí SH3, Catuaí Amarelo IAC 62, Catuaí Vermelho IAC 99, IAC Ouro Verde, IAC Ouro Amarelo, Obatã IAC 1669-20, Obatã Amarelo IAC 4739, Tupi IAC 1669-33, Tupi IAC 125 (Tupi RN), Catiguá MG1, Oeiras MG 6851, Pau-Brasil MG1, Sacramento MG1, IPR 99, IPR 100, IPR 103 and Sabiá tardio.

Each experimental plot were composed by a four-meter-long coffee row, having eight plants spaced 0.50 m apart each other and 3.5 m between rows, with the six central plants considered as the useful area. The 'Acauã' cultivar was used throughout the experiment border, whereas the Congo signal grass (*Urochloa ruziziensis*) was sown in between the rows.

By occasion of the second year of the plant formation, in the 2014/15 agricultural year, samplings from the 0.00-0.20 m layer were taken for evaluation of the chemical attributes in October 20014. The results were the following: pH ($CaCl_2$) 5.9; O.M. = 15 g dm^{-3}; P (resin) = 79 mg dm^{-3}; K^+ = 6.1 $mmol_c$ dm^{-3}, Ca^{2+} = 28 $mmol_c$ dm^{-3}; Mg^{2+} = 19 $mmol_c$ dm^{-3}; H+Al = 15 $mmol_c$ dm^{-3}; SB = 53.1 $mmol_c$ dm^{-3}; CEC = 68.1 $mmol_c$ dm^{-3} and V = 78%.

Based on the results from the soil chemical analysis, the mineral production fertilization was recommended, having an expected yield of 20-30 bags ha^{-1} of processed coffee (Raij et al., 1996). Fertilization was performed under the canopy projection of the plants and split in four parts, totaling 210 kg of N ha^{-1} and 40 kg of K_2O ha^{-1}.

Figure 1 illustrates the meteorological data from the 2014/2015 harvest. The mean values of the maximum, minimum and average temperatures, as well as the relative humidity as the accumulated annual precipitation for the 15 years prior to the experiment were 29.7 °C, 17.2 °C, 23.5 °C, 70% and 1382 mm, respectively. As for the normal annual average (from 1971 to 2014), the mean values of the maximum, minimum and average temperatures, as well as the relative humidity as the accumulated annual precipitation were 29.3 °C, 17.0 °C, 22.3 °C, 71% and 1417 mm, respectively.

The morphological attributes evaluated in the useful area from each plot were plant height (cm), measured from the ground level to the apical meristem; the crown diameter (cm), measured with two wood sticks to define the end of the most distant branches; the stem diameter (mm), measured at 10 cm from the soil surface with digital caliper; the plagiotropic branch length (cm), with 4 plagiotropic branches in the middle third from plants of each plot, two to the left and two to the right side of the planting row, measured with a tape measure; and the number of nodes in the plagiotropic branch, measured on the same marked for length analysis.

The morphological attributes were quantified again every 2 months, totaling five evaluation periods, with the stem diameter as the only exception, measured at every 4 months

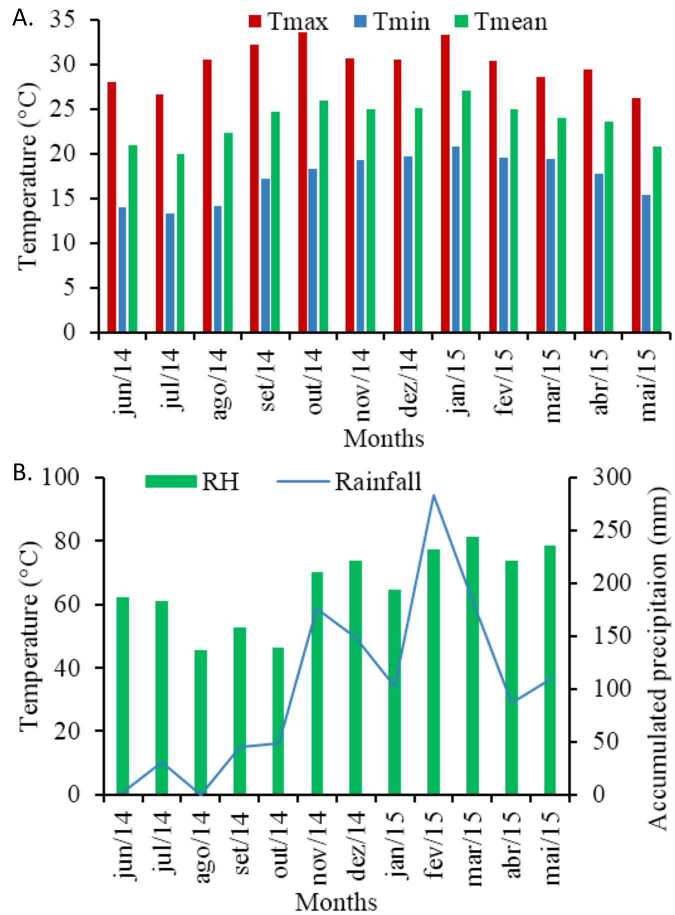

Figure 1. Maximum, minimum and average temperatures (T), relative humidity (RH) and monthly precipitation for the 2014/15 agricultural harvest.

due to the low perception of growth in this variable. The evaluations were held during the period from August 2014 to April 2015, thus passing through the winter, spring, summer and early autumn seasons.

By occasion of the fruit maturation, the soil under the plants was cleaned and then the fruits were harvested in the traditional method, staged three times, in order to obtain the largest fruit number during the cherry stage in each cultivar. The total fruit volume harvested in each plot was then quantified, separating 10 L of raw farm coffee for sun drying, on sieves, until reaching a water content of 12.5% on a wet base. Subsequently, the volume of the dried cherry coffee was weighed, processed and weighed once again. Through the mass ration between dried cherry and raw bean coffees, the benefit income (%) was thus established. In sequence, the yield of each cultivar was estimated, in bags of 60 kg ha^{-1}, based on the weight of raw beans, the volume of coffee fruits harvested in each plot and on the plant stand (5,714 plants ha^{-1}).

For post-harvest evaluations, 100-g samples of raw grain from each plot were used. This sample was for the size and shape classifying evaluation, by passing it through a set of sieves, namely a round sieve 17 (flat grain), round sieve 15 (flat grain), oblong sieve 10 (soft grain), round sieve 13 (flat grain) and bottom (sticks, stones, broken grains, among others). In the same sample, the total defective grains (black, green and burnt) were also counted. In each plot, four samples of 100 flat grains were selected, counted and weighed, with the resulting mean used to establish the weight of 100 grains.

The data obtained were subjected to the statistical analysis by using the Sisvar® software. Analysis of variance (ANOVA) was applied through the F test ($p < 0.05$) and when necessary, the means between treatments were clustered by the Scott-Knott test ($p < 0.05$). In the significant cases for the interaction cultivars x evaluation periods, the unfoldings were performed. With the aid of the R software , the simple correlations (r) among the measured variables were then determined, with subsequent application of the t test ($p < 0.05$) in order to verify the respective significances.

Results and Discussion

Significant differences ($p < 0.01$) were observed between cultivars (C) and periods (E) of evaluation regarding the morphological attributes, with significant interaction between C x E only for the crow diameter variable (Tables 2 and 3). These differences occur because the morphological attributes are influenced by the interaction between genotype x environment, resulting in the different plant development in response to the edaphoclimatic conditions (Carvalho et al., 2010).

During the evaluation of plant height, the cultivars Catuaí Amarelo IAC 62, IPR 99, Sacramento MG1 and IAC Ouro Amarelo had the highest values (Table 2). Increased plant height occurred in all evaluated periods, averaging 33.77 cm of increment between 16 and 24 months after planting, with the highest growth intensity (11.84 cm) verified between 18 and 20 months after planting.

As for the crow diameter, the cultivars Obatã IAC 1669-20, Tupi IAC 1669-33, IPR 99, Obatã Amarelo IAC 4739 and Sacramento MG1 had better performance. The most expressive growth intensity value, for this same variable, was found between 16 and 18 months after planting (26.38 cm), averaging 56.06 cm of increment in the crow diameter of the plants between 16 and 24 months after planting (Table 2).

On the evaluation of stem diameter, 5 out of 17 cultivars were superior to the others, with the cultivars Obatã Amarelo IAC 4739, IPR 99, Sacramento MG1, Obatã Amarelo IAC

Table 2. Mean values for plant height (PH), crown diameter (CD), stem diameter (SD), plagiotropic branch length (PBL) and number of nodes on the plagiotropic branch (NNPB) in function of the growth evaluation period of small-sized Arabica coffee cultivars.

Treatments	PH (cm)	CD (No.)	SD (mm)	PBL (cm)	NNPB (No.)
Cultivars (C)					
Catuaí SH3	102.15d	113.19d	27.37d	61.47b	20.94a
Catuaí Amarelo IAC 62	116.15a	131.18b	30.72a	67.22a	20.34a
Catuaí Vermelho IAC 99	112.18b	127.98b	29.74b	66.60a	20.97a
IAC Ouro Verde	107.83b	121.10c	29.27b	65.04b	20.57a
IAC Ouro Amarelo	113.05a	128.42b	29.62b	62.99b	19.42b
Obatã IAC 1669-20	111.06b	139.08a	31.44a	69.94a	20.80a
Obatã Amarelo IAC 4739	106.14c	134.17a	32.03a	68.04a	20.16a
Tupi IAC 1669-33	101.55d	135.70a	29.04b	66.67a	20.42a
Tupi IAC 125 (Tupi RN)	102.49d	131.16b	28.55c	64.19b	20.05a
Catiguá MG1	102.63d	123.60c	28.17c	62.16b	18.38c
Oeiras MG 6851	109.87b	114.38d	29.52b	53.43d	17.14d
Pau-Brasil MG1	109.60b	129.79b	28.28c	61.88b	19.21b
Sacramento MG1	113.66a	133.76a	31.77a	62.67b	17.19d
IPR 99	115.31a	135.47a	31.80a	65.96a	19.52b
IPR 100	110.10b	126.16b	29.34b	63.82b	20.37a
IPR 103	104.55c	117.00d	26.97d	56.96c	17.22d
Sabiá tardio	111.35b	120.14c	29.17b	59.86c	18.99b
Periods (E) [2]					
16 MAP (ago/14)	92.61	92.80	25.49	55.17	14.26
18 MAP (Oct/14)	97.68	119.18	--	57.94	17.08
20 MAP (Dec/14)	109.52	132.05	30.19	65.23	20.35
22 MAP (Feb/15)	117.84	143.09	--	67.86	22.15
24 MAP (Apr/15)	126.38	148.86	33.04	71.11	23.72
CV (%)	4.03	5.42	5.27	7.70	8.01
F test					
C	23.71**	25.73**	11.60**	14.21**	14.21**
E	685.68**	712.06**	407.32**	128.20**	410.03**
C x E	1.06ns	1.58**	0.535ns	0.570ns	0.599ns
Overall mean	108.81	127.19	29.57	63.46	19.51

Means followed by the same lowercase letter in the column do not differ from each other by the Scott-Knott test ($p \geq 0.05$). *($p < 0.05$), ** ($p < 0.01$) and ns (not significant), respectively by the F test. [(2)] Months after planting (MAP).

1669-20 and Catuaí Amarelo IAC 62 standing out. In the three evaluation periods of stem diameter, the one that was between 16 and 20 months after planting demonstrated the highest growth intensity, averaging 7.55 mm of increment between 16 and 24 months after planting (Table 2).

The unfolding of the C x E interaction for the crow diameter variable, illustrated in Table 3, shows significant differences ($p < 0.01$) for the analyzed variable.

These differences may have been only emphasized for this morphological attribute, due to the occurring variation in the canopy architecture resulting from the interaction of several environmental factors such as the temperature oscillation during the day, the coffee tree phenological phase (graining), amount of sun during the evaluation periods and days, among others. The abovementioned interactions that are caused by the environmental changes influence are a major difficulty in the breeding programs (Camargo, 2010).

When considering the evaluation of the number of nodes in the plagiotropic branch, the cultivars that best performed were the following: Catuaí SH3, Catuaí Amarelo IAC 62, Catuaí Vermelho IAC 99, IAC Ouro Verde, Obatã IAC 1669-20, Obatã Amarelo IAC 4739, Tupi IAC 1669-33, Tupi IAC 125 (Tupi RN) and IPR 100. During the evaluation periods (from 18 to 24 months after planting), the branches had a mean increase of 9.46 knots, with the most intense period in between 18 and 20 months after planting (3.27 knots), as demonstrated in Table 2.

The highest growth intensity of the morphological attributes during the evaluation periods occurred between 18 and 20 months after planting, coinciding with the spring and summer seasons, characterized in the region by increasing means of rainfall, insolation and temperature, compared to autumn and winter. When studying the vegetative growth of Arabica coffee under different water regimes, Ferreira et al. (2013) also identified seasonal growth of plagiotropic and orthotropic branches, with a higher growth rate during the time from September to December, a period when climatic conditions are favorable to the vegetative growth of coffee trees.

Between 20 and 24 months after planting, there was a gradual reduction or stabilization of the growth intensity of the evaluated attributes, a period related to the reproductive stage of the plants. This response pattern can be explained by the greater translocation of photoassimilates for fruit development and maturation at the expense of vegetative growth (Malavolta et al. 2002).

Based on the importance of the morphological attributes evaluated and when analyzing them together, the cultivars Obatã IAC 1669-20, Catuaí Amarelo IAC 62, Obatã Amarelo IAC 4739 and IPR 99 were superior in 4 out of the 5 evaluated morphological attributes, thus demonstrating a greater adaptability to the high-temperature regions conditions, as in the case of the present study. Moura et al. (2013), when evaluating the performance of 30 Arabica coffee cultivars, verified a greater vegetative vigor on the Obatã IAC 1669-20 cultivar in 2 out of the 3 studied environments. Carvalho et al. (2010), in an experiment with 25 Arabica coffee cultivars in 5 different places, verified a vegetative superiority on the Catuaí Amarelo IAC 62 cultivar. These mentioned studies, as well as this present one, all demonstrate the high vegetative vigor of Obatã IAC 1669-20 and Catuaí Amarelo IAC 62 in different production environments.

Table 3. Unfolding of the interactions for crow diameter in relation to the evaluation periods of small-sized Arabica coffee cultivars.

Cultivars	Crow diameter (cm)					
	Periods					
	16 MAP Aug/14	18 MAP o Oct/14	20 MAP Dec/14	22 MAP Feb/15	24 MAP Apr/15	F test
Catuaí SH3	77.15cD	104.15cC	116.75cB	130.33cA	137.58cA	47.943**
Catuaí Amarelo IAC 62	97.35aD	118.93bC	134.40bB	149.60aA	155.65bA	47.136**
Catuaí Vermelho IAC 99	96.58aD	115.30bC	130.68cB	145.98bA	151.40bA	42.587**
IAC Ouro Verde	89.45bD	108.20cC	125.45cB	137.63cA	144.78cA	42.461**
IAC Ouro Amarelo	95.21aD	117.68bC	133.00bB	145.23bA	151.03bA	42.729**
Obatã IAC 1669-20	99.48aD	129.60aC	146.23aB	157.28aA	162.83aA	54.727**
Obatã Amarelo IAC 4739	96.53aE	124.80aD	135.68bC	151.58aB	162.30aA	54.666**
Tupi IAC 1669-33	95.20aD	131.05aC	144.28aB	154.35aA	153.63bA	50.528**
Tupi IAC 125 (Tupi RN)	91.98aC	128.93aB	140.55aA	145.78bA	148.58bA	45.085**
Catiguá MG1	89.13bC	118.25bB	124.73cB	140.70bA	145.20cA	42.552**
Oeiras MG 6851	86.93bB	114.93bA	120.35cA	124.38cA	125.33dA	21.211**
Pau-Brasil MG1	97.98aC	124.15aB	139.25bA	142.58bA	145.00cA	32.115**
Sacramento MG1	93.33aD	127.93aC	137.33bC	148.78aB	160.48aA	55.727**
IPR 99	95.85aC	127.20aB	145.13aA	152.23aA	156.95aA	51.977**
IPR 100	94.83aD	114.78bC	128.45cB	141.83bA	150.93bA	41.512**
IPR 103	85.77bE	103.40cD	120.43cC	132.10cB	143.33cA	43.976**
Sabiá tardio	94.82aC	116.75bB	122.25cB	131.20cA	135.70cA	21.460**
F Test	2.646**	6.297**	7.392**	7.373**	8.355**	

Means followed by different lowercase letters in the columns differ from each other by the interaction cultivar in the period, and different uppercase letters in the row, period in the cultivar, by the Scott-Knott clustering test ($p < 0.05$). ** significance level at ($p < 0.01$) by the F test; MAP – months after planting.

The cultivars that had the highest yield were Obatã IAC 1669-20, Catuaí Amarelo IAC 62 and Catuaí Vermelho IAC 99, which did not statistically differ from each other (Table 4). These results corroborate the study of Teixeira et al. (2015), which when evaluating Arabica coffee genotypes in Ouro Preto do Oeste-RO, found yields of over 40 bags ha^{-1} on the cultivars Catuaí Vermelho IAC 15 and Obatã IAC 1669-20. Bergo et al. (2008) also found yields above 45 bags on the cultivars Obatã 1669-20 and Obatã IAC 4275 in a cultivar experiment conducted in Rio Branco-AC.

In general, 15 out of the 17 cultivars had yield values above the national mean (25.7 bags ha^{-1}), considering the last five harvests (from 2015 to 2019) (Conab, 2020). Considering that 33 bags ha^{-1} is the minimum yield for attaining the economic viability of coffee production for the producer (Goes & Chinelato, 2018), it is observed that 12 genotypes demonstrated yield values higher than this minimum mentioned.

The benefit income establishes the amount of dried cherry coffee needed to compose a bag of raw coffee beans, normally varying between 45 and 55%, according to the climatic conditions of the region and the harvest year. The farmer generally uses this parameter as an indicator of the coffee quality (Matiello et al., 2010).

During the evaluation of the benefit income, the cultivars IAC Ouro Verde, IPR 103, Catuaí Vermelho IAC 99, IPR 99, Sabiá tardio and IAC Ouro Amarelo stood out and did not differ statistically (Table 4).

In a broader sense, most cultivars had values considered as adequate for benefit income, between 45 and 55%. Paiva et al. (2010), evaluating the behavior of 20 small-sized Arabica coffee progenies, also identified a similar variation (from 43.7 to 55.6%) in this same evaluation type.

Regarding the variable of weight of 100 flat-type grains, the cultivars Tupi IAC 1669-33 and Tupi IAC 125 (Tupi RN) had the highest values (Table 4). Lara et al. (2014), evaluating the active germplasm bank of the coffee trees, found values between 11.35 and 14.15 g when analyzing the weight of 100 grains.

Coffee is a commodity that adds value according to its quality. The classification of its beans by size and format is one of the main criteria that is used to form more uniform batchest and define the price of the coffee bag.

Other important aspects for classifying the coffee quality are the intrinsic defects, those that are inherent to the bean (shell, broken, poorly grained, among others). The ones known as blacks, greens and burns are those that cause the greatest damage to the drink quality and depreciate the coffee price (Matiello et al., 2010).

The Tupi IAC 125 (Tupi RN) cultivar had the highest percentage of flat grains (sieve 17 above) 31.12%, the lowest amount of mocha-type grains 5.72% and total defects 6.75% (Table 5). Similar results of higher percentages of sieve 17 grains above were also found by Paiva et al. (2010) on the 'Tupi IAC 4093' cultivar.

Positive and significant correlations were verified between most of the evaluated morphological attributes. Only the plant height and the crow diameter correlated significantly with yield (Table 6). The plant height variable was positively correlated with crown diameter (0.4617***), stem diameter (0.5535***), plagiotropic branch length (0.2439*) and yield (0.3737**). According to Freitas et al. (2007), plants with higher height and crow diameter require a greater sap translocation, thus implying in a proportional increasing stem diameter. Carvalho et al. (2010) also found correlations between the plant height and the yield.

Table 4. Mean values of yield, benefit income and weight of 100 grains from the first crop of small-sized Arabic coffee cultivars.

Treatments	Yield (bags ha^{-1})	Benefit income (%)	Weight of 100 grains (g)
Cultivars			
Catuaí SH3	32.20d	45.33b	10.87c
Catuaí Amarelo IAC 62	48.05a	46.25b	10.83c
Catuaí Vermelho IAC 99	47.63a	49.70ª	11.56b
IAC Ouro Verde	43.10b	51.01ª	11.36b
IAC Ouro Amarelo	44.85b	49.06ª	10.54c
Obatã IAC 1669-20	51.90a	46.96b	10.65c
Obatã Amarelo IAC 4739	24.13e	38.16c	10.04d
Tupi IAC 1669-33	42.05b	45.01b	12.57a
Tupi IAC 125 (Tupi RN)	44.58b	46.99b	12.83a
Catiguá MG1	13.60f	41.16c	9.45d
Oeiras MG 6851	38.88c	47.95b	10.90c
Pau-Brasil MG1	41.38b	47.30b	9.86d
Sacramento MG1	16.28f	40.27c	10.79c
IPR 99	41.40b	49.60ª	11.62b
IPR 100	45.53b	45.88b	11.38b
IPR 103	32.80d	50.74ª	10.99c
Sabiá tardio	39.03c	49.15ª	11.39b
F test	29.896**	13.346**	11.414**
CV (%)	10.53	4.33	4.64
Overall Mean	38.08	46.49	11.04

Means followed by the same lowercase letter in the column do not differ from each other by the Scott-Knott test ($p \geq 0.05$). *($p < 0.05$), ** ($p < 0.01$) and ns (not significant), respectively by the F test.

Table 5. Mean percentage values regarding size and shape classification, with circular sieve 17 (PC17), circular sieve 15 (PC15), oblong sieve 10 (PO10), circular sieve 13 (PC13), bottom and defects (2) (D) in the sample of beans from the first crop of small-sized Arabic coffee cultivars.

Treatments	PC17	PC15	PO10	PC13	Bottom	D
	(%)					
Cultivars						
Catuaí SH3	15.76e	46.40a	7.24d	23.27c	7.34d	9.00d
Catuaí Amarelo IAC 62	22.63c	42.23b	12.77b	17.03d	5.35e	11.75c
Catuaí Vermelho IAC 99	26.16b	43.96a	10.28c	15.03d	4.58e	8.75d
IAC Ouro Verde	20.28d	47.74a	9.42d	17.53d	5.03e	8.00d
IAC Ouro Amarelo	13.59e	48.53a	8.21d	22.74c	6.93d	7.50d
Obatã IAC 1669-20	8.84f	48.49a	6.11e	30.03b	6.26d	11.00c
Obatã Amarelo IAC 4739	12.50e	39.22b	7.27d	30.89b	10.11c	17.50a
Tupi IAC 1669-33	25.97b	40.73b	10.64c	16.39d	5.60d	8.00d
Tupi IAC 125 (Tupi RN)	31.12a	34.43c	5.72e	19.04d	9.69c	6.75e
Catiguá MG1	6.37f	29.12d	8.46d	39.62a	16.43a	15.25a
Oeiras MG 6851	14.53e	45.14a	11.12c	22.16c	7.05d	8.50d
Pau-Brasil MG1	4.93f	38.26b	15.67a	29.56b	11.58b	6.50e
Sacramento MG1	7.20f	41.55b	12.95b	26.62b	11.68b	12.25c
IPR 99	21.36d	47.66a	8.31d	15.38d	7.30d	12.00c
IPR 100	24.01c	49.66a	5.79e	16.03d	4.52e	7.00e
IPR 103	18.85d	48.82a	7.49d	19.30d	5.54e	6.75e
Sabiá tardio	26.13b	38.92b	12.46b	16.90d	5.55e	6.25e
F test	58.186**	14.253**	30.385**	28.436**	54.642**	42.48**
CV (%)	11.82	7.07	11.06	11.8	11.17	10.39
Overall Mean	17.66	42.99	9.40	22.21	7.74	9.53

Means followed by the same lowercase letter in the column do not differ from each other by the Scott-Knott test ($p \geq 0.05$). *($p < 0.05$), ** ($p < 0.01$) and ns (not significant), respectively by the F test. (2) Defects (blacks, greens and burnt) at the 100g sample.

Table 6. Correlation coefficients between plant height (PH), yield (Yi), plagiotropic branch length (PBL), stem diameter (SD), crown diameter (CD) and number of nodes on the plagiotropic branch (NNPB) of small-sized Arabic coffee cultivars.

Correlation	PH (cm)	Yi (bags ha^{-1})	PBL	CD	SD (mm)	NNPB (cm)
			(cm)			
PH	1	0.3737**	0.2439*	0.5535***	0.4617***	0.0891^{NS}
Yi	0.3737**	1	0.1342^{NS}	0.1691^{NS}	0.2720*	0.2298^{NS}
PBL	0.2439*	0.1342^{NS}	1	0.3704**	0.4935***	0.8827***
CD	0.5535***	0.1691^{NS}	0.3704**	1	0.6338***	0.1446^{NS}
SD	0.4617***	0.2720*	0.4935***	0.6338***	1	0.2373^{NS}
NNPB	0.0891^{NS}	0.2298^{NS}	0.8827***	0.1446^{NS}	0.2373^{NS}	1

Significant level *($p < 0.05$), **($p < 0.01$), ***($p < 0.001$) and ^{NS} (not significant), by the t test ($p \geq 0.05$).

The crown diameter was positively correlated with the plagiotropic branch length (0.4935***), stem diameter (0.6338***) and yield (0.2720*). Teixeira et al. (2013) found similar results of positive correlations between crow diameter and other morphological attributes. The correlation between the crow diameter and the plagiotropic branches length can be explained by the increase in the branches size implying a proportional increase in the crow diameter. In a similar fashion, plants with larger crow diameters and consequently longer plagiotropic branches tend to need larger-diameter stems to sustain themselves, which justifies the high correlation coefficient between these two variables. This can be evidenced as 4 out of the 5 cultivars with larger crow diameters also had larger stem diameters (Table 2).

The plagiotropic branches length demonstrated a positive correlation with the number of nodes in the plagiotropic branch. These attributes were those that had the highest correlation coefficient (0.8827***) among the analyzed vegetative variables. Thereby, evaluating the plagiotropic branch length seems to be an efficient indicator of the number of productive nodes of the plant, one of the most important yield components (Freitas et al., 2007).

When analyzing the correlation coefficients and considering the interdependence among the quantified variables, it can be stated that plant height and crown diameter are the most suitable morphological attributes for the early evaluation of cultivars more adapted to high-temperature regions, due to these parameters correlating positively and significantly with other morphological attributes and directly with yield. Even so, the highest yield correlation was with plant height, with it significant at the 1% probability, thus turning into a more reliable attribute in the indirect selection of cultivars that are more adapted to high-temperature regions, as in the present study.

Plant height and crown diameter have been widely used as selection parameters in coffee breeding programs, with preference to smaller-sized plants as they facilitate the management, harvesting and adapt well to dense plantations. (Lara et al., 2014). However, for high-temperature regions, as the case of the present study, plant height had a direct correlation with yield. This occurs because cultivars tolerant to high temperatures demonstrate a greater growth than the sensitive genotypes (Teixeira et al., 2015; Craparo et al., 2015), and may also be one of the factors for indirect selection of the cultivars adaptation.

The stem diameter is also an important parameter to be considered, since according to Rena et al. (1998), it has a high influence on the root system development, thus acting as a good indicator. The plagiotropic branches length is also important, as it is usually correlated positively with the number of nodes, one of the main yield parameters of the plant (Freitas et al., 2007).

The historical average annual temperature (from 1971 to 2014) of the present study region is 22.30 °C, while the temperature of the 15 years prior to the present study harvest (from 2001 to 2015) was 23.47 °C (Figure 1). According to the agroclimatic risk zoning for the Arabica coffee cultivation in Brazil, the average annual temperature for the region to be considered suitable for it must be between 18 and 23 °C (Camargo, 1977). Hence, there is a change in the region classification, and in several others in Brazil, as to the aptitude of Arabica coffee cultivation in recent years, passing from "suitable" to "marginal due to excessive temperature".

Under high temperatures, Arabica coffee plants have increased membrane fluidity and protein denaturation, directly affecting their photosynthetic rate (DaMatta & Ramalho, 2006). Morphologically, cultivars tolerant to high temperatures tend to have leaf cuticles with greater light reflection and leaf movements opposite to the direct sunlight incidence, while physiologically they tend to have higher amounts of heat-shock protein content, thus avoiding protein aggregation (Larcher, 2003). Associating this to the present study, the cultivars Catuaí Amarelo IAC 62, Catuaí Vermelho IAC 99 and Obatã IAC 1669-20 can be morphologically and physiologically more tolerant to high temperatures, as they had the highest mean yields (Table 4).

This classification change in aptitude requires additional agronomic techniques for the cultivation of coffee in "marginal areas due to excessive temperature", such as using irrigation and planting coffee plants under the tree production system, thus generating a microclimate with lower temperature (Teixeira et al., 2015; Rahn et al., 2018). Moreover, the recommendation of cultivars adapted to these conditions of high temperatures must be specific, since many of the Arabica coffee cultivars have high productive potential in "suitable" regions, yet their agronomic performance in "marginal" regions to cultivation is unknown.

Evaluating the genetic diversity among 16 Arabica coffee genotypes in the Brazilian Cerrado, Machado et al. (2017) verified that the cultivars Catucaí 2 SL and Catiguá MG2 were among the genotypes with the greatest genetic divergence. Furthermore, the authors also found that the cultivar Catuaí Amarelo IAC 62, one of the used in the present study, stood out in terms of yield. The genetic divergences of the Arabica coffee cultivars on their adaptation in high-temperature regions are associated to the content of protective molecules, such as the carotenes and the raffinose, with the activity of antioxidant enzymes, such as SOD and CAT, and with the regulation of the expression of some cultivar genes (Martins et al., 2016). For that matter, cultivars with greater adaptability in high-temperature regions present a greater expression of these said factors.

Hence, studies like this one are necessary for recommending cultivars more adapted to high-temperature regions, either for the immediate recommendation of these genotypes to producers or also as a information source for future breeding researches, aiming at selecting genotypes more tolerant to high temperatures, given the climate changes occurring in the last decades.

Conclusions

Plant height is the morphological attribute tending to have greater correlation with the productive potential from the Arabica coffee cultivars in high-temperature regions, thus allowing the indirect selection of genotypes more adapted to these conditions.

In general, when considering the vegetative vigor and the productive performance, the cultivars Obatã IAC 1669-20 and Catuaí Amarelo IAC 62 proved to be promising recommendations for cultivation in high-temperature regions.

Literature Cited

Alvares, C.A.; Stape, J.L.; Sentelhas, P.C.; Gonçalves, J.L.M.; Sparovek, G. Koppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, n.6, p.711–728, 2013. https://doi.org/10.1127/0941-2948/2013/0507.

Beckage, B.; Gross, L.J.; Lacasse, K.; Carr, E.; Metcalf, S.S.; Winter, J.M.; Howe, P.D.; Fefferman, N.; Franck, T.; Zia, A.; Kinzig, A.; Hoffman, F.M. Nature Climate Change, v. 8, n. 1, p. 79-84, 2018. https://doi.org./10.1038/s41558-017-0031-7.

Bergo, C.L.; Pereira, R.C.A.; Sales, F. Avaliação de genótipos de cafeeiros arábica e robusta no estado do Acre. Ciência e Agrotecnologia, v.32, n.1, p.11-16, 2008. https://doi.org/10.1590/S1413-70542008000100001.

Camargo, A. P. Zoneamento de aptidão climática para a cafeicultura de arábica e robusta no Brasil. In: Instituto Brasileiro de Geografia e Estatística - IBGE. Recursos naturais, meio ambiente e poluição: contribuições de um ciclo de debates. v.2, meio ambiente e poluição. Rio de Janeiro: IBGE; Supren, 1977. p. 68-76. https://biblioteca.ibge.gov.br/visualizacao/livros/liv81992_v2.pdf. 06 Set. 2019.

Camargo, M.B.P.D. The impact of climatic variability and climate change on arabic coffee crop in Brazil. Bragantia, v.69, n.1, 239-247, 2010. http://dx.doi.org/10.1590/S0006-87052010000100030.

Carvalho, A.M.; Mendes, A.N.G.; Carvalho, G.R.; Botelho, C.E.; Gonçalves, F.M.A.; Ferreira, A.D. Correlação entre crescimento e produtividade de cultivares de café em diferentes regiões de Minas Gerais, Brasil. Pesquisa Agropecuária Brasileira, v.45, n.3, p. 269-275, 2010. https://doi.org/10.1590/S0100-204X2010000300006

Companhia Nacional de Abastecimento - Conab. Séries históricas das safras: café arábica. 2020. https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras/item/download/30436_5eb40fdf857245d53dcca87fd5752861. 10 Abr. 2020.

Craparo, A.C.W.; Van Asten, P.J.; Läderach, P.; Jassogne, L.T.; Grab, S.W. *Coffea arabica* yields decline in Tanzania due to climate change: Global implications. Agricultural and Forest Meteorology, v.207, p.1-10, 2015. https://doi.org/10.1016/j.agrformet.2015.03.005.

DaMatta, F.M.; Ramalho, J.D.C. Impacts of drought and temperature stress on coffee physiology and production: a review. Brazilian Journal of Plant Physiology, v.18, n.1, p.55-81, 2006. https://doi.org/10.1590/S1677-04202006000100006.

Empresa Brasileira de Pesquisa Agropecuária - Embrapa. Sistema brasileiro de classificação dos solos. 3.ed. Brasília: Embrapa, 2013. 353 p.

Ferreira, E.P.B.; Partelli, F.L.; Didonet, A.D.; Marra, G.E.R.; Braun, H. Crescimento vegetativo de *Coffea arabica* L. influenciado por irrigação e fatores climáticos no Cerrado Goiano. Semina: Ciências Agrárias, v.34, n.6, supl. 1, p.3235-3244, 2013. https://doi.org/10.5433/1679-0359.2013v34n6Supl1p3235.

Freitas, Z.M.T.S.; Oliveira, F.J.; Carvalho, S.P.; Santo, V.F.; Santos, J.P.O. Avaliação de caracteres quantitativos relacionados com o crescimento vegetativo entre cultivares de café arábica de porte baixo. Bragantia, v.66, n.2, p.267-275, 2007. https://doi.org/10.1590/S0006-87052007000200010.

Goes, T.B.; Chinelato, G.A. Viabilidade econômico-financeira da cultura do café arábica na região da Alta Mogiana. Revista IPecege, v.4, n.4, p.31-39, 2018. https://doi.org/10.22167/r.ipecege.2018.4.31.

International Coffee Organization - Ico. Trade Statistics, 2019. http://www.ico.org/trade_statistics.asp?section=Statistics. 23 Jul. 2019.

Lara, J.M.R.A.; Rezende, J.C.; Carvalho, G.R.; Pereira, A.A.; Carvalho, J.P.F.; Filho, O.G. Caracterização de formas botânicas diversas do Banco Ativo de Germoplasma de cafeeiros do Estado de Minas Gerais, Brasil. Bragantia, v.73, n.4, p.383-389, 2014. https://doi.org/10.1590/1678-4499.0208.

Larcher, W. Physiological plant ecology – ecophysiology and stress physiology of functional groups. 4.ed. Berlin: Springer-Verlag, 2003. 513p.

Machado, C.M.S.; Pimentel, N.S.; Golynsk, A.; Ferreira, A.; Vieira, H.D.; Partelli, F. L. Genetic diversity among 16 genotypes of *Coffea arabica* in the Brazilian cerrado. Genetics and Molecular Research, v. 16, n. 3, 2017. https://doi.org/10.4238/gmr16039794.

Malavolta, E.; Favarin, J.L.; Malavolta, M.; Cabral, C.P.; Heinrichsand, R.; Silveira, J.S.M. Repartição de nutrientes nos ramos, folhas e flores do cafeeiro. Pesquisa Agropecuária Brasileira, v.37, n.7, p.1017-1022, 2002. https://doi.org/10.1590/S0100-204X2002000700016.

Ministério da Agricultura, Pecuária e Abastecimento - Mapa. Registro Nacional de Cultivares 2020. http://sistemas.agricultura.gov.br/snpc/cultivarweb/cultivares_registradas.php. 10 Abr. 2020.

Martins, M.Q.; Rodrigues, W.P.; Fortunato, A.S.; Leitão, A.E.; Rodrigues, A.P.; Pais, I.P.; Martins, L.D.; Silva, M.J.; Reboredo, F.H.; Partelli, F.L.; Campostrini, E.; Tomaz, M.A.; *Scotti*-Campos, P.; Ribeiro-Barros, A.I.; Lidon, F.J.C.; DaMatta, F.M.; Ramalho, J.C. Protective response mechanisms to heat stress in interaction with high [CO2] conditions in *Coffea* spp. Frontiers in Plant Science, v. 7, article 947, 2016. https://doi.org/10.3389/fpls.2016.00947.

Matiello, J.B.; Santinato, R.; Garcia, A.W.R.; Almeida, S.R.; Fernandes, D.R. Cultura de café no Brasil: manual de recomendações. Rio de Janeiro: Mapa; Varginha: Procafé, 2010. 387 p.

Moura, W.D.M.; Lima, P.C.; Fazuoli, L.C.; Condé, A.B.T. Desempenho de cultivares de café em sistema de cultivo orgânico na zona da mata mineira. Coffee Science, v.8, n.3, p.256-264, 2013. http://www.coffeescience.ufla.br/index.php/Coffeescience/article/view/428/pdf_37. 06 Set. 2019.

Paiva, R.N.; Carvalho, C.H.S.; Mendes, A.N.G.; Almeida, S.R.; Matiello, J.B.; Ferreira, R.A. Field performance of coffee progenies (*Coffea arabica* L.) in Varginha, Minas Gerais State. Coffee Science, v.5, n.1, p.49-58, 2010. http://www.coffeescience.ufla.br/index.php/Coffeescience/article/view/271/255. 06 Sep. 2019.

Rahn, E., Vaast, P., Läderach, P., Van Asten, P., Jassogne, L., Ghazoul, J. Exploring adaptation strategies of coffee production to climate change using a process-based model. Ecological Modelling, v.371, p.76-89, 2018. https://doi.org/10.1016/j.ecolmodel.2018.01.009.

Raij, B.V.; Cantarella, H.; Quaggio, J.A.; Furlani, A.M.C. Recomendações de adubação e calagem para o Estado de São Paulo. 2.ed. Campinas: Instituto Agronômico de Campinas; Fundação IAC, 1996. 285 p. (IAC. Boletim Técnico, 100).

Rena, A. B., Nacif, A. P., Guimarães, P. T. G., Bartholo, G. F. Plantios adensados de café: aspectos morfológicos, ecofisiológicos, fenológicos e agronômicos. Informe Agropecuário, v.19, n.193, p.61-70, 1998. http://www.epamig.br/download/ia_193_cafeicultura-tecnologia-para-producao_1998/#. 07 Set. 2019.

Teixeira, A.L.; Gonçalves, F.M.A.; Rezende, J.C.; Rocha, B.R.; Pereira, A.A. Principal component analysis on morphological traits in juvenile stage arabica coffee. Coffee Science, v.8, n.2, p.205-210, 2013. http://www.coffeescience.ufla.br/index.php/Coffeescience/article/view/411/pdf_148. 06 Sep. 2019.

Teixeira, A.L.; Souza, F.F.; Pereira, A.A.; Oliveira, A.C.B.; Rocha, R.R. Selection of arabica coffee progenies tolerant to heat stress. Ciência Rural, v.45, n.7, p.1228-1234, 2015. https://doi.org/10.1590/0103-8478cr20130317.

United States Department of Agriculture - USDA. Coffee: world markets and trade. 2019/20 Forecast overview. Washington: Foreign Agricultural Service; USDA, 2019. 8p. https://apps.fas.usda.gov/psdonline/circulars/coffee.pdf. 23 Jul. 2019.