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Performance of arabica coffee cultivars under high temperature conditions

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The aim of this study was to evaluate the grain yield of Arabica coffee cultivars grown under high temperatures in regions of low altitude and high mean temperatures in the State of Rondônia, Brazil. Thirty-five Arabica coffee cultivars provided by Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) were evaluated. A randomized block design was used with three replications, spacing of 3.0 x 1.0 m, with four plants per plot. All the crop seasons showed a significant difference for the green coffee yield trait. In joint analysis, a significant difference was detected among the cultivars. In the mean of the four harvests, green coffee yield was 24.60 bags ha^{-1}. The yield of the cultivars CatucaíAmarelo 24/137 and ObatãVermelho IAC 1669-20 stood out, with yields greater than 35 bags ha^{-1}. Four cultivars with better performances were selected with a gain from selection of 40.93% in green coffee yield. In regard to the maturation cycle, 29 cultivars exhibited an early cycle, five medium cycles and one late cycle.

Key words: *Coffea arabica* L., coffee plant breeding, heat tolerance.

INTRODUCTION

According to the International Coffee Organization (ICO), worldwide coffee consumption in 2020 will be 166.10 million bags, which represents a 17% increase compared to the consumption of 140 million bags in 2012. Brazil currently constitutes the largest producer and exporter of the grain, achieving a record crop of 50.8 million bags in 2012. Of this amount, 76% of the production is of the *Coffea Arabica* species, while 24% is of the *Coffea canephora* species (Porto et al., 2012). The temperature factor has limited the growth and expansion of arabica coffee in various countries, including Brazil. The *C. arabica*s pecies expresses its full potential at mean annual temperatures ranging from 18 to 23°C. Above 23°C, innumerable physiological disorders are observed in the flowers and fruits of the coffee plant, resulting in yield losses and poor beverage quality. The occurrence of high temperatures leads to lack of uniformity and early maturation of the fruit, resulting in loss of quality (Camargo, 1985; Damatta and Ramalho, 2006). Moreover, high air temperatures during flowering, associated with a prolonged dry season result in abortion of flowers and thus, significant yield reduction (Fazuoli et al., 2007).

The average annual temperature in the state of Rondônia, Brazil, is approximately 26°C, and due to this, all coffee grown in the state is of the *C. canephora*

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species, without representation of the arabica species in production. All the Arabica coffee consumed in Rondônia and other states of the Northern region is imported from typical producing regions like Minas Gerais and São Paulo (Souza and Santos, 2009). As all of the production in the state is composed of grains of the canephora species, local industries produce coffees with a minimum of Arabica coffee. In other words, many coffees available to the local consumer are, in practice, 100% canephora.

In the North region alone, where the annual per capita consumption is 4.80 kg of roasted coffee, there is an estimated demand of 1.66 million bags. Considering that all the coffee produced and processed in the region is, in practice, composed of canephora grains, 830 thousand bags of Arabica coffee would be necessary for composition of the blends, considering a percentage of 50% Arabica/canephora. In the state of Rondônia, these values come to 81 thousand bags. And this is without considering the perspective of increase in consumption and the special or "gourmet" coffee market.

Although, there are some Arabica coffee farms in the northern region, the genetic materials used are of unknown origin, or even cultivars from other regions that were introduced without recommendation. Currently, there is no Arabica coffee cultivars recommended for the state of Rondônia. On the other hand, the perception of an increasing demand of Arabica in the region, associated with growth of the special or "gourmet" coffee market, justifies the recommendation of a cultivar adapted to the soil and climate conditions of the region.

In light of the above, the aim of this study was to evaluate the agronomic performance of Arabica coffee cultivars in the state of Rondônia so as to introduce them in the next value for cultivation and use (VCU) trials.

MATERIALS AND METHODS

The experiment was set up in September 2005 in the Embrapa experimental field, municipality of Ouro Preto do Oeste, Rondônia state, Brazil, which is located at the coordinates 10°44'53"S and 62°12'57"W. The climate in the region is classified as Tropical Wet and Dry, Aw (Köppen), with mean annual temperatures of 25.8°C and mean annual rainfall of 2,300 mm. The mean altitude of the region is 240 m, with relative air humidity near 82% most of the year.

The experiment was composed of 35 cultivars of arabica coffee (recommended for other regions of the country) (Table 2), provided by the Empresa de Pesquisa Agropecuária de Minas Gerais (Crop and Livestock Research Company of Minas Gerais) – EPAMIG. A randomized block experimental design was used with three replications, spacing of 3.0 x 1.0 m and four plants per plot. The management practices and fertilization were conducted according to the recommendations by Marcolan et al. (2009).

The following traits were evaluated: yield – in 60 kg bags of green coffee per hectare (bags ha^{-1}) – harvest was performed in individual plots, and production evaluated in liters of "field coffee" ("café da roça" - coffee at all stages of maturity) per plot. After that, conversion of the volume of coffee collected to bags ha^{-1} was performed by approximation of values, considering average yield of 480 L of "field coffee" for each 60 kg bag of green coffee, which corresponds to the average yield adopted in all regions. Maturation cycle was defined by the time interval between flowering and harvest. The interval of 20 to 30 days between harvests was used as a criterion to classify the genotypes as early (E), medium (M) or late (L). Percentage of empty locule fruits – based on a one liter coffee sample, a selection of fifty fruits in the cherry stage was made. Then the selected fruits were deposited in a container with water. The number of floaters was counted and this result was multiplied by two, obtaining the percentage of empty locule fruits (Medina-Filho and Bordignon, 2003).

The data obtained in reference to green coffee yield were subjected to analysis of variance with the significance of the effects verified by the F test at 5% probability. Selective accuracy ($\hat{r}_{\hat{g}g}$), determined by means of the expression: $\hat{r}_{\hat{g}g} = (F-1/F)^{1/2}$, in which F is the value of the Snedecor F test for the genotype effect (Resende and Duarte, 2007), was estimated so as to gauge experimental precision. Analyses of variance and gain from selection were performed using the computational software GENES.

RESULTS

A significant difference was detected for green coffee yield in all the crop seasons (Table 1). With the exception of the first (45.44%), all the following crop seasons exhibited estimates of selective accuracy of high magnitude (83.36 % $< \hat{r}_{\hat{g}g} <$ 91.85%), indicating good experimental precision. The lowest mean yield of green coffee was observed in the 2007/2008 crop season (5.04 bags ha^{-1}). The reason for low yield was that this was the first production crop season. In the 2008/2009 crop season, the general mean yield of green coffee was 12.64 bags ha^{-1}. The 2009/2010 and 2011/2012 crop seasons obtained satisfactory production, with mean yields of 37.58 and 43.13 bags ha^{-1}, respectively. These values are expressive when considering that the trials were conducted at low altitude and under high temperature conditions (Figure 1). For the mean value of the four harvests, green coffee yield was 24.60 bags ha^{-1} (Table 2). Of the total, 22% of the genotypes exhibited yields above 30 bags ha^{-1}. The cultivars Catucaí Amarelo 24/137 and Obatã Vermelho IAC 1669-20 stood out, with yields of 42.72 and 36.34 bags ha^{-1}, respectively. The heritability estimate observed for green coffee yield was 88.01% (Table 1).

For the characteristic of empty locule fruits, the mean value of the cultivars was 11% (Table 2). There was no incidence of orange rust throughout the entire crop cycle, making it impossible to evaluate the genotypes in regard to resistance to the pathogen. The evaluation of four production crop seasons made it possible to verify the reliability of the genetic parameters in each set of crop seasons (Table 3 and Figure 2). It was possible to observe that evaluation of the 3rd and 4th crop season alone would already be sufficient to estimate the genetic parameters with efficiency, with a coefficient of determination (R^2) of 73.65%.

On the other hand, it is also perceived that, in this

Table 1. Summary of joint analysis of variance and estimates of heritability (h^2) and selective accuracy ($\hat{r}_{\hat{g}g}$) for green coffee yield (bags ha^{-1}), in reference to the crop seasons 2007/2008, 2008/2009, 2009/2010 and 2011/2012. Ouro Preto do Oeste, RO, Brazil, 2012.

SV	DF	Mean square
		Green coffee yield (bags ha^{-1})
Blocks	2	102.6731
Cultivars	34	531.3806**
Crop seasons	3	36308.5789**
Cultivars x crop seasons	339	190.0339**
Residue	910	63.7360
Overall mean	24.60	
Heritability (h^2)	88.01	
Selective accuracy ($\hat{r}_{\hat{g}g}$)	80.15	

**, *: Significant at 1 and 5% by the F test, respectively. SV: Source of Variation; DF: Degree of Freedom.

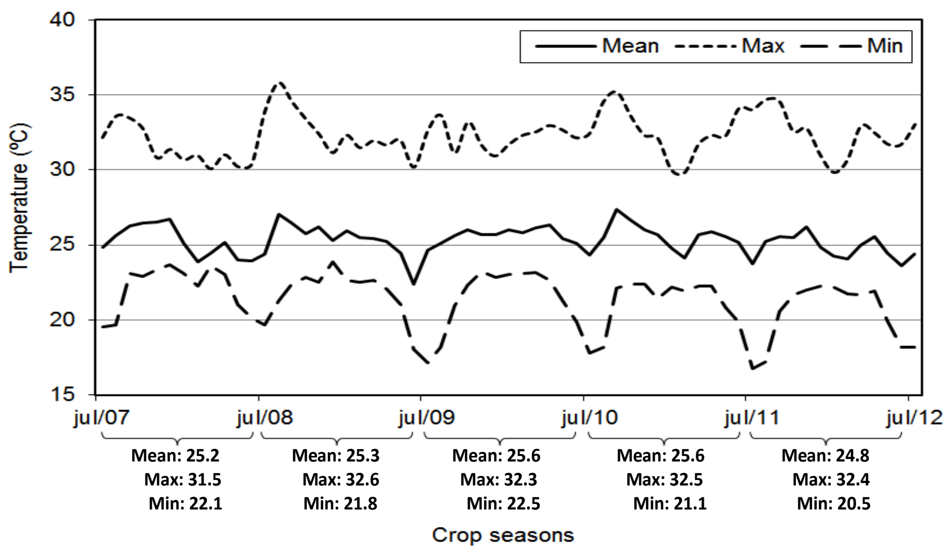

Figure 1. Representation monthly of maximum, average and minimum temperatures during the period July/2007 to July/2012. Maximum, average and minimum temperatures are also represented by crop seasons (2007/2008, 2008/2009, 2009/2010 and 2011/2012). Ouro Preto do Oeste, Rondônia, Brazil, 2012.

case, the estimates obtained without the inclusion of the fourth harvest would not be very reliable. When the joint estimate of all the crop seasons was used, the coefficient of determination was 70.50%. In relation to the maturation cycle, it may be observed that all the harvests were carried out from the months of February to April. In relation to the difference among cultivars, 29 were classified as early cycle (January/February), 5 as medium cycle (March) and 1 as late cycle (April) (Table 2).

DISCUSSION

The low accuracy detected in the first harvest (45.44%) is normally explained by the greater variation in genotypic values for green coffee yield. In subsequent harvests, these differences tend to diminish, as was observed in the experiment. This reinforces the need for evaluations in more than one crop season, lending reliability to the selection process and to the estimates of the genetic values. The use of accuracy as a measure of experimental precision, suggested by Resende and Duarte (2007), has the advantage of not depending on the mean value, which provides greater security in use of the phenotypic expression as an indicator of genotypic variation. Accuracy values above 70% indicate high experimental precision.

Carvalho et al. (2010) evaluated some of these

Table 2. List of the 35 cultivars of *Coffeaarabica*for green coffee yield (bags ha^{-1}), percentage of empty locule fruits (%), maturation cycleand fruit color in regard to the crop seasons 2007/2008, 2008/2009, 2009/2010 and 2011/2012.Ouro Preto do Oeste, Rondônia, Brazil, 2012.

Cultivar	Green coffee yield (bags ha^{-1})	Empty locule fruits (%)	Maturation cycle[1]	Fruit color[2]
CatucaíAmarelo 24/137	42.72	15	E	Y
ObatãVermelho IAC 1669-20	36.34	8	M	R
IPR 103	33.01	5	M	R
Acauã	32.09	15	L	R
CatucaíAmarelo 2SL	31.87	12	E	Y
IPR 99	31.27	19	E	Y
IPR 100	30.68	12	E	R
Tupi	30.46	20	E	R
Ouro Verde Vermelho	29.05	9	E	R
Rubi MG 1192	28.26	17	E	R
Araponga MG 01	27.95	10	E	R
H419-3-3-7-16-1	27.35	7	E	Y
IAPAR 59	27.17	11	E	R
CatucaíVermelho 758/15	26.64	11	E	R
CatuaíVermelho IAC 144	26.29	8	E	R
Palma II	26.25	15	E	R
Pau Brasil MG 01	24.68	9	E	R
Topázio MG 1190	24.62	17	E	Y
Ouro Verde Amarelo	23.36	12	E	Y
Paraíso H419-10-6-2-12-1	22.86	20	M	Y
Oeiras MG 6851	22.20	20	E	R
Paraíso H419-10-2-5-1	21.58	17	E	Y
CatucaíVermelho 20/15/ Cv 476	21.24	9	E	R
Paraíso H419-10-6-2-10-1	20.62	17	M	Y
Sabiá 398	20.37	23	E	R
Sacramento MG 01	20.27	23	E	R
IPR 98	20.00	7	E	R
CatucaíAmarelo 20/17 Cv 479	18.48	21	E	Y
Catinguá MG 02	18.15	12	E	R
CatuaíAmarelo	17.98	10	E	Y
Acaiá do Cerrado	17.55	13	E	R
Obatã Amarelo Ms Faz. Onça	16.88	11	M	Y
IPR 104	16.13	12	E	R
Catinguá MG 01	15.72	12	E	R
IcatuVermelho	10.89	6	E	R
Overall Mean	24.60	13		
Mean of selected cultivars (4)	36.04	11		
Gain from selection (%)	40.93			

[1]E = Early; M = Medium; L = Late.[2]R = Red; Y = Yellow.

Cultivars in four municipalities in the south of Minas Gerais and obtained yields similar to those observed in Rondônia. This indicates the importance of including them in Value for Cultivation and Use trials for the purpose of extending the recommendation for planting of these cultivars in the state.

According to Borém (1999), for a good selection process, the genetic material used as a control must be represented by cultivars recommended for the region where the selection process is performed. However, in the case of non-existence of these materials, cultivars recommended in other regions are used, or even genetic materials from the breeding program itself that show good performance in the soil and climate conditions of

Table 3. Estimate of the coefficient of determination (R^2) in relation to the number and time of harvest. Values in reference to the sets of two, three and four crop seasons.Ouro Preto do Oeste, Rondônia, Brazil, 2012.

No. of harvests	Crop seasons	Component	R^2
2	1st and 2nd	0.45	62.30
2	2nd and 3rd	0.43	60.06
2	3rd and 4th	0.58	73.65
3	1st, 2nd and 3rd	0.39	65.88
3	2nd, 3rd and 4th	0.44	70.02
4	All the crop seasons	0.37	70.50

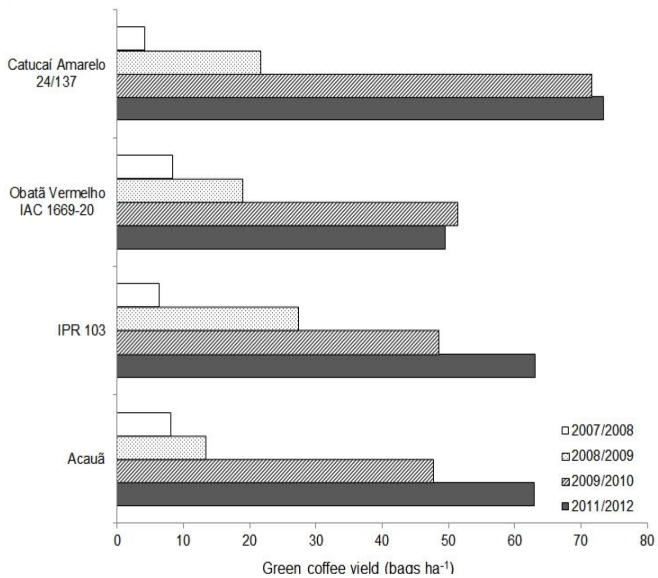

Figure 2. Annual production performance of the four selected cultivars of *Coffeaarabica* in regard to the crop seasons of 2007/2008, 2008/2009, 2009/2010 and 2011/2012 (bags ha^{-1}). Ouro Preto do Oeste, Rondônia, Brazil, 2012.

the region.

The percentage of empty locule fruits observed was similar to that found in the commercial plantings of the southeast of Brazil, indicating that this characteristic was not negatively affected by the high temperatures. Heritability greater than 88%, for its part, ensures success in selection of superior genotypes and indicates the proportion of genetic variance in regard to total phenotypic variance, that is, the heritable proportion of total variability (Mohsin et al., 2009). The significant difference detected among cultivars indicates the existence of genetic variability (Table 1), and that allowed the selection of four better classified cultivars in regard to green coffee yield, so as to include them in the next Value for Cultivation and Use trials. The cultivars selected were CacucaíAmarelo 24/137, ObatãoVermelho IAC 1669-20, IPR 103 and Acauã (Figure 2). The gain from selection obtained was 10.07 bags ha^{-1}, which represents an increase of 40.93% in green coffee yield (Table 2).

The yield of the cultivars was the main criterion used in measuring their tolerance to heat stress. Wahid et al. (2007) affirms that heat tolerance is the ability of the plant to develop and produce under high temperature conditions. Falconer and Mackay (1996) showed that the yield trait of grains is governed by various genes of small effect on the phenotype, classifying this trait as quantitative, that is, there is a strong influence of the environment on expression of this trait. The maturation cycle was not used as a selective criterion; however, evaluation of it becomes necessary since the introduction of both early cycle and late cycle cultivars is desired. According to Bardin-Camparotto et al. (2012), the thermal factor affects the maturation cycle of the coffee fruits which, when subjected to heat stress conditions, tend to show an earlier maturation cycle.

Historically, January and February are the best months for negotiations in the coffee market. In this period, Arabica coffee price quotations are, on average, 40% greater than the annually registered values. On the other hand, these are the months in which there are the greatest volumes of rain in the state, making the use of dryers and covered yards necessary for drying coffee.

The next stage of research is the introduction of selected cultivars in the advanced competitive trials (VCU) together with other elite progenies selected in the breeding program for heat tolerance. Sensory and physiological analysis will be performed in these advanced trials, since they will be conducted in at least four places. The desire is for an extension of recommendation of these cultivars for planting in the Northern region of Brazil and the release of at least one new Arabica coffee cultivar which is heat tolerant.

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