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Genotype-environment interaction for the sensory profile of *Coffea arabica* lines in high temperature regions in the Western Amazon

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ABSTRACT. The aim of this study was to select *Coffea arabica* lines with improved adaptability to tropical edaphic conditions. Competitive trials were set up at three locations of the states of Rondônia and Acre. Each trial was composed of 21 lines in the F5 generation and four reference cultivars evaluated as controls. To analyze beverage quality, six liters of coffee fruit at the M3 maturity stage was collected for each line in the environments of Alta Floresta do Oeste, RO (E1), Porto Velho, RO (E2), and Rio Branco, AC (E3). On the same day, after collection, the fruit was washed and placed to dry (natural processing) in full sun over canvas, until the samples reached 11-12% moisture. Sensory analysis of the samples was carried out by three judges/cuppers (Q Grader), according to the sensory analysis method of the Specialty Coffee Association of America. Analysis of variance showed that the effect of the genotype x environment interaction was significant, indicating differentiated performance of the lines grown in the different locations. Environments E2 and E3 were not favorable for beverage quality, whereas environment E1 showed better conditions for production of specialty coffees. In sensory analysis, six lines had higher final beverage quality scores than the controls. Line 2 had a final score of 80, line 11 had a final score of 79, and line 12 had a final score of 77. In addition to good beverage quality, lines 2, 11 and 12 also had yields higher than 30 bags ha^{-1} in the average of three harvest periods, indicating the possibility of selecting lines with improved adaptation to tropical regions.

Key words: *Coffea arabica*; Line x environment interaction; Beverage quality

INTRODUCTION

Arabica coffee (*Coffea arabica*.) originated on the African continent at an altitude of 1600-2800 meters above sea level and mean air temperature from 18ºC-20ºC (Moat et al., 2017). This species produce a beverage of greater economic value, with strong aroma, sweetness and less body compared to that made from *C. canephora* (Partelli et al., 2014; Rendón et al., 2014; Souza et al., 2018).

The Western Amazon is considered a marginal area for growing *C. arabica*, since low altitudes and high temperatures of the tropics favor flower abortion and accelerates fruit maturation, reducing the sugar and aromatic precursors contents that confer flavor to the beverage (DaMatta et al., 2012; Rodrigues et al., 2016). In the Western Amazon, the fruit ripens during the period of greatest rainfall, from February to April, making post-harvest procedures more difficult (Teixeira et al., 2014). In this scenario, the selection of coffee plants with good productivity, late maturation cycle, and good beverage quality has the potential to subsidize the development of new cultivars better adapted to tropical climate regions.

Coffee beverage quality is quantified in sensory analysis tests, using terminology established by the International Coffee Organization (ICO) and attributing scores according to the protocol and the attributes of the coffee beverage (Cheng et al., 2016). Beverages with scores above 80 points are considered specialty coffees, with prices that can be 40 to 80% greater than commodity coffees (Martinez et al., 2014).

Beverage quality depends both on genotype and environment effects (Sunarharum et al., 2014). The main attributes of the beverage evaluated during cupping, such as acidity, body, flavor, and aroma are affected by the environment factor, which influences plant nutrition and cycle maturation. Plant performance is evaluated considering the interaction of genotypes and environments (GE) that may favor or reduce the quality of the beverage produced at these locations (Czerny et al., 1999; Alves et al., 2011). In environments that are marginal for coffee growing, it is important to select lines that associate greater adaptability, understood as better performance, with greater stability, defined as the ability to maintain the response in different environments (Rocha et al., 2016).

The Additive Main Effect and Multiplicative Interaction (AMMI) is a selection tool based on multivariate analysis that allows simultaneous evaluation of numerous genotypes, quantifying their performance in different environments in a biplot dispersion (Santos et al., 2017). To analyze the GE interaction, the biplot is interpreted considering the magnitude and sign of the genotypes scores, in which low scores represent genotypes of higher stability. To order the genotypes of higher adaptability,] the non parametric methodology of Lin and Binns (1988) was employed; it considers the mean square distance between the cultivar mean and the maximum response observed in the environments. The environmental quality index (Ij) was also used in the classification of the environments in relation to their contribution to the plant to performance (Schmildt et al., 2011).

Our objective was to quantify the genotype x environment interaction for beverage quality in various environments of the Western Amazon to assist in the selection of *C. arabica* lines with greater adaptability to tropical edaphic conditions.

MATERIAL AND METHODS

Genetic material

We evaluated 21 arabica coffee lines that were in the F5 generation and four commercial cultivars recommended for the Southeast region of Brazil. These lines were pre-selected in evaluations made by Teixeira et al. (2013; 2015) (Table 1).

The commercial cultivars used as controls were Acauã, Catuaí Amarelo 2SL, Obatã IAC 1669-20, and Tupi. Acauã is a cultivar with high resistance to water deficit and good beverage quality (Carvalho, 2008), Catucaí Amarelo 2SL stands out for good resistance to rust, high yield and good beverage quality (Carvalho et al., 2012). Obatã IAC 1669-20 is a cultivar resistant to rust that has late maturity and good beverage quality (Fazuoli et al., 2018), and the Tupi cultivar has short height, resistance to rust, and medium beverage quality, being recommended for growing in regions of fertile soil and mild climate (Carvalho, 2008).

Table 1. Listing of the *Coffea arabica* lines in the F5 generation and four control cultivars (T22-T25), with their respective institutions of origin.

Line	Origin	Line	Origin
1 (UFV 8710)	Epamig/UFV	14 (P27-2)	IAC
2 (H419-10-6-2-1-6)	Epamig/UFV	15 (P27-4)	IAC
3 (H419-10-6-2-1-10)	Epamig/UFV	16 (P29-5)	IAC
4 (H419-10-6-2-1-7)	Epamig/UFV	17 (P29-6)	IAC
5 (H419-10-6-2-1-8)	Epamig/UFV	18 (P94-1)	IAC
6 (H419-10-6-2-3-21)	Epamig/UFV	19 (P94-5)	IAC
7 (H419-6-2-5-3-17)	Epamig/UFV	20 (P109-4)	IAC
8 (H514-7-10-6-17)	Epamig/UFV	21 (P109-6)	IAC
9 (H514-7-10-6-12)	Epamig/UFV	T22 (Catucaí Amarelo 2SL1)	Fundação Procafé
10 (H514-7-10-6-29)	Epamig/UFV	T23 (Obatã IAC1669-20 1)	IAC
11 (H514-7-10-6-25)	Epamig/UFV	T24 (Acauã1)	Fundação Procafé
12 (H514-7-10-6-9)	Epamig/UFV	T25 (Tupi1)	IAC
13 (H514-7-10-6-2-3-9)	Epamig/UFV		

EPAMIG: Agricultural Research Company of Minas Gerais, IAC: Agronomic, Institute of Campinas; UFV: Federal University of Viçosa, T22-T25: commercial cultivars used as testers.

Experimental trials

The experimental design used was randomized blocks, with 25 treatments and three replications of four plants per plot. Management practices were carried out according to the recommendations of the production system for coffee growing in Rondônia at a spacing of 3.00 x 1.00 meters (Marcolan et al., 2009). All the experiments were irrigated from the first flowering up to the beginning of the rainy period, from July to October. The environments where the trials were conducted are described below:

Trial 1- Municipality of Alta Floresta do Oeste, RO, on the rural property of Jacinto Migliorini, at 13°03'35” S and 62°33'53” W and altitude of 350 m. The predominant climate of the region is humid tropical, with a well-defined dry season from June to August, type “Aw” (Alvares et al., 2013) (Figure 1). In this environment, the soil chemical characteristics at the depth of 0-20 cm are pH, 6.00; P, 24 mg/dm^3; K, 0.64 cmolc/dm^3; Ca, 8.25 cmolc/dm^3; Mg, 0.97 cmolc/dm^3; Al+H, 5.45 cmolc/dm^3; Al, 0.00 cmolc/dm^3; OM, 30.30 g/kg; and V, 64.00%.

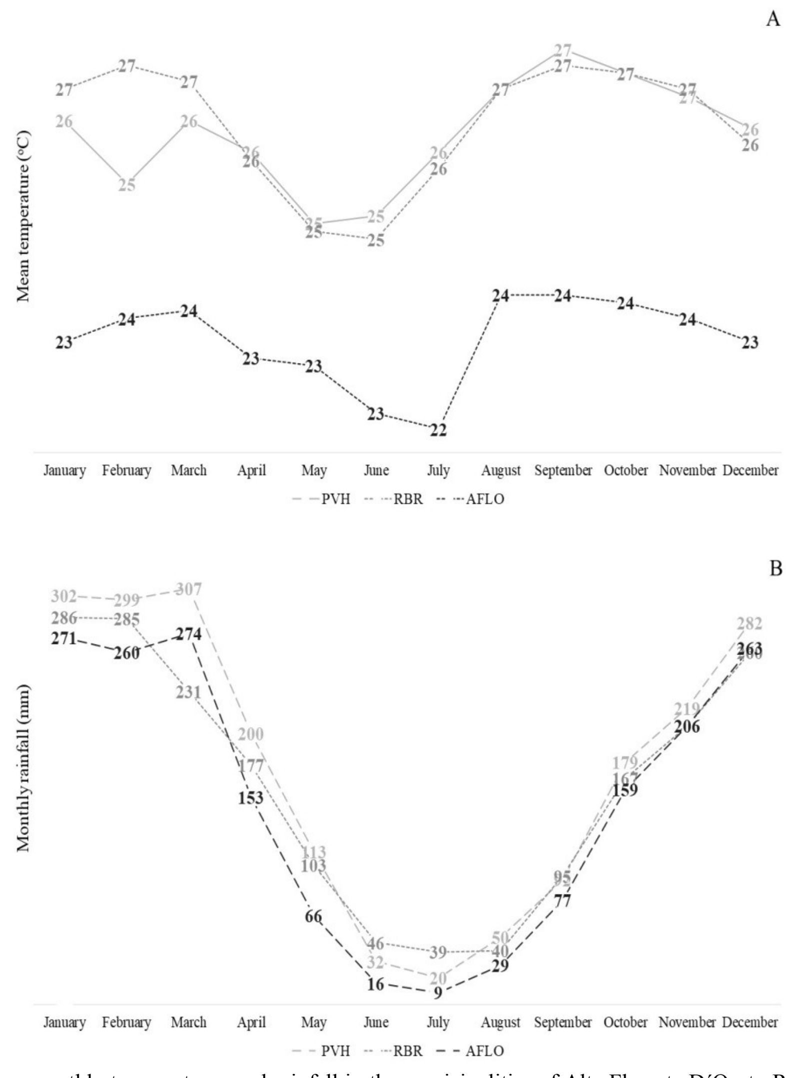

Figure 1. Mean monthly temperatures and rainfall in the municipalities of Alta Floresta D´Oeste-RO (E1), Porto Velho-RO (E2) and Rio Branco-AC (E3) according to the climatological records from 1981 to 2010.

Trial 2- Municipality of Porto Velho, RO, in the experimental field of Embrapa Rondônia, at 08º 47’ 56” S and 63º 50’ 49” W and altitude of 88 m. The predominant climate of the region is rainy tropical with a dry winter, of type “Am” with an average temperature of 26.0 °C with a maximum of 37°C and minimum of 20°C (Alvares et al., 2013) (Figure 1). In this environment, the soil chemical characteristics at the depth of 0-20 cm are pH, 5.40; P, 2.00 mg/dm3; K, 0.09 cmolc/dm3; Ca, 1.48 cmolc/dm3; Mg, 1.02 cmolc/dm3; Al+H, 13.53 cmolc/dm3; Al, 0.87 cmolc/dm3; OM, 50.90 g/kg; and V, 16.00%.

Trial 3 – Municipality of Rio Branco, AC, in the experimental field of Embrapa Acre, at 10° 1' 30.98" S and 67°42' 21.77" W and altitude of 180 m. The predominant climate is tropical humid, type “Aw” (Köppen), with a well-defined dry season from June to August (Alvares et al., 2013). Mean temperature is 26.2°C and mean annual rainfall is 1935 mm. Mean monthly temperature ranges from 24.7ºC to 26.9ºC (Figure 1). In this environment, the soil chemical characteristics at the depth of 0-20 cm are pH, 5.45; P, 3.78 mg/dm^3; K, 0.15 cmolc/dm^3; Ca, 2.10 cmolc/dm^3; Mg, 0.55 cmolc/dm^3; Al+H, 1.88 cmolc/dm^3; OM, 11.18 g/kg; and V, 59.80%.

Sample collection

Coffee fruit was collected in the 2017/2018 crop season in the various environments, as described above. Six liters of coffee fruit was collected per cultivar in the M3 maturity stage, which is light red and physiologically ripe. On the same day, after collection, the fruit was washed and placed to dry (natural processing) in full sun over canvas, until the samples reached 11-12% moisture. The coffee was hulled in a sample preparation room at the experimental field of Embrapa, at Ouro Preto do Oeste, RO. The coffee beans were packaged in three replications of 500 gram samples.

Sensory analysis

Sample roasting and sensory analysis of the samples was carried out in the laboratory of the “Prove Café Company” in Venda Nova do Imigrante - ES (Brazil) by three judges/cuppers (Q Grader) trained and certified for the analysis of specialty coffees, according to the sensory analysis method of the Specialty Coffee Association of America (Lingle, 2011; SCAA, 2014).

In the SCAA (2014) methodology, evaluations are conducted blindly. The samples were evaluated between 08 and 24 hours after roasting. Then, they were ground in a Ditting 5.5 electric mill (Ditting Maschinen AG, Bachenbulach, Switzerland) to medium/coarse grain size. Five cups of each coffee batch were tasted, using a concentration of 8.25 g of ground coffee in 150 mL water, in accordance with the midpoint of the balance chart (SCAA, 2014). The infusion point of water occurred after the water reached 92.2 - 94.4 ºC. The tasters (judges/cuppers) started evaluations when cup temperature reached 55 ºC, respecting the time of 4 minutes for tasting after infusion.

At each evaluation, five cups of coffee were sampled and scored in the range of 0 to 10 points for each of the following attributes: fragrance/aroma, uniformity, absence of defects, sweetness, taste, acidity, body, balance and overall impression. The final score represented the sum of the attributes, summarized in a single value from the arithmetic mean among the panelists. Each processing method was evaluated separately. If the coffee sample achieves a final score greater than or equal to 80 points, it is classified as a specialty coffee. The sensory opinions of the cuppers of each sample were registered during the coffee cupping sessions as the beverage nuances of the coffee (Lingle, 2011).

Yield evaluation

Hulled coffee yield (bags ha^{-1}) was evaluated in the 2014/15, 2015/16, and 2016/17 crop seasons. Each plot was harvested and weighed in the field using a precision balance. After that, 3 kg samples were collected, and dried on a cement drying yard with a barge-type covering until reaching 11-12% moisture, thus obtaining the quotient between field coffee and hulled coffee. The hulled coffee yield in 60 kg bags per hectare was determined through the following equation:

$$Yield = \frac{\left(\frac{uc}{np}\right)}{60} * 3.333 * prop \quad \text{(Eq. 1)}$$

where Yield is coffee yield in bags per hectare; uc is uncleaned coffee production per plot (kg); np is the number of plants per plot; 3,333 refers to the number of plants per hectare; prop is the proportion between hulled coffee and uncleaned coffee expressed in percentage; and 60 corresponds to the weight of a bag of hulled coffee in kilograms

Statistical analysis

The significance of the genotypes effects in each environment was tested individually, according to the Cruz and Carneiro (2006) model:

$$Y_{ij} = m + G_i + B_j + E_{ij} \quad \text{(Eq. 2)}$$

where Y_{ij} refers to observation of the i-th genotype, in the j-th block; m is the experimental average; G_i is the effect of the i-th genotype (line effect); B_j is the j-th block effect; and E_{ijk} is the experimental error that affects all the observations made during the experiment.

After verifying the homogeneity of variances, combined analysis of variance was performed to quantify the effect of the genotype x environment (G x E) interaction, according to Cruz and Carneiro (2006) model, as follows in equation:

$$Y_{ijk} = m + G_i + B / A_{jk} + A_j + GA_{ij} + E_{ijk} \quad \text{(Eq. 3)}$$

Where Y_{ijk} refers to observation of the i-th genotype, in the k-th block, and in j-th environment; m is the experimental average; G_i is the effect of the i-th arabica coffee line (genotype) ; B/A_{jk} is the effect of the k-th block within the j-th environment; A_j is the effect of the j-th environment; GA_{ij} is the effect of the interaction between the i-th genotype and the j-th environment; and E_{ijk} is the experimental error. The genotype effects were considered to be random, while the environmental effect was considered to be fixed.

To quantify the contribution of the different environments to the genotypes performance, the environmental quality index (I_j) was estimated based on Eberhart and Russel (1966), as follows in equation:

$$I_j = \bar{y}_j - \bar{y} \quad \text{(Eq. 4)}$$

where I_j is the environmental quality index; $\overline{y}_j$ is the overall average of the genotypes in environment j, and $\overline{y}$ is the overall mean average of the genotypes in all the environments. This index allows classification of the environments that have I_j greater than or equal to zero as "favorable", and environments with negative I_j as "unfavorable".

The broad-sense heritability measures the relative proportion between the genotypic and environmental effects on expression of the characteristics, as follows in equation:

$$h_g^2 = \frac{\sigma_g^2}{\sigma_g^2+\sigma_e^2} \quad \text{(Eq. 5)}$$

in which h_g^2 is the broad sense heritability, σ_g^2 is the genotypic variance, σ_e^2 is the environmental variance.

The AMMI analysis according to Zobel et al., (1988) combines in a single model additive components for the main effects of genotype (gi) and environments (ej), and multiplicative components for the effect of GE interaction (geij). The model that describes the mean yield of a genotype i in environment j is given by:

$$Y_{ij} = \mu + g_i + a_j + \sum_{c=1}^{q} \sqrt{\lambda_k}\alpha_{jk}\gamma_{ik} + \delta_{ij} + e_{ij} \quad \text{(Eq. 6)}$$

Where Y_{ij} is the beverage quality score of genotype i in environment j, μ is the overall mean; g_i is the effect of genotype i; a_j is the effect of environment j; λ_k is the k-th singular value of the original matrix interactions (GE); γ_{ik} is the element corresponding to the i-th genotype in the k-th singular vector of the GE matrix column; α_{jk} is the element corresponding to the j-th environment in the k-th singular vector of the GE matrix row; δ_{ij} is the residue not explained by the principal components;e_{ij} is the average experimental error associated with observation, assumed to be independent ε ~N(0, σ2).

To quantify the genotypes adaptability and stability in different environments, the estimator proposed by Lin and Binns (1988) was interpreted as follows in equation:

$$P_i = \frac{\sum_{j=1}^{n}(X_{ij} - M_j)^2}{2n} \quad \text{(Eq. 7)}$$

where P_i is the estimated adaptability and stability of the i-th genotype; Xij is the yield of the i-th genotype in the j-th environment; M_j is the maximum response observed among all genotypes in the j th environment; and n is the number of environments. This estimator was interpreted by considering the decomposition of P_i into favorable and unfavorable environments. The statistical analyses were performed using the software GENES (Cruz, 2016).

RESULTS AND DISCUSSION

Individual analyses of variance (ANOVA) were interpreted to quantify the experimental accuracy and post-harvest practices (Table 2). The environment of Alta Floresta do Oeste, RO (E1) presented higher beverage quality scores compared to Porto

Velho, RO (E2), and Rio Branco, AC (E3). This environment of lower mean temperature (23.4°) and higher altitude (350 m) was also classified as favorable to beverage quality (I_j =4.4). Lower temperatures tend to favor accumulation of sugar in the coffee beans upon retarding fruit maturation (Alves et al., 2011; DaMatta et al., 2012). Figueiredo et al. (2018) evaluated the beverage quality of *C. arabica* in three environments with differents altitudes and observed that all the environments were suitable for coffee production, although only the environment of highest altitude was favorable for production of specialty coffees (ALT $\cong$ 920 m).

Coefficient of variation estimates can be considered low, indicating high experimental accuracy and adequate performance of post-harvest procedures (Table 2). Lower estimates of the coefficient of variation (CV < 5%) were also observed by Oliveira et al., (2013) for the attributes of acidity, body, aftertaste, balance, and overall impression of the *C. arabica* beverage. Souza et al., (2018) observed estimates of coefficients of variation higher than those of this study, with a range of 12.1 to 15.7% in the evaluation of ten attributes of the Robust Tasting Protocol for 130 *C. canephora* genotypes.

The beverage quality is influenced both by the genotype and by the environment (Damata et al., 2012; Moreira et al., 2015; Ribeiro et al., 2020). The climate, the soil, the coffee management and post-harvest processing are some important factors to the beverage quality. Just as the cultive in regions of high temperatures accelerates the fruit ripening cycle, the use of irrigation with high doses of nitrogen may reduce the beverage quality by accelerating fruit ripening (Martinez et al., 2014). Clemente et al., (2013) evaluated the influence of mineral nutrition on the beverage quality of the variety Catuaí Vermelho IAC 99, observing that only K contributed to an increase in the levels of caffeine, total phenols, total sugars, reducers, color index and total acidity.

The region where coffee is grown in the Western Amazon is subject to the climatic types Am and Aw, characterized as typically tropical, humid and hot climates, with small annual thermal amplitude and expressive daytime thermal amplitude from May to September (Alvares et al., 2013). Coffee is grown in low-lying regions between 95 and 405 m, average annual air temperatures between 25 and 27°C, with maximum temperatures between 30 and 35°C and minimum between 18 and 20°C (Alvares et al., 2013). The Alta Floresta D´Oeste environment, which presented a final beverage quality score higher than the other environments, has higher altitude (350m) and lower average temperature (Figure 1), with rainfall similar to that of the other environments (Figure 1).

Besides environmental effects, genotype is also an important factor for beverage quality. The beverage quality scores showed individual heritability estimates ranging from 0.88 to 0.94, which, according to Cruz and Carneiro (2006) indicates predominance of the genotypes effect on the beverage quality expression (Table 2). Carvalho et al. (2016) evaluated agronomic characteristics of 33 progenies from the Catucaí group, having observed that two progenies showed superior quality compared to the control Catucai Amarelo 2SL. Cheng et al. (2016) also observed that beverage quality was influenced by both the genotype and the environment. However, the metabolism of coffee is not yet fully understood, and it is necessary to consider the unpredictability genotype x environment interaction, which must be studied considering each line separately.

Combined analysis of variance indicated that the effects of the genotype x environment interaction (GE) were significant at 1% probability (Table 3). In the occurrence of interaction, the response of the lines must be interpreted individually, due to the differential response of beverage quality in the different environments (Cheng et al., 2016). The G×E interaction also limits the seletion of lines of wide adaptability, since the interaction is characterized by changes in the relative performance of genotypes in different environments (Cruz and Carneiro, 2006). Mota et al., (2020) when evaluating the cultivars Bourbon Amarelo and Catucaí in five environments of Minas Gerais, observed that the cultivars presented different profiles of volatile compounds, and different sensorial analyzes according to the environment.

Table 2. Summary of the mean beverage quality final scores of 21 *Coffea arabica* lines and four testers evaluated in three environments of the Western Amazon.

Lines	Alta Floresta D´Oeste RO (E1)	Porto Velho RO (E2)	Rio Branco AC (E3)	Mean[1]	Pi
2	81.0	79.0	80.3	80	1
11	79.3	79.0	77.7	79	2
12	78.0	75.0	78.7	77	3
20	77.5	75.1	75.1	76	4
T25	81.7	71.3	73.2	75	5
13	76.5	75.2	73.5	75	6
T23	80.0	72.3	71.5	75	7
T24	81.7	65.6	75.5	74	8
T22	81.8	67.0	73.3	74	9
10	75.2	70.5	73.7	73	10
15	77.7	66.6	73.3	73	11
5	82.8	60.0	73.9	72	12
6	77.3	67.3	71.8	72	13
1	75.3	73.9	66.1	72	14
7	74.3	70.4	67.3	71	15
19	72.3	66.0	73.0	70	16
17	77.9	60.7	71.8	70	17
16	71.3	61.5	75.0	69	18
14	72.0	61.3	74.3	69	19
8	76.2	64.1	65.8	69	20
3	66.0	64.4	73.2	68	21
21	70.3	61.7	70.0	67	22
4	84.7	62.0	60.6	67	23
18	75.0	60.3	64.9	67	24
9	69.3	70.3	69.0	61	25
BQ_{mean}	77	68	72		
BQ_{max}	85	79	80		
BQ_{min}	66	60	61		
Ij	4.4	-4.2	-0.1		
$CV_{(\%)}$	3.57	3.56	3.68		
F	8.54**	18.23**	8.62**		
h^2	0.88	0.94	0.88		

Mean[1] : Lines and testers beverage quality final score means, Pi: ranking according to Linn & Binns (1988), BQ_{mean}: Mean beverage quality final scores, BQ_{max}: Maximum beverage quality final scores, BQ_{min}: Minimum beverage quality final scores, Ij: environmental index, $CV_{(\%)}$: coefficient of variation in percentage, F: F test of analysis of variance, h^2: mean heritability of lines. T22-T25: commercial cultivars used as testers. Final beverage quality was scored from the sum of each attribute scoring evaluated individually, on a scale ranging from 0 to 10. If the coffee sample achieves a final score greater than or equal to 80 points, it is classified as a specialty coffee.

The estimated heritability can be considered of medium magnitude (h^2 =48.58), which indicates the existence of the G x E interaction of the complex type (Table 3) (Sturion and Resende, 2005). Complex interactions are characterized by changes in the performance of the lines in different environments (Cruz and Carneiro, 2006). The ratio between the coefficients of genetic and environmental variation (CVg/Cve) also indicates the possibility of obtaining gains from lines selection. According to Ramalho et al. (2000), when this ratio is similar or higher than 1, the better the conditions for obtaining gains from selection (Table 3).

Table 3. Summary of the analysis of variance and estimated genetic parameters of the beverage quality final scores of 21 *Coffea arabica* lines and four testers evaluated in three environments of the Western Amazon.

SV	DF	SS	MS	F
Treatments (G)	24	2737.69	114.07	1.94*
Environment (E)	2	2762.74	1381.37	23.54**
GxE	48	2815.55	58.65	8.64**
Residual	150	1018.47	6.79	
Total	224	9334.44		
Overall mean	72.24			
C.V.%	3.61			
Genetic parameters				
Genotypic variance	6.16			
G x E variance	17.29			
Residual variance	6.79			
Herdability	48.58			
Intraclass correlation	20.36			
CVg	3.43			
CVg/Cve	0.95			

SV: Source of variation, DF: degrees of freedom, SS: sum of squares, MS: mean square, F: F test of analysis of variance, CVg/CVe: genetic coefficient of variation / environmental coefficient of variation, CVg: genetic coefficient of variation, ** Significant at 1% probability, * Significant at 5% probability.

The biplot of IPCA1 versus beverage quality final scores was interpreted to identify the lines of higher adaptability on the x-axis, and higher stability on the y-axis, since the most stable lines approach zero on that axis. In that way the lowest scores on the y axis, characterize lines with stable performance in all the environments (Dias et al., 2017). Many lines had low scores on the y axis, 15, 10, 12, 11, 2, 13, T23 17, 21, 4, 18, 14, 16, 8, 7 and 1. However, only a smaller set showed higher stability associated with a higher adaptability, interpreted as the highest beverage quality grades (Figure 2).

The controls T23 Obatã IAC1669-20 1, T24 Acauã and T25 Tupi showed higher beverage quality scores and lower stability. The cultivar Obatã IAC 1669-20 of late maturation cycle and the cultivar Acauã resistant to water deficit showed higher beverage quality compared to cultivar Tupi, usually recommended for cultivation in regions fertile soils and mild climate (Carvalho, 2008; Fazuoli et al., 2018). The control T22 Catucaí Amarelo 2SL of high productivity in regions of high temperatures had higher beverage quality grade in the Alta Floresta D´Oeste – RO (A1) environment (Carvalho et al., 2012; Souza et al., 2019).

The controls T25 Tupi, T24 Acauã and T22 Catucaí Amarelo 2SL showed better quality only in the A1 environment (81.7, 81.7, 81.8). The lines 5 and 4 showed similar performance of better beverage quality grades in the A1 environment (82.8 and 84.7) and scores below 75 points in other environments.

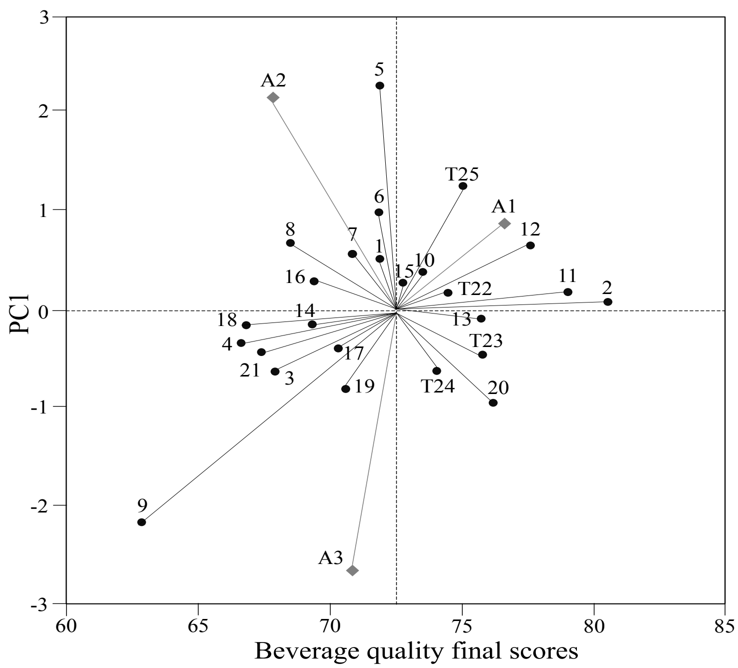

Figure 2. Biplot of IPCA1 (82%) versus beverage quality final scores of 21 *Coffea arabica* lines and 4 testers evaluated in three environments of the Western Amazon: Alta Floresta D ´Oeste - RO (E1); Porto Velho – RO (E2) and Rio Branco – AC (E3). The lines are identified by numbers and the commercial cultivars by the prefix T (testers).

Lines 2, 11 and 12 had also nuances that were appreciated in the evaluations of the beverage quality. The line 2 had nuances described as exotic, fruity, sweet, and citric. The line 11 had the nuances of fruity, citric, and sweet, and the line 12 and 13 had citric nuances. Complexies sensory descriptors were not associated with higher beverage quality scores and sweetness was the sensory descriptor with the greatest impact on the beverage quality. In the literature the nuances of fruity, caramel, chocolate, floral and sweet are associated with better beverage quality (Scholz et al., 2013; Moreira et al., 2015).

The selection of plants for the development of new cultivars may consider a set of favorable agronomic characteristics (Botelho et al., 2010). To select lines of higher beverage quality and also of higher productivity, the selection was made considering the beverage quality and the three-year average productivity, evaluated by Souza et al. (2019) (Figure 3). The A and C quadrants represent the lines that have divergent perfomance to beverage quality and yield, whether because they exhibited low beverage quality and high mean yield (Quadrant A) or because they exhibited high beverage quality and low mean yield (Quadrant C) (Figure 3).

The line 20 and the control T25 were classified in quadrant C of good beverage quality and low productivity (below 30 bags ha^{-1}). Despite its higher beverage quality score, the control T25 (Obatã IAC1669-20) showed lower productivity than the control T22 (Catucai Amarelo 2SLCAK), which was considered as the best control for associating higher beverage quality and productivity (36.90 bags ha^{-1}) (Figure 3).

The quadrants of convergent performance are those that exhibited high beverage quality and high mean yield (Quadrant B), and low beverage quality and low mean yield (Quadrant D). Of the twenty-one evaluated lines, thirteen (62%) were grouped in quadrant D of low productivity and low quality of the drink. These genotypes showed low adaptability to environments and should not be considered for cultivation in the Western Amazon. Beksisa et al., (2018), evaluating the GxA interaction of *C. arabica* productivity in 8 environments in Ethiopia, also observed only two superior lines, with the environment being the most relevant factor in productivity (42.75%). Bonomo et al. (2004) evaluated 28 F3 progenies from crosses between Timor Hybrid, Catuaí Vermelho and Catuaí Amarelo, in which six progenies had superior performance for a set of agronomic traits.

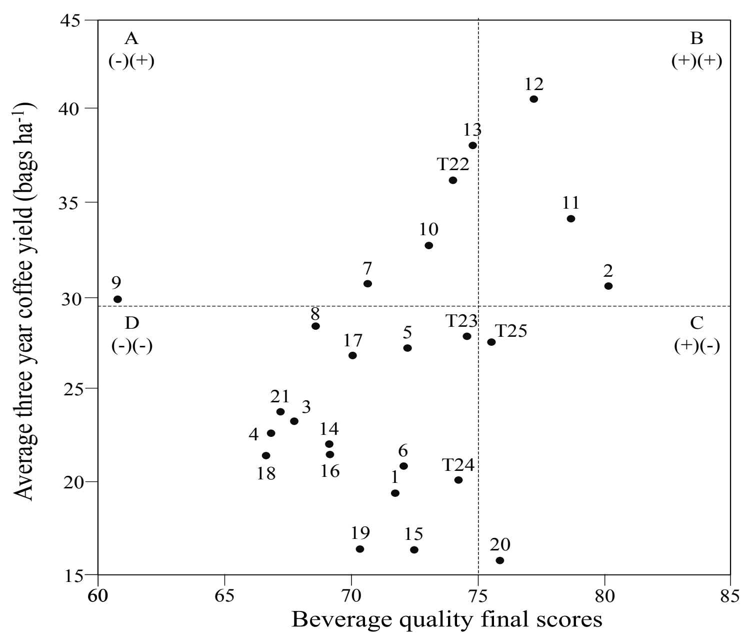

Figure 3. Biplot of the mean three years coffee yield and the beverage quality scores of 21 *Coffea arabica* lines and four testers evaluated in three environments of the Western Amazon: Alta Floresta D ´Oeste - RO (E1); Porto Velho – RO (E2) and Rio Branco – AC (E3). The lines are identified by numbers and the commercial cultivars by the prefix T (testers). Quadrant A(+)(-): low beverage quality final scores and high coffee yield, Quadrant B (+)(+): high beverage quality final scores and high coffee yield, Quadrant C(-)(+): high beverage quality final scores and low coffee yield, Quadrant D(-)(-): low beverage quality final scores and low coffee yield.

Lines 2, 11 and 12 were grouped in Quadrant B, differing from other genotypes, with average yields of 30.34, 34.75 and 41.42 bags per hectare and final beverage quality grades of 80, 79 and 77 in all environments, having better performance than the best control (T22-Catuaí Amarelo 2SL) of 36.90 bags ha^{-1} and beverage quality score of 74 in the environments. Zaidan et al. (2017) evaluated the *C. arabica* beverage quality in 14 municipalities of Minas Gerais, with altitudes ranging from 600 to 1200 m, in which they observed the higher beverage quality of the cultivar Catuaí Amarelo at altitudes near to 700 m. Dias et al., (2017) selected two superior *C. arabica* lines from 10 progenies evaluated in 13 environments.

Negative correlation estimates between two characteristics of interest can hinder the selection of plants seeking to increase both characteristics simultaneously (Dias et al., 2004). Coffee yield and beverage quality showed a correlation estimate of 0.30, which is not significant according to the t test at 5% probability. Other studies also indicate that the correlation between coffee yield and beverage quality is low, or nonexistent (Freitas et al., 2020). In *C. canephora*, Dalazen et al., (2020) observed that the most cultivated clones in the state of Rondônia due to their higher productive potential, show little difference in beverage quality. Selecting clones in the same region, Teixeira et al. (2020) also did not observe an association between coffee yield and beverage quality.

The adaptation of genotypes to specific environments is essential for the development of new cultivars (Cargnin et al., 2006). The lines 2, 11 and 12 are in the fifth generation of self-fertilization (F5) of the Coffee Genetic Improvement Program, from crosses between commercial cultivars carried out by EPAMIG and UFV. These lines were selected to advance generations for the development of new varieties.

CONCLUSIONS

The environment of Alta Floresta do Oeste (A1), was favorable for beverage quality with means of up to 5 points higher in the beverage quality scores.

The estimates of genetic parameters indicated a predominance of the genetic component in the expression of the beverage quality and a tendency of the selected lines to maintain their genetic superiority in different environments of the Western Amazon.

Among those genotypes of higher beverage quality only the lines 2 (H419-10-6-2-1-6), 11 (H514-7-10-6-2511), and 12 (H514-7-10-6-9) also had higher productivity.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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