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Genetic dissimilarity and growth of coffee in Cerrado

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Genetic dissimilarity can be used to identify promising genotypes for cultivation in specific conditions. Thus, the objective of this work is to study the genetic dissimilarity among 35 genotypes of *Coffea arabica* in the Cerrado, under irrigation, using phenological data and multivariate statistics. Plant height, stem diameter, canopy diameter, number of orthotropic branch nodes, length of orthotropic branch internodes, length of primary plagiotropic branches, and average plagiotropic branch internode length were evaluated at 6, 12, 18 and 24 months after planting. Data were analyzed using Hierarchical Agglomerative Cluster Analysis and Principal Component Analysis. Three clusters were formed for each evaluation (6, 12, 18 and 24 months). At 6 months, the most distant group consisted of Yellow Catucaí 2SL, Araponga MG 1, Sacramento MG 1, 23 II, Yellow Catucaí 20/15 pit 479, Sarchimor MG 8840, IBC-Palma 2, and New Acauã genotypes. At 12 months, the most distant group consisted of Yellow Catucaí 2SL, Asa Branca, Sacramento MG 1, and Sarchimor MG 8840. At 18 months, the most distant group consisted of Yellow Catucaí 2SL, Tupi IAC 1669-33, 23 II, Red Obatã IAC 1969-20, Sacramento MG 1, and Sarchimor MG 8840. At 24 months, Yellow Catucaí 2SL was distinct from the other 34 genotypes. Phenological variables strongly contributed to genetic dissimilarity (>75%) and there was a positive correlation for most variables.

Key words: Environment, *Coffea arabica* L., phenology, multivariate analysis, genetic, dissimilarity.

INTRODUCTION

Coffee production has contributed significantly to economic and social development in Brazil and is of great importance to Brazilian agribusiness. Brazil has been the world's largest producer and exporter of coffee for over 150 years (Paiva et al*.,* 2010). National productivity in 2018 was 1903.2 kg per hectare. In 2019, 1509.6 kg per hectare was estimated (CONAB, 2019).

The Brazilian coffee industry has undergone significant changes as crop has moved into the Cerrado areas, particularly in its production system (Oliveira et al., 2010). The Cerrado produces excellent quality coffee due to its two well-defined seasons: rainy summer and dry winter (Fernandes et al., 2012). In addition, controlled water stress can be used to standardize the flowering and ripening of fruits in the Cerrado (Guerra et al., 2005).

Brazil has 131 registered cultivars of *Coffea arabica* L. However, not all are able to adapt to different growing conditions and reach their productive potential. Botelho et al. (2010) point out that genotype with superior behavior in a certain environment may not behave satisfactorily under other conditions. Thus, it is necessary to improve and select genotypes to ensure that they express desired

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traits. The development of new cultivars is achieved through genetic improvement processes (Paiva et al*.,* 2010), which require genetic variability in the population (Ivoglo et al*.,* 2008). Evaluating progenies in several locations is an important step in the final phase of a plant breeding program. With this information, the interaction between genotype and environment can be determined. Additionally, when interactions exist, subsidies can be provided to encourage cultivation at specific sites (Pinto et al*.,* 2012). By characterizing genetic divergence, efficiency in the selection of parents in breeding programs can be increased (Silva et al*.,* 2013). In this process, hundreds to thousands of individuals are evaluated to identify superior and divergent genotypes for certain characteristics in order to design by recombination (Silva et al*.,* 2016). The dissimilarity analysis is used to quantify genetic variability and the relative contribution of the variables to the genetic dissimilarity, allowing for the identification of promising combinations (Torres et al*.,* 2015).

The genetic dissimilarity allows one to identify promising genotypes for breeding programs and to recommend for cultivation. Giles et al. (2019) verified genetic divergence among 34 genotypes of *Coffea* sp. and conclude that phenotypic variations occurred predominantly due to genetic causes. Thus, the objective was to study the genetic dissimilarity among 35 genotypes of *C. arabica* in the Cerrado, under drip irrigation, using phenological data and multivariate statistics.

MATERIALS AND METHODS

The experiment was conducted at the Ceres Campus of the Federal Institute Goiano, GO. The Ceres Campus is located in the center of Goiás in the São Patrício Valley (UTM: E = 649,582.00 m and N= 8,302,194.00 m), and is characterized by having flat relief, very deep eutroferric red nitosol, clay texture, and an altitude of 556 m. The climate, according to the classification of Köppen, is Aw type (tropical climate with wet and dry seasons- Tropical Seasonal, dry winter), with an average annual temperature of 25.4ºC (average minimum: 19.3°C; average maximum: 31.5°C). The annual precipitation is approximately 1700 mm.

The experiment was conducted on April 8, 2015 in a randomized complete block design. The experiment consisted of 35 treatments, 31 cultivars and 4 progenies (Table 1) with four replication and 10 plants that were placed 3.50 × 0.75 m apart. The eight central plants were considered for analysis. During the experiment, recommended management practices as fertilization, phytosanitary management and irrigation for the crop were followed. In the dry season, drip irrigation occurred on Mondays, Wednesdays, and Fridays to account for the need for the crop (Kc) and evapotranspiration in a class A tank. Fertilization was performed based on soil analysis results and recommendations of the 5th approximation of the Soil Fertility Commission of the State of Minas Gerais (Guimarães et al*.,* 1999). At 6, 12, 18 and 24 months after planting, stem diameter (DST), canopy diameter (DCA), plant height (HEI), number of orthotropic branch nodes (NOBN), average length (cm) of orthotropic branch internodes (ALOBI), total number of nodes at the 2nd plagiotropic branch pair (TNPB), total length (cm) at the 2nd plagiotropic branch pair (TLPB), and average length (cm) of plagiotropic branch internodes (ALPBI) were measured.

Data were analyzed using Analysis of Variance, F, and the Scott-Knott test at 0.05 of means for phenological parameters. Hierarchical Agglomerative Cluster (HAC) was used to examine dissimilarity by measuring average Euclidian distance. Additionally, Ward's agglomeration method was used to obtain dendrograms and the Pearson's method (n) for Principal Component Analysis (PCA) was used to obtain the correlation matrix and distance Biplot. Statistical analyses of genetic data were performed using the software XLSTAT 2014.5.03. The number of groups in the dendrogram was determined by the automatic truncation function, which attempts to create homogeneous groups (XLSTAT-MX, 2005).

RESULTS AND DISCUSSION

Coffee genotypes showed differences in phonological variables at 6, 12, 18, and 24 months after planting (Tables 1 to 4). Evaluations that occurred at 6 and 18 months after planting coincided with the end of the dry season, while evaluations that occurred 12 and 24 months after planting coincided with the end of the wet season. Temporal variability was observed in genotype behavior, as the growth of each material to diverse edaphoclimatic conditions differed among evaluations.

Meireles et al*.* (2009) state that various phenological phases of *C. arabica* are affected by environmental conditions, especially by photoperiodic variation and meteorological conditions (rainfall distribution and air temperature). In this experiment, the evaluations at 6 and 18 months after planting, in month October, of season rainy beginning and the photoperiod increasing, peaking in December. At 12 and 24 months after planting, month of April, the end of the rainy season and the photoperiod with short days, with minimum in June. Genetic diversity was observed between genotypes in the adaptability and interaction of the genotypes with the environment, so multivariate techniques were used to evaluate genetic divergence.

The 35 genotypes were clustered into three groups at each evaluation using Hierarchical agglomerative cluster analysis (Figures 1 to 4). Differences in genotypes were observed among groups for each evaluation. At 6 months, the most distant group consisted of Yellow Catucaí 2SL, Araponga MG 1, Sacramento MG 1, 23 II, Yellow Catucaí 20/15 pit 479, Sarchimor MG 8840, IBC-Palma 2, and New Acauã. At 12 months, the most distant group consisted of Yellow Catucaí 2SL, Asa Branca, Sacramento MG 1, and Sarchimor MG 8840. At 18 months, the most distant group consisted of Yellow Catucaí 2SL, Tupi IAC 1669-33, 23 II, Red Obatã IAC 1969-20, Sacramento MG 1, and Sarchimor MG 8840. At 24 months, Yellow Catucai 2SL was distinct from the other genotypes.

Genotype divergence in each group within and among evaluations may be associated with the interaction of the genotypes with the environment, as the environment may increase or decrease the genotype expression.

Table 1. Phenological variables of coffee trees six months after the plantation was cultivated and irrigated in the Cerrado of Goiás.

Genotype	DST** (mm)	DCA (cm)	HEI (cm)	NOBN	ALOBI (cm)	TNPB	TLPB (cm)	ALPBI (cm)
Oeiras MG 6851	12.2^{c}*	44.6^{c}	65.9^{c}	12.2^{c}	5.5^{b}	15.8^{b}	60.2^{c}	3.8^{c}
Catiguá MG 1	13.5^{b}	46.2^{c}	66.4^{c}	12.4^{b}	5.5^{b}	17.9^{b}	64.8^{c}	3.5^{d}
Sacramento MG 1	14.8^{a}	66.4^{a}	76.9^{b}	14.4^{a}	5.3^{c}	20.4^{a}	83.3^{a}	4.1^{b}
Catiguá MG 2	13.4^{b}	56.3^{b}	64.9^{c}	13.1^{a}	5.0^{d}	18.2^{b}	72.9^{b}	4.0^{b}
Araponga MG 1	14.8^{a}	62.2^{a}	69.8^{c}	13.6^{a}	5.2^{c}	21.7^{a}	87.1^{a}	4.0^{b}
Paraíso MG 419-1	12.7^{c}	46.7^{c}	63.0^{d}	12.8^{b}	5.0^{d}	18.7^{b}	66.8^{c}	3.6^{d}
Pau Brasil MG 1	13.8^{b}	52.0^{c}	65.2^{c}	13.6^{a}	4.8^{d}	19.7^{a}	76.5^{b}	3.9^{c}
Catiguá MG 3	13.2^{b}	49.9^{c}	62.5^{d}	12.8^{b}	4.9^{d}	17.3^{b}	67.1^{c}	3.8^{c}
Topázio MG 1190	14.3^{a}	48.7^{c}	66.7^{c}	12.9^{b}	5.2^{c}	19.0^{a}	67.2^{c}	3.5^{d}
'23 II'	15.4^{a}	61.3^{a}	76.6^{b}	13.4^{a}	5.8^{b}	19.3^{a}	85.4^{a}	4.5^{a}
IPR 104	15.1^{a}	51.7^{c}	64.2^{c}	12.3^{b}	5.3^{c}	18.6^{b}	70.2^{c}	3.8^{c}
Sarchimor MG8840	15.2^{a}	57.8^{b}	69.9^{c}	11.6^{c}	6.1^{b}	17.9^{b}	78.9^{b}	4.4^{a}
Red Catucaí 20/1 pit 476	12.9^{c}	45.6^{c}	63.3^{d}	12.0^{c}	5.3^{c}	17.1^{b}	60.8^{c}	3.5^{d}
Tupi IAC 1669-33	13.9^{a}	56.4^{b}	56.8^{e}	12.8^{b}	4.5^{d}	20.3^{a}	74.7^{b}	3.7^{c}
Red Obatã IAC 1669-20	14.8^{a}	56.3^{b}	64.8^{c}	12.1^{c}	5.4^{c}	18.7^{b}	74.4^{b}	4.0^{b}
Yellow Obatã IAC 4932	13.7^{b}	47.5^{c}	64.5^{c}	13.3^{a}	4.9^{d}	17.4^{b}	66.2^{c}	3.8^{c}
Red Catuaí IAC 15	12.9^{c}	45.8^{c}	67.4^{c}	13.7^{a}	4.9^{d}	18.3^{b}	64.4^{c}	3.5^{d}
Yellow Catuaí IAC 062	13.7^{b}	48.9^{c}	71.1^{c}	14.1^{a}	5.1^{c}	20.8^{a}	74.0^{b}	3.6^{d}
IPR 98	14.6^{a}	55.8^{b}	61.8^{d}	12.3^{b}	5.1^{c}	20.2^{a}	70.3^{c}	3.5^{d}
IPR 99	14.7^{a}	50.4^{c}	69.4^{c}	12.7^{b}	5.5^{b}	18.3^{b}	72.5^{b}	4.0^{b}
IPR 100	13.7^{b}	46.7^{c}	66.3^{c}	12.8^{b}	5.2^{c}	19.8^{a}	72.3^{b}	3.7^{c}
IPR 103	13.5^{b}	48.3^{c}	68.1^{c}	13.0^{a}	5.3^{c}	18.3^{b}	70.0^{c}	3.8^{c}
Yellow Catucaí 2SL	14.5^{a}	55.8^{b}	97.4^{a}	14.1^{a}	6.9^{a}	17.8^{b}	82.9^{a}	4.7^{a}
Yellow Catucaí 24/137	12.8^{c}	50.1^{c}	67.3^{c}	12.4^{b}	5.5^{b}	17.8^{b}	67.1^{c}	3.8^{c}
Yellow Catucaí 20/15 pit 479	14.0^{a}	53.8^{b}	79.2^{b}	13.9^{a}	5.7^{b}	19.9^{a}	79.7^{b}	4.0^{b}
Red Catucaí 785/15	13.7^{b}	51.1^{c}	69.3^{c}	14.4^{a}	4.8^{d}	19.4^{a}	65.2^{c}	3.4^{d}
Acauã 2 and 8	14.0^{a}	45.6^{c}	57.9^{e}	11.5^{c}	5.1^{c}	17.8^{b}	59.9^{c}	3.4^{d}
Late Sabiá or Sabiá 398	14.9^{a}	50.3^{c}	66.4^{c}	13.4^{a}	5.0^{d}	19.5^{a}	74.2^{b}	3.8^{c}
Asa Branca	12.8^{c}	47.4^{c}	66.5^{c}	11.8^{c}	5.8^{b}	16.2^{b}	68.4^{c}	4.2^{b}
IBC - Palma 2	13.5^{b}	58.9^{b}	67.2^{c}	13.7^{a}	4.9^{d}	20.7^{a}	76.4^{b}	3.7^{c}
Acauã	14.5^{a}	52.8^{b}	63.9^{c}	13.0^{a}	4.9^{d}	20.2^{a}	70.8^{c}	3.5^{d}
New Acauã	14.5^{a}	56.4^{b}	67.4^{c}	13.3^{a}	5.2^{c}	20.9^{a}	78.1^{b}	3.7^{c}
'H-419-3-3-7-16-4-1'	13.9^{a}	53.1^{b}	65.3^{c}	12.6^{b}	5.2^{c}	18.6^{b}	68.9^{c}	3.7^{c}
'Paraíso H 419-10-6-2-12-1'	11.4^{c}	44.6^{c}	55.1^{e}	11.8^{c}	4.7^{d}	17.8^{b}	64.2^{c}	3.6^{d}
'Paraíso H 419-10-6-2-10-1'	12.6^{c}	45.1^{c}	62.3^{d}	11.5^{c}	5.5^{b}	18.2^{b}	65.8^{c}	3.6^{d}

*Averages followed by the same letter in the column do not differ by Scott-Knott test at 5% probability of error. **Stem diameter (DST), canopy diameter (DCA), plant height (HEI), number of orthotropic branch nodes (NOBN), average length (cm) of orthotropic branch internodes (ALOBI), total number of nodes at the 2nd plagiotropic branch pair (TNPB), total length (cm) at the 2nd plagiotropic branch pair (TLPB), and average length (cm) of plagiotropic branch internodes (ALPBI).

Fernandes et al. (2012) reported that coffee tree growth was highest in the hottest and rainy months, which would be October to April in this experiment, period in which we obtained better results of growth of the studied genotypes. In addition, longer days occur during this time, providing greater energy availability in the form of solar radiation and temperature (Camargo and Camargo, 2001). The number of groups formed by Ward's agglomerative method shows that there is wide variability among the evaluated genotypes. Guedes et al. (2013) verified genetic divergence among coffee trees of the Maragogipe germplasm in the Alto Paranaíba region of the State of Minas Gerais, using the Tocher method. This shows that the genetic divergence among coffee plants is mainly due to genetics, as recommended by Giles et al. (2019).

The cultivars Sacramento MG 1, Sarchimor MG8840, and Yellow Catucaí 2SL showed similar phenological traits and were included in the same group until 24 months, when Yellow Catucaí 2SL formed a new group.

Table 2. Phenological variables of coffee trees 12 months after the plantation was cultivated and irrigated in the Cerrado of Goiás.

Genotype	DST** (mm)	DCA (cm)	HEI (cm)	NOBN	ALOBI (cm)	TNPB	TLPB (cm)	ALPBI (cm)
Oeiras MG 6851	26.0^{c}*	102.3^{d}	99.6^{e}	17.9^{d}	5.6^{c}	32.9^{b}	103.9^{e}	3.1^{d}
Catiguá MG 1	26.6^{c}	104.8^{c}	100.4^{e}	18.3^{c}	5.5^{c}	33.3^{b}	114.3^{d}	3.5^{b}
Sacramento MG 1	30.0^{b}	139.8^{a}	116.3^{c}	20.8^{a}	5.6^{c}	41.0^{a}	150.4^{b}	3.7^{b}
Catiguá MG 2	26.7^{c}	118.3^{b}	98.0^{f}	18.9^{c}	5.2^{d}	38.2^{a}	127.6^{c}	3.3^{c}
Araponga MG 1	29.0^{b}	127.4^{b}	108.8^{d}	20.5^{b}	5.3^{d}	38.7^{a}	137.5^{c}	3.6^{b}
Paraíso MG 419-1	23.5^{d}	103.1^{d}	97.9^{f}	18.8^{c}	5.3^{d}	37.8^{a}	118.0^{d}	3.2^{d}
Pau Brasil MG 1	27.0^{c}	105.4^{c}	102.3^{e}	20.1^{b}	5.1^{e}	37.4^{a}	126.3^{c}	3.4^{c}
Catiguá MG 3	23.5^{d}	89.3^{e}	92.1^{f}	16.4^{e}	5.6^{c}	26.7^{c}	93.9^{e}	3.5^{b}
Topázio MG 1190	28.3^{b}	107.4^{c}	102.7^{e}	19.8^{b}	5.2^{d}	38.8^{a}	120.4^{d}	3.1^{d}
‘23 II’	28.9^{b}	120.9^{b}	107.4^{d}	17.9^{d}	6.0^{b}	31.3^{b}	129.2^{c}	4.2^{a}
IPR 104	28.5^{b}	109.4^{c}	101.7^{e}	18.7^{c}	5.5^{c}	34.6^{b}	122.0^{d}	3.5^{b}
Sarchimor MG8840	29.0^{b}	132.3^{a}	109.3^{d}	17.6^{d}	6.2^{b}	37.6^{a}	148.3^{b}	3.9^{a}
Red Catucaí 20/1 pit 476	26.6^{c}	106.3^{c}	103.6^{e}	19.8^{b}	5.3^{d}	37.3^{a}	123.2^{d}	3.3^{c}
Tupi IAC 1669-33	26.2^{c}	122.2^{b}	98.2^{f}	20.5^{b}	4.8^{e}	35.6^{a}	127.9^{c}	3.6^{b}
Red Obatã IAC 1669-20	29.4^{b}	120.9^{b}	107.4^{d}	18.8^{c}	5.7^{c}	38.3^{a}	137.5^{c}	3.6^{b}
Yellow Obatã IAC 4932	26.1^{c}	99.5^{d}	100.3^{e}	18.3^{c}	5.5^{c}	38.8^{a}	130.1^{c}	3.4^{c}
Red Catuaí IAC 15	26.9^{c}	106.6^{c}	105.7^{d}	18.9^{c}	5.6^{c}	38.6^{a}	125.7^{c}	3.3^{c}
Yellow Catuaí IAC 062	28.2^{b}	108.4^{c}	110.3^{d}	20.1^{b}	5.5^{c}	40.2^{a}	131.9^{c}	3.3^{c}
IPR 98	29.4^{b}	112.6^{c}	100.0^{e}	18.9^{c}	5.3^{d}	40.9^{a}	136.5^{c}	3.4^{c}
IPR 99	28.8^{b}	108.6^{c}	103.2^{e}	18.7^{c}	5.5^{c}	38.0^{a}	130.4^{c}	3.5^{b}
IPR 100	27.9^{b}	110.0^{c}	106.9^{d}	20.5^{b}	5.2^{d}	42.6^{a}	139.6^{c}	3.3^{c}
IPR 103	27.8^{b}	108.1^{c}	112.9^{c}	19.5^{b}	5.8^{c}	38.4^{a}	135.3^{c}	3.5^{b}
Yellow Catucaí 2SL	32.8^{a}	136.3^{a}	145.8^{a}	19.2^{c}	7.7^{a}	38.7^{a}	164.3^{a}	4.3^{a}
Yellow Catucaí 24/137	26.4^{c}	106.8^{c}	106.9^{d}	19.1^{c}	5.6^{c}	33.3^{b}	113.9^{d}	3.4^{b}
Yellow Catucaí 20/15 pit 479	29.1^{b}	119.6^{b}	121.2^{b}	21.3^{a}	5.7^{c}	41.1^{a}	141.8^{b}	3.5^{b}
Red Catucaí 785/15	27.5^{b}	100.8^{d}	107.8^{d}	21.5^{a}	5.0^{e}	38.5^{a}	116.2^{d}	3.0^{d}
Acauã 2 and 8	27.3^{b}	102.6^{d}	96.3^{f}	18.2^{c}	5.3^{d}	31.9^{b}	106.3^{e}	3.4^{c}
Late Sabiá or Sabiá 398	28.0^{b}	117.1^{b}	103.6^{e}	19.8^{b}	5.2^{d}	40.0^{a}	143.6^{b}	3.6^{b}
Asa Branca	27.3^{b}	122.4^{b}	107.2^{d}	18.5^{c}	5.8^{c}	37.6^{a}	153.8^{b}	4.1^{a}
IBC - Palma 2	27.5^{b}	105.8^{c}	105.9^{d}	20.2^{b}	5.3^{d}	31.3^{b}	106.0^{e}	3.4^{b}
Acauã	28.4^{b}	108.1^{c}	104.1^{e}	20.1^{b}	5.2^{d}	34.5^{b}	118.8^{d}	3.5^{b}
New Acauã	28.8^{b}	114.1^{c}	107.6^{d}	21.6^{a}	5.0^{e}	39.0^{a}	126.2^{c}	3.3^{c}
‘H-419-3-3-7-16-4-1’	27.4^{b}	120.3^{b}	104.6^{d}	18.6^{c}	5.7^{c}	39.7^{a}	133.6^{c}	3.3^{c}
‘Paraíso H 419-10-6-2-12-1’	24.2^{d}	97.1^{d}	93.1^{f}	18.4^{c}	5.0^{e}	35.3^{b}	102.6^{e}	2.9^{d}
‘Paraíso H 419-10-6-2-10-1’	25.4^{c}	108.3^{c}	97.8^{f}	17.6^{d}	5.6^{c}	37.8^{a}	126.2^{c}	3.3^{c}

*Averages followed by the same letter in the column do not differ by Scott-Knott test at 5% probability of error. **Stem diameter (DST), canopy diameter (DCA), plant height (HEI), number of orthotropic branch nodes (NOBN), average length (cm) of orthotropic branch internodes (ALOBI), total number of nodes at the 2nd plagiotropic branch pair (TNPB), total length (cm) at the 2nd plagiotropic branch pair (TLPB), and average length (cm) of plagiotropic branch internodes (ALPBI).

This result may be attributed to the fact that this genotype had the highest averages for phenology traits (DST = 56.2 mm, DCA = 210.4 cm, HEI = 226.2 cm, ALOBI = 6.9 cm, TNPB = 58, 6, and TLPB = 205.1 cm) compared to the other genotypes. High phenology averages for Yellow Catucaí 2SL may be due to that fact that this cultivar is a hybrid (Icatu × Catuaí) and is highly adaptable, which is a known characteristic of 'Catuaí' (Botelho et al., 2010). However, densification between plants could have caused superior development of this cultivar. Pereira et al. (2011) found that the spacing between lines and between plants influenced the growth and architecture of *Coffea arabica* trees. However, this genotype-environment interaction is unique to this cultivar, since the other cultivars did not show the same pattern of development.

Three groups were identified at 6 months (Figure 1). Yellow Catucaí 2SL, Araponga MG 1, Sacramento MG 1,

Table 3. Phenological variables of coffee trees 18 months after the plantation was cultivated and irrigated in the Cerrado of Goiás.

Genotype	DST** (mm)	DCA (cm)	HEI (cm)	NOBN	ALOBI (cm)	TNPB	TLPB (cm)	ALPBI (cm)
Oeiras MG 6851	34.9^{c}*	127.3^{d}	120.9^{e}	25^{c}	6.8^{e}	54.0^{b}	185.8^{d}	4.4^{e}
Catiguá MG 1	36.0^{c}	131.7^{c}	123.4^{d}	24^{c}	6.0^{d}	51.0^{b}	167.3^{c}	3.8^{d}
Sacramento MG 1	41.3^{b}	167.3^{a}	144.1^{b}	27^{a}	6.0^{d}	50.8^{a}	164.7^{a}	3.7^{c}
Catiguá MG 2	35.9^{c}	148.8^{b}	123.7^{d}	25^{c}	5.9^{e}	50.4^{a}	164.2^{b}	3.6^{d}
Araponga MG 1	39.3^{b}	138.3^{c}	133.4^{c}	28^{a}	5.6^{e}	49.6^{a}	160.9^{b}	3.5^{c}
Paraíso MG 419-1	34.5^{c}	135.7^{c}	119.3^{e}	26^{b}	5.5^{f}	49.3^{a}	159.3^{c}	3.5^{f}
Pau Brasil MG 1	35.7^{c}	127.6^{d}	126.3^{d}	26^{b}	5.5^{e}	48.9^{a}	157.3^{c}	3.4^{d}
Catiguá MG 3	33.7^{c}	115.6^{d}	113.3^{e}	22^{d}	5.3^{d}	48.7^{c}	154.2^{d}	3.4^{d}
Topázio MG 1190	38.7^{b}	136.8^{c}	127.4^{d}	27^{a}	5.3^{f}	48.6^{a}	151.4^{b}	3.4^{f}
‘23 II’	40.8^{b}	152.6^{b}	139.8^{b}	23^{d}	5.3^{b}	48.0^{b}	150.5^{b}	3.3^{a}
IPR 104	39.0^{b}	142.8^{c}	128.3^{d}	27^{b}	5.2^{e}	47.6^{a}	150.4^{b}	3.3^{e}
Sarchimor MG8840	41.0^{b}	171.8^{a}	138.9^{b}	23^{d}	5.1^{b}	47.5^{a}	150.1^{a}	3.3^{b}
Red Catucaí 20/1 pit 476	35.6^{c}	134.0^{c}	125.6^{d}	27^{a}	5.1^{f}	47.4^{a}	148.7^{b}	3.2^{e}
Tupi IAC 1669-33	35.0^{c}	155.9^{b}	129.8^{d}	28^{a}	5.1^{f}	46.8^{a}	147.1^{b}	3.2^{d}
Red Obatã IAC 1669-20	39.1^{b}	157.0^{b}	137.4^{c}	25^{c}	5.1^{c}	46.8^{a}	145.8^{a}	3.2^{d}
Yellow Obatã IAC 4932	37.3^{c}	136.4^{c}	127.8^{d}	24^{c}	5.0^{d}	46.5^{a}	144.8^{b}	3.2^{d}
Red Catuaí IAC 15	36.8^{c}	138.6^{c}	132.0^{c}	26^{b}	4.9^{d}	45.4^{a}	142.0^{b}	3.2^{e}
Yellow Catuaí IAC 062	38.2^{b}	136.6^{c}	134.1^{c}	27^{b}	4.9^{d}	44.4^{a}	141.3^{b}	3.2^{e}
IPR 98	38.8^{b}	150.7^{b}	127.8^{d}	26^{b}	4.9^{e}	44.2^{a}	136.9^{b}	3.2^{e}
IPR 99	39.8^{b}	139.6^{c}	135.7^{c}	25^{c}	4.9^{c}	44.2^{a}	135.9^{b}	3.2^{e}
IPR 100	38.2^{b}	140.1^{c}	130.9^{c}	27^{a}	4.9^{e}	44.1^{a}	135.1^{a}	3.2^{e}
IPR 103	38.2^{b}	139.9^{c}	139.2^{b}	25^{c}	4.9^{c}	42.7^{a}	135.0^{a}	3.1^{c}
Yellow Catucaí 2SL	46.4^{a}	172.1^{a}	179.1^{a}	26^{b}	4.8^{a}	42.7^{a}	134.0^{a}	3.1^{b}
Yellow Catucaí 24/137	35.4^{c}	137.4^{c}	136.9^{c}	26^{b}	4.8^{d}	42.5^{a}	133.6^{c}	3.1^{e}
Yellow Catucaí 20/15 pit 479	41.0^{b}	144.6^{c}	147.5^{b}	28^{a}	4.8^{d}	42.3^{a}	132.9^{a}	3.1^{d}
Red Catucaí 785/15	36.6^{c}	127.8^{d}	127.0^{d}	29^{a}	4.8^{f}	41.3^{a}	132.5^{c}	3.1^{f}
Acauã 2 and 8	37.0^{c}	124.1^{d}	123.6^{d}	24^{c}	4.8^{d}	40.8^{b}	130.9^{c}	3.1^{d}
Late Sabiá or Sabiá 398	37.6^{c}	156.9^{b}	131.4^{c}	27^{a}	4.8^{e}	39.8^{a}	125.4^{a}	3.1^{e}
Asa Branca	36.8^{c}	155.6^{b}	136.9^{c}	23^{d}	4.7^{b}	39.1^{a}	125.2^{b}	3.0^{b}
IBC - Palma 2	36.7^{c}	117.9^{d}	128.0^{d}	27^{a}	4.7^{f}	39.1^{b}	125.1^{c}	3.0^{c}
Acauã	38.7^{b}	143.3^{c}	130.6^{c}	27^{a}	4.6^{e}	38.4^{a}	121.6^{b}	3.0^{e}
New Acauã	38.4^{b}	146.4^{b}	134.1^{c}	28^{a}	4.6^{e}	34.1^{a}	116.8^{b}	2.9^{d}
‘H-419-3-3-7-16-4-1’	37.4^{c}	149.4^{b}	124.9^{d}	26^{b}	4.6^{e}	31.9^{a}	109.6^{b}	2.8^{d}
‘Paraíso H 419-10-6-2-12-1’	33.9^{c}	123.9^{d}	113.8^{e}	25^{c}	4.6^{f}	31.6^{a}	107.2^{c}	2.8^{f}
‘Paraíso H 419-10-6-2-10-1’	34.4^{c}	133.0^{c}	119.3^{e}	24^{c}	4.4^{e}	29.3^{a}	98.6^{b}	2.7^{e}

*Averages followed by the same letter in the column do not differ by Scott-Knott test at 5% probability of error. **Stem diameter (DST), canopy diameter (DCA), plant height (HEI), number of orthotropic branch nodes (NOBN), average length (cm) of orthotropic branch internodes (ALOBI), total number of nodes at the 2nd plagiotropic branch pair (TNPB), total length (cm) at the 2nd plagiotropic branch pair (TLPB), and average length (cm) of plagiotropic branch internodes (ALPBI).

23 II, Yellow Catucaí 20/15 pit 479, Sarchimor MG8840, IBC-Palma 2, and New Acauã formed the first group, which had the highest averages for most analyzed variables (DST, DCA, NOBN, TNPB, and TLPB). The second group consisted of the genotypes 7, 28, 21, 18, 20, 14, 4, 15, 19, 33, 11, and 31, which had the highest averages of phenological development for DST, NOBN, and TNPB. The third group, whichconsisted of treatments 26, 9, 24, 22, 29, 2, 17, 8, 35, 6, 16, 1, 13, 27, and 34, had the smallest number of significant variables, with DCA and TLPB showing homogeneity. At this stage of growth, the phenological variables that showed significant differences for most genotypes were DST, NOBN, and TNPB (Table 1).

The dendrogram for the evaluation at 12 months shows three groups that were divided into subgroups (Figure 2). The first group comprised 8, 34, 1, 27, 26, 30, 2, 24, 6, 9, 11, 31, 16, 17, 7, 13, 20, and 35 and had the smallest

Table 4. Phenological variables of coffee trees 24 months after the plantation was cultivated and irrigated in the Cerrado of Goiás.

Genotype	DST** (mm)	DCA (cm)	HEI (cm)	NOBN	ALOBI (cm)	TNPB	TLPB (cm)	ALPBI (cm)
Oeiras MG 6851	41.2^{d}*	145.6^{e}	151.7^{e}	30.9^{b}	4.9^{d}	43.4^{c}	139.7^{e}	3.2^{d}
Catiguá MG 1	41.5^{d}	159.5^{d}	156.8^{e}	31.4^{b}	5.1^{c}	46.7^{c}	151.3^{d}	3.3^{d}
Sacramento MG 1	49.3^{b}	191.4^{b}	177.8^{c}	34.1^{a}	5.2^{c}	47.6^{c}	179.0^{b}	3.8^{b}
Catiguá MG 2	43.5^{d}	164.8^{d}	155.3^{e}	31.8^{b}	4.9^{d}	43.3^{c}	148.5^{d}	3.5^{c}
Araponga MG 1	45.7^{c}	173.5^{c}	171.8^{d}	35.8^{a}	4.8^{d}	49.6^{c}	167.2^{c}	3.5^{c}
Paraíso MG 419-1	41.4^{d}	156.5^{d}	150.0f	31.9^{b}	4.7^{d}	51.8^{b}	153.4^{d}	3.0^{e}
Pau Brasil MG 1	42.8^{d}	163.1^{d}	153.3^{e}	30.4^{c}	5.1^{c}	48.1^{c}	147.4^{d}	3.1^{d}
Catiguá MG 3	40.3^{d}	137.1^{e}	143.4f	28.5^{c}	5.1^{c}	35.1^{d}	129.2^{e}	3.7^{b}
Topázio MG 1190	45.8^{c}	173.3^{c}	165.3^{d}	32.1^{b}	5.2^{c}	58.5^{a}	169.7^{c}	2.9^{e}
'23 II'	46.6^{c}	177.9^{c}	166.9^{d}	27.9^{c}	6.1^{b}	40.9^{d}	161.3^{c}	4.1^{a}
IPR 104	44.3^{c}	178.8^{c}	163.1^{d}	32.1^{b}	5.1^{c}	58.4^{a}	167.3^{c}	2.9^{e}
Sarchimor MG8840	47.4^{c}	182.0^{c}	170.8^{d}	29.2^{c}	5.9^{b}	47.1^{c}	171.6^{c}	3.7^{c}
Red Catucaí 20/1 pit 476	42.2^{d}	170.9^{d}	162.4^{d}	32.9^{b}	4.9^{d}	52.7^{b}	157.8^{d}	3.0^{e}
Tupi IAC 1669-33	41.8^{d}	168.1^{d}	155.6^{e}	30.8^{b}	5.1^{c}	43.4^{c}	148.1^{d}	3.4^{c}
Red Obatã IAC 1669-20	47.2^{c}	193.1^{b}	162.9^{d}	29.3^{c}	5.6^{c}	54.1^{b}	175.4^{b}	3.3^{d}
Yellow Obatã IAC 4932	46.6^{c}	176.8^{c}	155.5^{e}	28.7^{c}	5.4^{c}	54.0^{b}	162.6^{c}	3.3^{d}
Red Catuaí IAC 15	43.8^{d}	176.9^{c}	165.1^{d}	31.3^{b}	5.4^{c}	53.6^{b}	163.6^{c}	3.1^{d}
Yellow Catuaí IAC 062	43.8^{d}	183.9^{c}	169.8^{d}	33.2^{b}	5.1^{c}	60.3^{a}	176.9^{b}	3.0^{e}
IPR 98	44.8^{c}	180.6^{c}	160.3^{d}	31.8^{b}	5.1^{c}	56.5^{a}	166.8^{c}	3.0^{e}
IPR 99	46.1^{c}	184.3^{c}	164.6^{d}	31.6^{b}	5.2^{c}	57.6^{a}	178.1^{b}	3.1^{d}
IPR 100	45.1^{c}	188.2^{b}	165.6^{d}	32.8^{b}	5.1^{c}	61.6^{a}	182.3^{b}	3.0^{e}
IPR 103	45.7^{c}	188.4^{b}	167.9^{d}	32.9^{b}	5.3^{c}	57.8^{a}	181.8^{b}	3.2^{d}
Yellow Catucaí 2SL	56.2^{a}	210.4^{a}	226.2^{a}	32.9^{b}	6.9^{a}	58.6^{a}	205.1^{a}	3.5^{c}
Yellow Catucaí 24/137	43.4^{d}	168.9^{d}	171.0^{d}	33.5^{b}	5.1^{c}	53.3^{b}	162.1^{c}	3.1^{d}
Yellow Catucaí 20/15 pit 479	49.5^{b}	194.1^{b}	188.4^{b}	36.4^{a}	5.2^{c}	59.3^{a}	181.5^{b}	3.1^{d}
Red Catucaí 785/15	45.3^{c}	157.2^{d}	163.5^{d}	31.3^{b}	5.3^{c}	55.2^{b}	150.3^{d}	2.8^{e}
Acauã 2 and 8	42.6^{d}	151.9^{e}	159.1^{e}	32.4^{b}	4.9^{d}	38.4^{d}	128.9^{e}	3.4^{c}
Late Sabiá or Sabiá 398	44.8^{c}	194.4^{b}	165.4^{d}	32.5^{b}	5.1^{c}	61.4^{a}	178.4^{b}	2.9^{e}
Asa Branca	45.3^{c}	197.4^{b}	163.9^{d}	26.8^{c}	6.2^{b}	52.9^{b}	189.3^{b}	3.6^{c}
IBC - Palma 2	42.4^{d}	144.1^{e}	160.2^{d}	32.1^{b}	5.0^{c}	47.0^{c}	144.6^{d}	3.3^{d}
Acauã	45.6^{c}	177.0^{c}	166.2^{d}	32.6^{b}	5.2^{c}	52.3^{b}	161.1^{c}	3.1^{d}
New Acauã	45.0^{c}	186.7^{b}	167.2^{d}	35.6^{a}	4.7^{d}	52.4^{b}	165.4^{c}	3.2^{d}
'H-419-3-3-7-16-4-1'	44.6^{c}	180.6^{c}	162.8^{d}	32.4^{b}	5.1^{c}	58.4^{a}	178.1^{b}	3.1^{d}
'Paraíso H 419-10-6-2-12-1'	41.9^{d}	157.8^{d}	145.3f	31.6^{b}	4.6^{d}	49.9^{c}	138.3^{e}	2.8^{e}
'Paraíso H 419-10-6-2-10-1'	41.8^{d}	167.4^{d}	148.4f	27.4^{c}	5.5^{c}	55.0^{b}	162.1^{c}	3.0^{e}

*Averages followed by the same letter in the column do not differ by Scott-Knott test at 5% probability of error. **Stem diameter (DST), canopy diameter (DCA), plant height (HEI), number of orthotropic branch nodes (NOBN), average length (cm) of orthotropic branch internodes (ALOBI), total number of nodes at the 2nd plagiotropic branch pair (TNPB), total length (cm) at the 2nd plagiotropic branch pair (TLPB), and average length (cm) of plagiotropic branch internodes (ALPBI).

averages for most variables, particularly HEI and TLPB. The second group had the highest average for TNPB and the lowest for HEI and consisted of treatments 4, 14, 10, 32, 18, 22, 28, 19, 21, 25, 5, 15, and 33. The third group was formed by Yellow Catucaí 2SL, Asa Branca, Sacramento MG1, and Sarchimor MG8840 cultivars. This group had the highest averages for most of the analyzed variables, especially DST, DCA, TNPB, TLPB, and ALPBI (Table 2).

The dendrogram of the 18-month evaluation had three groups (Figure 3). The first group had the lowest averages for ALOBI and ALPBI, but the TNPB variable had higher averages. This group consisted of genotypes 34, 35, 33, 31, 32, 19, 28, 29, 30, 26, 27, 25, 17, 18, 21, 24, 20, and 22. The second group consisted of genotypes 1, 8, 11, 16, 9, 13, 7, 2, 6, 4, and 5 and presented highest average for TNPB, whereas this group had the lowest averages for HEI, ALOBI, and ALPBI. The third group

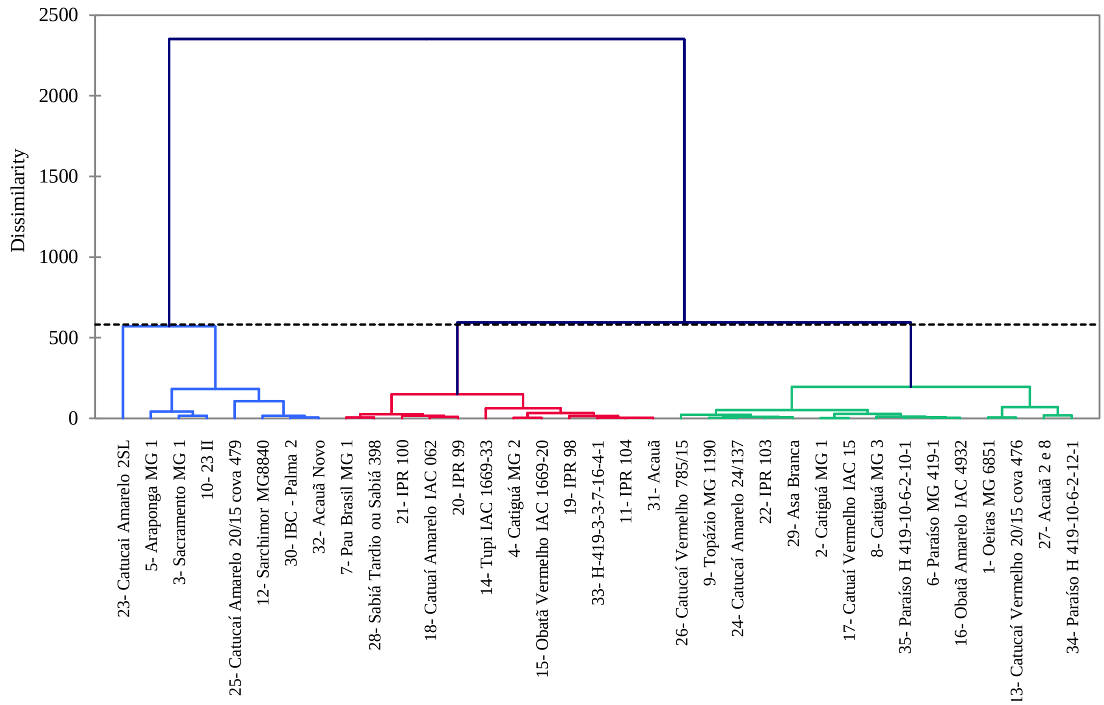

Figure 1. Dendrogram showing the grouping of 35 genotypes of *C. arabica* at 6 months. Hierarchical Agglomerative Cluster was used with mean Euclidian distance and Ward's agglomeration method to analyze 8 phenological characteristics.

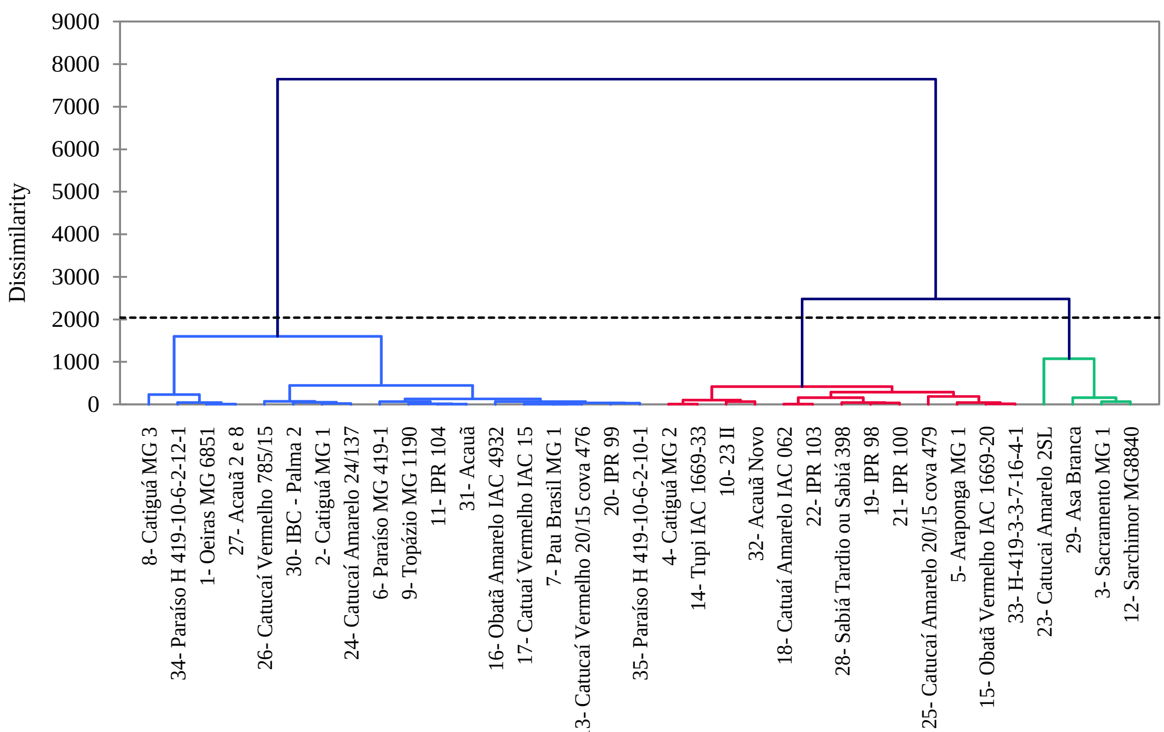

Figure 2. Dendrogram showing the grouping of 35 genotypes of *C. arabica* at 12 months. Hierarchical Agglomerative Cluster was used with mean Euclidian distance and Ward's agglomeration method to analyze 8 phenological characteristics.

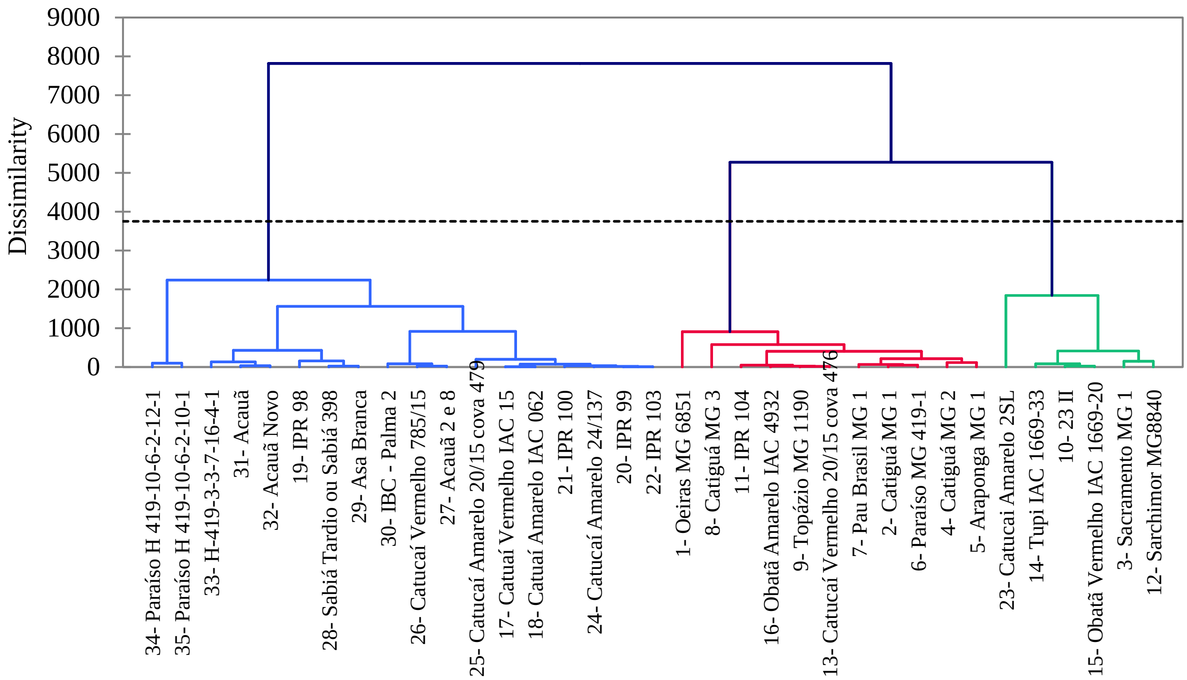

Figure 3. Dendrogram showing the grouping of 35 genotypes of *C. arabica* at 18 months. Hierarchical Agglomerative Cluster was used with mean Euclidian distance and Ward's agglomeration method to analyze 8 phenological characteristics.

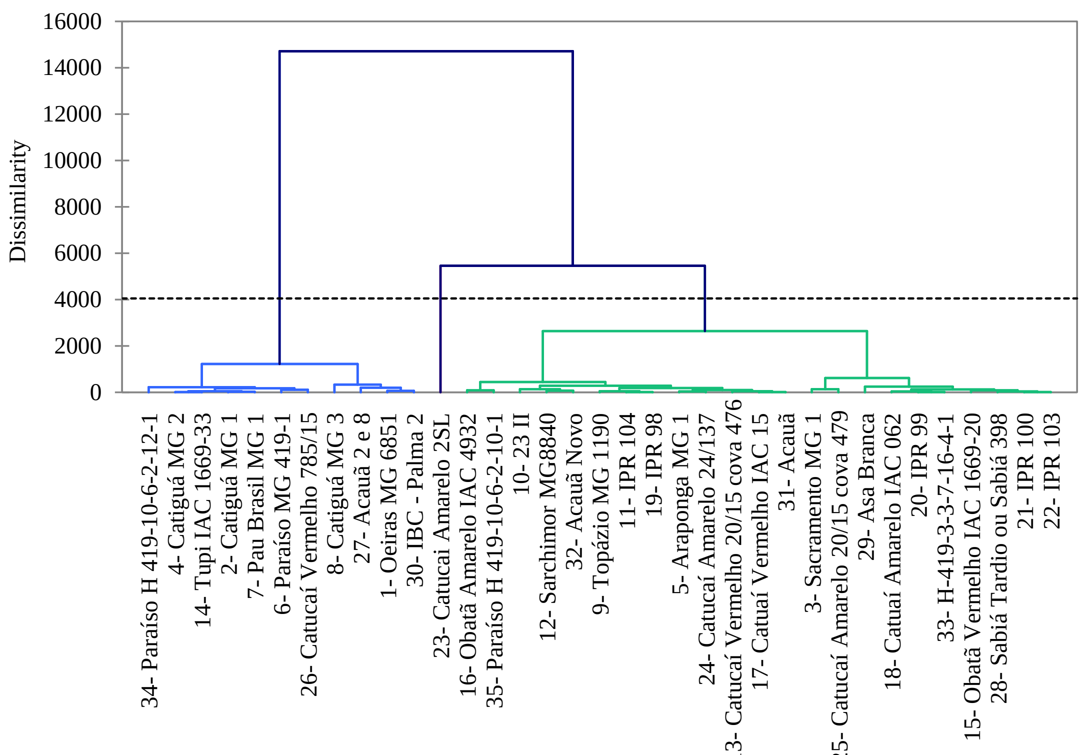

Figure 4. Dendrogram showing the grouping of 35 genotypes of *C. arabica* at 24 months. Hierarchical Agglomerative Cluster was used with mean Euclidian distance and Ward's agglomeration method to analyze 8 phenological characteristics.

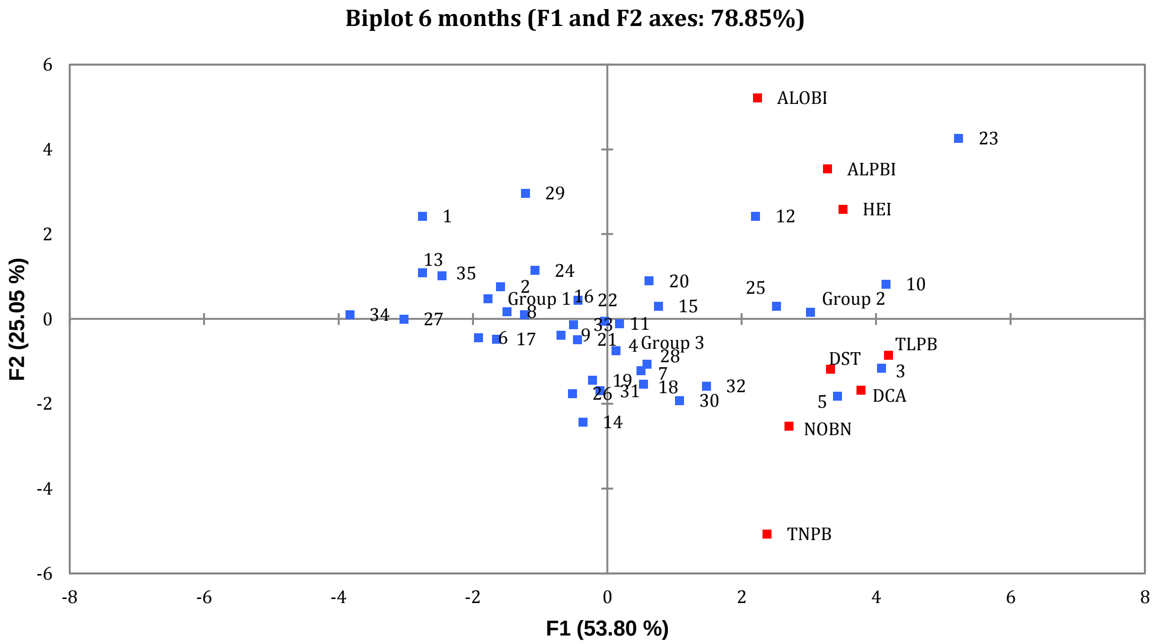

Figure 5. Biplot of the relative contribution of the variables to the genetic dissimilarity of each group in the phenological evaluation performed at 6 months, evidencing the frequencies.

consisted of Yellow Catucaí 2SL, Tupi IAC 1669-33, 23 II, Red Obatã IAC 1669-20, Sacramento MG 1, and Sarchimor MG8840 and had the highest average values for DCA, TNPB, and TLPB but the lowest averages for ALOBI. This group formed two subgroups when regrouped, one of which consisted of Yellow Catucaí 2SL, probably because it had high average values for DST, DCA, HEI, ALOBI, TNPB, and TLPB (Table 3).

The first group formed in the 24th month dendrogram consisted of the treatments 34, 4, 14, 2, 7, 6, 26, 8, 27, 1, and 30 (Figure 4). This group had the lowest averages, particularly for DST, DCA, HEI, and TLPB. The second group consisted entirely of the genotype Yellow Catucaí 2SL. The third group consisted of the treatments 16, 35, 10, 12, 32, 9, 11, 19, 5, 24, 13, 17, 31, 3, 25, 29, 18, 20, 33, 15, 28, 21, and 22 and had the lowest averages for HEI and ALPBI, with only TNPB having a greater amount of significant averages (Table 4).

PCA results showed that the relative contribution of phenological variables to genetic dissimilarity (frequency) was 78.85% at 6 months (Figure 5), with the F1 component contributing 53.80% and the F2 component contributing 25.05%. For the second evaluation period (12 months), a frequency of 81.38% was observed (Figure 6) with F1 contributing 57.99% and F2 contributing 23.39%. At 18 and 24 months, the relative contribution was 79.73% (F1 = 47.48% and F2 = 32.25%) and 81.97% (F1 = 47.48% and F2 = 32.25%), respectively (Figures 7 and 8). Thus, variability in the contribution of phenological variables was observed mainly at 18 and 24 months. This could be due to a decrease in photo-assimilated reserves, causing a decrease in the growth rate of the plants, as they were in the process of filling the grains, which is considered to be a substantial photo-assimilates drain (Arantes et al*.,* 2006).

The PCA shows that there was a large contribution of the phenological variables to genetic dissimilarity (>75%) in the four evaluation periods. Rodrigues et al. (2013) verified that evaluation methods of productivity, stability, and adaptability, the harmonic mean of the genetic values, the relative performance of the genetic values, and the harmonic mean of the relative performance of the predicted must be part of the selection criteria for recommendation of genotypes of coffee for commercial plantations.

However, phenological patterns can vary within the same plant species if evaluated in different ecosystems, and variation can occur between populations, individuals, and years (Mantovani et al*.,* 2003). Moreover, several factors can influence these phenological variations, such as exposure to light, leaf damage, water stress, or flower abortion. Thus, the influence of these factors on coffee phenology should be considered when examining a particular genotype in different regions and conditions. By analyzing the contribution rate of phenological variables over four evaluation periods (Figure 9), a contribution percentage equal to or greater than 25%was observed for: ALOBI, TNPB, and ALPBI at 6 months; NOBN, ALOBI, TNPB, and ALPBI at 12 months; DST, DCA, HEI,

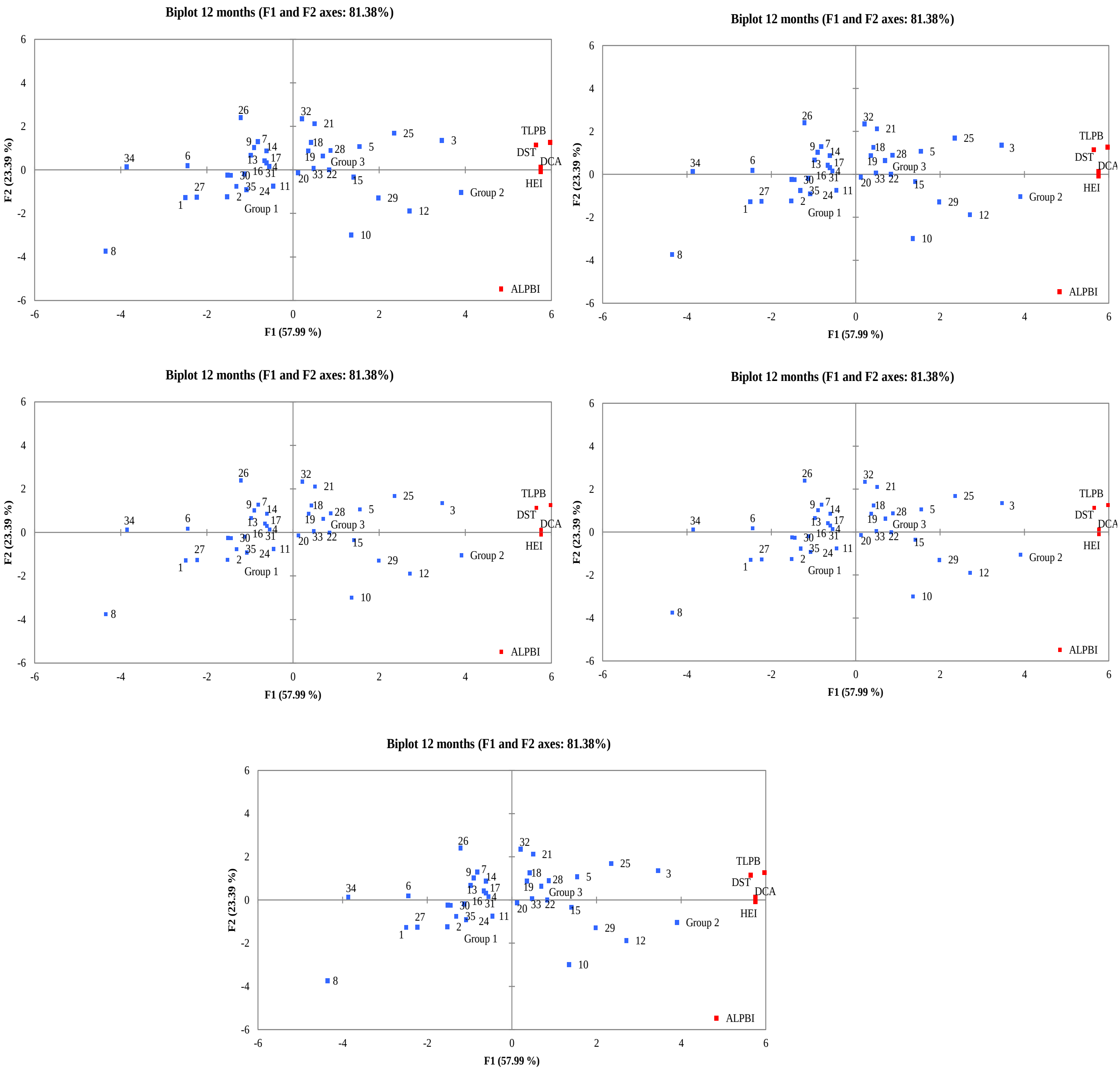

Figure 6. Biplot of the relative contribution of the variables to the genetic dissimilarity of each group in the phenological evaluation performed at 12 months, evidencing the frequencies.

TLPB, and ALPBI at 18 months; and ALOBI, TNPB, and ALPBI at 24 months. ALPBI contributed throughout the four evaluation periods. Moreover, the greatest number of variables contributing ≥25% was observed for the 18 month evaluation, showing that this may be the best stage of development to evaluate genotypes and examine genetic divergence under edaphoclimatic conditions.

Conclusion

Genetic dissimilarity was evidenced between the 35 genotypes of *C. arabica* in the Cerrado, under drip irrigation, using phenological data and multivariate statistics. At 24 months after planting, the genotype Yellow Catucaí 2SL shows great dissimilarity. There was a large percentage of the contribution of phenological

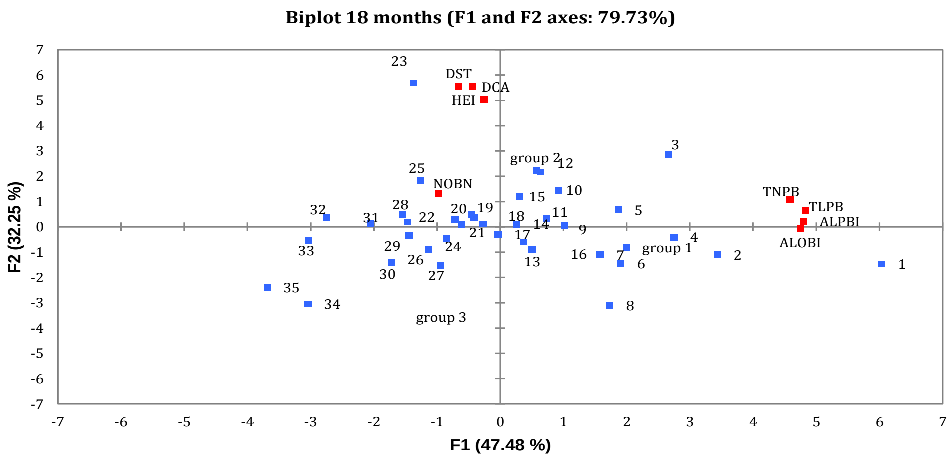

Figure 7. Biplot of the relative contribution of the variables to the genetic dissimilarity of each group in the phenological evaluation performed at 18 months, evidencing the frequencies.

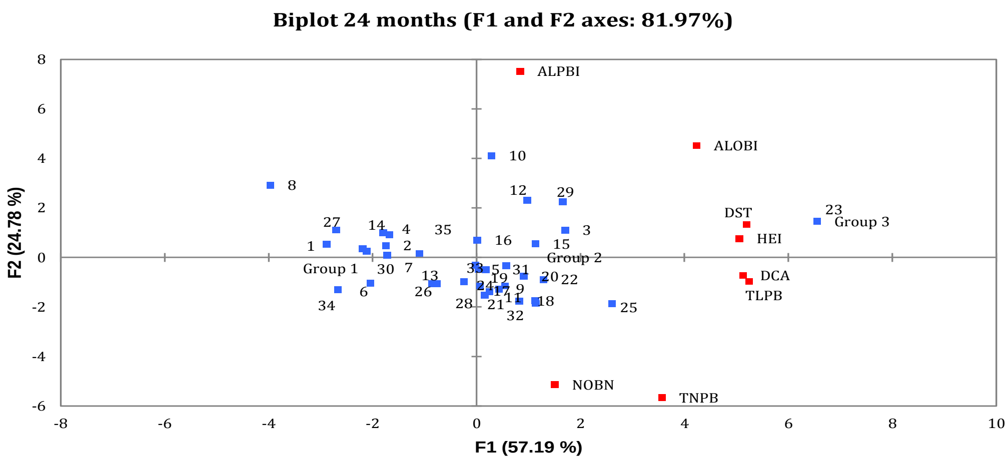

Figure 8. Biplot of the relative contribution of the variables to the genetic dissimilarity of each group in the phenological evaluation performed at 24 months, evidencing the frequencies.

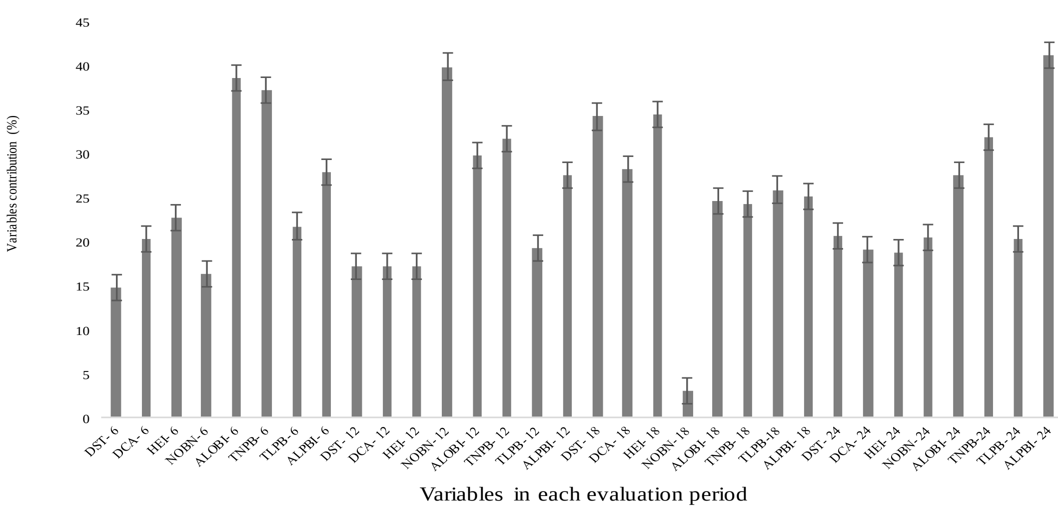

Figure 9. Contribution of the phenological variables to genetic dissimilarity in coffee over the four evaluation periods.

variables to genetic dissimilarity (> 75%), in the four evaluations.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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