PODESTÁ, G. S.; SOUSA NETO, A. T., SOUSA, V. F. O., COSTA, J. E., ARAÚJO, I. S., DINIZ, R. W., SILVA, G. R., OLIVEIRA, A. C. B. Vegetative and yield performance of arabica coffee genotypes in a *brejo de altitude* region. **Revista de Agricultura Neotropical**, Cassilândia-MS, v. 11, n. 4, e9001, Oct./Dec., 2024. ISSN 2358-6303. DOI: https://doi.org/10.32404/rean.v11i4.9001.

Vegetative and yield performance of arabica coffee genotypes in a *brejo de altitude* region

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Received: 26/07/2024; Accepted: 18/10/2024.

ABSTRACT

Developing new cultivated plant varieties plays a crucial role in strengthening various aspects of agriculture. Comparative data on the performance of traditional and modern coffee varieties are essential for promoting sustainable agro-ecosystems and rural development. This study aimed to evaluate the vegetative and yield performance of Arabica coffee genotypes in a brejo de altitude within the Brazilian semi-arid region. The biometric and yield characteristics of 21 coffee genotypes, including four traditional Brazilian varieties, were assessed using a randomized block design with three replications, analyzing nine growth and production variables. High coffee yields (kg ha^{-1}) were observed. In the first year, genotypes T21 I, T5 II, T1 I, T15 I, and Campos Altos demonstrated strong performance, though with no significant differences in most traits. Cluster analysis grouped the genotypes into five distinct phenological categories. In the second year, genotypes T5 II, T15 I, and T21 I exhibited superior agronomic traits, highlighting their potential viability for coffee cultivation in Paraíba, Brazil. This study contributes to coffee research in Northeast Brazil and offers valuable insights for future decision-making.

Keywords: Plant adaptation; Climate change; *Coffea arabica*; Yield; Modern varieties.

Aspectos vegetativos e de produtividade de genótipos de café arábica em área de brejo de altitude

RESUMO

O surgimento de novas variedades comerciais de plantas cultivadas é importante para fortalecer vários aspectos da agricultura. Informações comparativas e dados sobre o comportamento de variedades de café tradicionais e modernas devem ser repassados aos produtores para obter ganhos na sustentabilidade dos agroecossistemas e na promoção do desenvolvimento rural. Nesse contexto, o presente estudo teve como objetivo avaliar o desempenho vegetativo e de rendimento de genótipos de café arábica em um Brejo de altitude na região semiárida brasileira. O desempenho biométrico e de rendimento de 21 genótipos de café, incluindo quatro variedades tradicionais do Brasil, foi investigado em um delineamento de blocos completamente casualizados com três repetições, usando nove variáveis de crescimento e produção. Altos rendimentos em quilogramas por hectare de café foram encontrados. Entre os genótipos estudados, T21 I, T5 II, T1 I, T15 I e Campos Altos se destacaram no primeiro ano, embora sem diferenças significativas na maioria dos atributos estudados. A análise de clusters separou os genótipos em cinco grupos principais amplamente diferenciados pela fenologia. Os genótipos T5 II, T15 I e T21 I mostraram superioridade em relação aos outros no segundo ano de cultivo, demonstrando características agronômicas promissoras e viabilidade potencial para o cultivo de café na região da Paraíba, Brasil. Este estudo enriquece a pesquisa sobre café no Nordeste do Brasil e fornece novos insights para a tomada de decisões futuras.

Palavras-chave: Adaptação de plantas; Alterações climáticas; *Coffea arabica*; Rendimento; Variedades modernas.

1. Introduction

Arabica coffee (*Coffea arabica* L.) is highly valued in commercial markets due to its beans, which, after fermentation, develop an intense aroma that enhances the product's quality and market price (Carmo et al., 2020; Lemos et al., 2020). However, climate change significantly affects the cultivation of various crops, particularly in arid and semi-arid regions, posing long-term risks to coffee production (Akumaga & Tarhule, 2018; Huet et al., 2020).

Advancements in agricultural technologies have introduced strategies to mitigate the adverse effects of climate variability on production. These include fertilizer application, pest and disease control, and the adoption of efficient irrigation systems (Tuomisto et al., 2012).

Selecting improved genotypes provides a sustainable solution to reducing external energy inputs in conventional agricultural systems, including the use of pesticides, synthetic fertilizers, agricultural machinery, and fossil fuels (Alluvione et al., 2011; Tuomisto et al., 2012). This approach also helps lower greenhouse gas (GHG) emissions, deforestation, and biodiversity loss (Gonçalves et al., 2013; Corrêa et al., 2021).

However, although Brazil is the world's largest producer and exporter of coffee beans (Volsi et al., 2019), the country's diverse environments significantly influence the availability of modern cultivars. These cultivars are shaped by plant performance under various edaphoclimatic conditions, particularly in terms of increased yield, resistance to pests and diseases, tolerance to water deficits, and fruit uniformity.

Studies on quantitative growth, focusing on vegetative and yield-related aspects, play a critical role in understanding the interaction between genotypes and environments. Such research facilitates the development and selection of high-yielding cultivars adapted to different cultivation conditions (Zeist et al., 2019), strengthening coffee cultivation strategies both nationally and internationally.

The *brejos de altitude* (altitudinal humid forest enclaves) of Northeast Brazil, found in states such as Paraíba (Medeiros et al., 2017), Ceará (Silvera et al., 2020), and Pernambuco (Farias et al., 2016), occur on land ranging from 400 to 1100 meters in altitude. These areas possess a microclimate shaped by topographic factors, making them highly favorable for agricultural production.

In the region of Areia, located at an altitude of approximately 618 meters (Medeiros et al., 2017), coffee cultivation had historically been a predominant activity. However, it declined over the years and eventually disappeared. Recently, coffee farming has experienced a revival with the introduction of 21 coffee genotypes, aiming to restore and rejuvenate local coffee production. This initiative seeks not only to recover the region's agricultural heritage but also to integrate innovation and sustainability into coffee farming practices. The data presented in this article represent the initial findings of this effort, offering valuable perspectives for advancing coffee cultivation in the region.

From this perspective, the present study aimed to evaluate the vegetative and yield performance of Arabica coffee genotypes in a *brejo de altitude* within the Brazilian semi-arid region.

2. Material and Methods

Field studies were conducted over two consecutive years, 2018–2019 and 2019–2020, in the municipality of Areia, state of Paraíba, Brazil (06°57'46" S, 35°41'31" W, and 623 m of elevation). The experimental area features clay-sandy soil classified as Oxisol. The local climate is classified as Aw' (hot and humid) according to the Köppen System (Alvares et al., 2013), with an average annual temperature of 22 ºC, high humidity, and an average annual rainfall of 1,400 mm. The rainiest period spans from April to July (Ribeiro et al., 2018).

The chemical properties of the soil (Table 1) were characterized before the beginning of the experimental procedures using samples collected from the 0-0.20 m soil layer, following the chemical analysis protocols of Embrapa (2017).

A randomized block design with three replications was employed. The treatments consisted of 21 genotypes, including 20 elite progenies and the cultivar MGS Ametista (Table 2). The genotypes are part of the Coffee Breeding Program developed by the Agricultural Research Company of Minas Gerais (EPAMIG) in collaboration with partner institutions. All genotypes evaluated exhibit some level of resistance to rust. Each experimental unit comprised five plants, spaced 3.0 m × 0.5 m.

Growth data were collected at 12 and 24 months of cultivation, while yield data were obtained 24 months after planting (August 2020). Evaluations focused on the three central plants within each experimental unit.

The soil was prepared using conventional cultivation methods, including plowing and harrow leveling, followed by manual pit opening. All plots were fertilized directly in the pits with doses equivalent to 90 kg N ha^{-1}, 150 kg P ha^{-1}, and 120 kg K ha^{-1}, applied as ammonium sulfate, single superphosphate, and potassium chloride, respectively, based on current crop recommendations (Ribeiro et al., 1999).

Table 1. Chemical attributes of the soil in a *brejo de altitude* in Areia-PB, Brazilian semi-arid region.

	pH (water)	P	K	Na	H+Al	Al	Ca	Mg	SB	CEC	OM
		mg dm^{-3}		cmolc dm^{-3}							g kg^{-1}
2018	5.60	3.26	50.16	0.11	3.40	0.10	3.47	2.41	6.11	9.61	14.83
2019	6.06	2.10	30.00	0.08	0.34	0.0	2.24	2.28	4.67	5.01	24.00

P e K (Mehlich^{-1} extractor); SB: sum of bases; CEC: cation exchange capacity (effective); OM: organic matter.

Plant height (PH) was determined in meters after harvest using a measuring tape, from the base of the plant to the first established leaf on the main (orthotropic) branch, which produces the plagiotropic branches. Stem diameter (StD) was measured in millimeters at a basal height of 5 cm above ground level using a digital caliper. Crown diameter (CrD) was measured in meters using a measuring tape, and the final value was calculated using Equation (1).

$$CrD = ((W \times L) / 2) \quad (1)$$

CrD is stem diameter in meters, W is leaf width (m), and L is leaf length (m).

Leaf area was measured using the gravimetric method described by Kemp (1960) and Huerta and Alvim (1962), by which the greatest length and width of a leaf belonging to the first pair established in the orthotropic branch were measured in centimeters using a ruler. The measures were then inserted into equation (2).

$$LA = 0.667 \times L \times W \quad (2)$$

LA is leaf area (cm^2), L is the greatest leaf length (cm), and W is the greatest leaf width (cm).

The number of plagiotropic branches was determined by manually counting all productive branches on the vertical (orthotropic) branch. Vegetative vigor was assessed in the field prior to harvest using a subjective grading scale from 5 to 10, where 5 represented the least vigorous plants and 10 the most vigorous.

Vegetative vigor was assessed in the field prior to harvest using a subjective grading scale from 5 to 10, where 5 represented the least vigorous plants and 10 the most vigorous.

After the growth evaluations, coffee was manually harvested. All fruits from the three central plants in each plot were collected. A 2-L aliquot of coffee cherry (fresh or moist fruits) was selected per plot for natural drying under a plastic cover on a masonry yard. Drying continued until the fruits reached a moisture content of 11–12%, resulting in "coffee in coconut" (dry fruits).

These were subsequently processed by removing the husks to produce the processed coffee, ready for commercialization). The processed coffee was weighed (kg) to determine the coffee mass per plot. This mass was converted using Equation (3) and expressed as kilograms of processed coffee per hectare (kg ha^{-1}) using Equation (4):

$$Vfs = (1 \, x \, A) / Wgs \quad (3)$$

Vfs is the volume of coffee cherry fruits harvested (in liters) necessary to obtain 1 kg of processed coffee, expressed in L kg^{-1}; A is the aliquot volume used to quantify a fruit sample, expressed in liters (L); and Wgs is the weight of dry coffee beans (after drying and processing), in kg.

$$CY = \{[(Pp / Np) \times E] / Vsf\} \quad (4)$$

Coffee yield (CY) is expressed in kg ha^{-1} and calculated using the following parameters: Pp, the fruit production per plot (L plant^{-1}); Np, the number of productive plants per plot; E, the plant density (plants ha^{-1}), based on a spacing of 6,666.66 plants ha^{-1}; and Vsf, the volume of coffee cherry fruits required to produce 1 kg of processed coffee (L kg^{-1}). A 1-L fruit sample was collected from each plot and taken to the laboratory for analysis. The sample was manually washed to remove impurities and subjected to density separation. The percentages of fruits at different maturity stages (green, ripe, raisin, and dry) were then determined. Additionally, the Brix degree of the fruits was measured using a manual refractometer (Briobrix® Model 103) with a resolution of 0.2%.

Data were tested for normality using the Shapiro-Wilk test (1965) and for homogeneity of variances using the Bartlett test. Subsequently, the data were subjected to analysis of variance (ANOVA) and the F-test ($p < 0.05$), following the methodology outlined by Banzatto and Kronka (2013), with genotypes serving as the source of variation. The means of the variables were grouped using the Scott-Knott test ($p > 0.05$). The statistical model for this design is:

$$Yij = m + bj + ti + eij \quad (5)$$

Y_{ij} is the value observed for the studied trait, in treatment i (i = genotype 1, 2, ..., 21) and in block (or replication) j (j = 1, 2, 3); m is the overall mean (of all observations) of the experiment; t_i is the effect of treatment i; e_{ij} is the error associated with observation Y_{ij} or the effect of uncontrolled factors on it. Cluster analysis was then performed by Ward's method (Ward.D2 algorithm) using the Euclidean distance as a measure of similarity (Murtagh; Legendre, 2014). All analyses were performed using the software R 3.6.3 (R Core Team, 2020).

Table 2. Characteristics of the Arabica coffee genotypes used in the study in a *brejo de altitude* in Areia-PB, Brazilian semi-arid region.

Treatment	Genotype	Genotype Description	Seed Generation
1	T4 I	H419-6-2-7-3-6-3-1	F7
2	T8 I	H419-6-2-5-3-3-2-1	F7
3	Araponga 2	MGS Ametista	Fn
4	Paraíso MG3 A.	H419-6-2-3-4-1-1	F6
5	T1 I	H419-3-3-7-16-2-1-1	F7
6	T2 II	H419-3-3-7-16-11-1-1	F7
7	T23 II	H514-7-8-3-3-1-9-3-1	F8
8	Paraíso MG4 V.	H419-6-2-5-2-1-1	F6
9	T10 I	H419-6-2-5-3-7-3-1	F7
10	T9 I	H419-6-2-5-3-2-3-1	F7
11	T15 I	H419-6-2-5-3-13--6-1	F7
12	T3 I	H419-6-2-7-3-15-2-1	F7
13	T13 II	H419-6-2-5-3-8-3-10	F7
14	T13 I	H419-6-2-5-3-8-3-1	F7
15	T24 I	H514-7-8-3-3-1-9-5-1	F8
16	T7 I	H419-6-2-5-3-3-4-1	F7
17	T21 I	H514-7-8-3-3-1-7-1	F7
18	Catiguá A. FBS	H514-7-8-3-3-1-10-1	F7
19	T5 II	H419-6-2-7-3-14-3-1	F7
20	T16 II	H419-6-2-3-4-11-5-1	F7
21	Campos Altos	H514-7-8-2-1-1-1-1	F7

3. Results and Discussion

The biometric parameters of plant height, stem diameter, crown diameter, and number of plagiotropic branches did not vary in the first year, regardless of the genotypes studied (Table 3). However, genotypes T4 I, T8 I, Araponga 2, T10 I, T9 I, T15 I, T3 I, T13 I, T21 I, T5 II, T16 II, and Campos Altos produced 20.36% more leaf area than the other treatments ($p > 0.05$). In the first year, the biometric parameters varied as follows: plant height ranged from 0.60 m to 0.78 m, stem diameter from 13.78 mm to 18.67 mm, crown diameter from 0.59 m to 0.77 m, and the number of plagiotropic branches from 22 to 30.2. These values are considered moderate for *Coffea arabica*, taking cultivation and environmental factors into account. Sousa et al. (2019) investigated genetic divergence in 35 Arabica coffee cultivars in the Cerrado and reported average values of 1.05 m for height, 26.76 mm for stem diameter, and 1.12 m for crown diameter under irrigated cultivation, highlighting the favorable conditions for vegetative performance in an environment with water supplementation. In the second year after planting, the assumptions of analysis of variance for experiments conducted in completely randomized blocks were satisfied for all studied characteristics ($p > 0.01$; Table 3), indicating morphological variability among genotypes. This variability is promising, as phenotypic diversity is critical for plant genetic improvement (Spinoso-Castillo et al., 2020). The coefficients of variation (CV%) ranged from 10.9% to 18.3%, reflecting low variability and high experimental precision for the evaluated characteristics. In the second year, plant height grouped the genotypes into two categories. The first group included genotypes T5 II, T21 I, T15 I, T2 II, and T1 I, with an average height of 1.20 m, which was 12.67% higher than the other treatments. Stem diameter ranged from 25.16 mm (T7 I) to 37.27 mm (T21 I). Crown diameter varied between 0.92 m (T7 I) and 1.35 m (T5 II), with genotypes T5 II, T21 I, T15 I, T9 I, T13 II, and T16 II exhibiting values 14.62% greater than the other treatments.

While the number of branches did not differ significantly among genotypes, it ranged from 30.88 (T3 I) to 40.22 (T5 II). Leaf area ranged from 35.64 cm^2 (T2 II) to 55.57 cm^2 (T3 I), with genotypes Paraíso MG3 Amarelo, T1 I, T2 II, T23 II, Paraíso 4 Vermelho, T24 I, T13 I, T7 I, and Catiguá Amarelo showing significantly lower values compared to the other genotypes.

Parameters such as height and diameter are critical for plant survival and development, particularly after transplantation and during the early growth years, as they are predictive indicators of field survival and robustness (Gallegos-Cedillo, 2021). Genotypes with greater growth in height and diameter suggest higher survival and production potential. Among the 21 Arabica coffee genotypes tested, 11 achieved the highest ratings for vegetative vigor (Table 3). Vegetative vigor strongly correlates with yield and is widely used as an evaluation parameter to estimate coffee yield potential (Severino et al. 2002).

Table 3. Plant height (PH), stem diameter (StD), crown diameter (CrD), number of plagiotropic branches (NB), and leaf area (LA) of 21 Arabica coffee genotypes in a *brejo de altitude* in Areia-PB, Brazilian semi-arid region.

Genotypes	PH (m)		StD (mm)		CrD (m)		NB (un.)		LA (cm^2)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
T4 I	0.61a	1.07b	13.78a	25.83c	0.68a	1.05b	22.00a	34.89a	32.15a	53.57a
T8 I	0.66a	1.08b	14.78a	30.18c	0.59a	1.02b	26.22a	35.11a	32.32a	48.66a
Araponga 2	0.60a	1.01b	14.33a	29.94c	0.59a	1.08b	24.00a	34.78a	30.12a	51.16a
Paraíso MG3 A.	0.68a	1.00b	15.22a	28.24c	0.67a	1.06b	22.89a	33.67a	29.24a	41.83b
T1 I	0.70a	1.16a	15.78a	33.35b	0.71a	1.07a	28.22a	39.22a	27.27b	40.68b
T2 II	0.70a	1.16a	15.89a	32.96b	0.65a	1.14a	23.33a	35.67a	24.78b	35.64b
T23 II	0.65a	1.05b	14.00a	30.62b	0.61a	1.03b	25.33a	35.89a	25.09a	39.46b
Paraíso 4 V.	0.60a	1.06b	14.22a	28.44c	0.66a	1.03b	23.78a	33.89a	24.15b	39.22b
T10 I	0.65a	1.07b	15.11a	30.95c	0.70a	1.05b	25.11a	34.56a	25.81a	47.03a
T9 I	0.63a	1.09b	17.22a	31.44a	0.67a	1.28b	24.00a	35.78a	29.21a	49.12a
T15 I	0.78a	1.22a	15.89a	34.53a	0.69a	1.29a	28.44a	37.56a	31.95a	54.96a
T3 I	0.61a	1.00b	14.33a	30.55b	0.60a	1.08b	25.56a	30.89a	33.96a	55.57a
T13 II	0.66a	1.03b	16.00a	30.83a	0.66a	1.10b	25.33a	35.44a	26.65b	41.05a
T13 I	0.63a	1.07b	15.11a	31.53b	0.64a	1.20b	23.33a	36.11a	29.74a	50.47b
T24 I	0.67a	1.03b	15.11a	28.06c	0.62a	1.03b	23.56a	34.33a	31.90a	44.74b
T7 I	0.63a	1.06b	14.56a	25.16c	0.63a	0.92b	24.22a	33.89a	21.08b	37.39b
T21 I	0.73a	1.24a	17.67a	37.28a	0.77a	1.30a	22.89a	36.67a	38.82a	53.74a
Catiguá A. FBS	0.67a	1.11b	16.67a	31.45b	0.60a	1.12b	27.11a	34.67a	25.04b	43.65b
T5 II	0.78a	1.27a	18.67a	32.02a	0.72a	1.35a	30.22a	40.22a	31.73a	52.83a
T16 II	0.67a	1.06b	17.44a	32.46a	0.65a	1.19b	25.33a	32.67a	30.10a	52.41a
Campos Altos	0.75a	1.10b	16.44a	31.79b	0.68a	1.16b	27.78a	38.89a	29.65a	47.16a
Mean	0.67	1.09	15.62	30.84	0.66	1.12	25.17	35.46	29.08	46.68
CV%	12.9	12.3	10.9	13.2	12.9	16.1	14.2	18.3	13.63	14.2

Means followed by different letters in the columns belong to the same group by the Scott-Knott test (p> 0.05).

The timing of fruit harvest is closely linked to coffee quality (Coelho et al., 2020). In the first year, the average percentages of coffee fruits at different maturation stages (Table 4) were as follows: green fruits ranged from 28.2% to 71.1%; ripe (cherry) fruits from 9.17% to 60.3%; raisin fruits from 1.9% to 47.7%; and dried fruits from 0.9% to 14.3%. Only six genotypes (T13 II, T13 I, T21 I, Catiguá Amarelo FBS, T1 I, and Paraíso 4 Vermelho) had green fruit averages below 40%.

Table 4. Vegetative vigor, percentage of green, ripe, raisin, and dry fruits, Brix, and grain yield (kg ha^{-1}) for 21 genotypes of Arabica coffee in a *brejo de altitude* in Areia-PB, Brazilian semi-arid region.

Genotypes	Vigor	Green F.	Ripe F.	Raisin F.	Dry F.	º Brix	Yield
T4 I	8.67a	44.66b	40.33b	10.12d	4.89c	22.78a	1131.60c
T8 I	8.00b	49.17b	27.76d	15.69c	7.38b	17.56a	2339.40a
Araponga 2	7.50b	68.91a	24.91d	1.95e	4.23c	18.22a	1578.00b
Paraíso MG3 A.	7.67b	71.17a	17.75e	8.89d	2.19c	21.06a	1374.00c
T1 I	8.00b	35.51c	41.68b	18.29c	4.51c	20.06a	1729.80b
T2 II	8.17a	60.77a	32.51c	4.93e	1.79c	19.78a	555.00d
T23 II	8.33a	43.64b	27.91d	26.12b	2.33c	17.78a	1251.00c
Paraíso 4 V.	7.33b	37.96c	41.73b	17.46c	2.86c	18.50a	776.40d
T10 I	7.33b	50.98b	28.47d	17.21c	3.33c	19.17a	1575.60b
T9 I	8.83a	41.88b	34.74c	21.62b	1.77c	19.17a	933.00c
T15 I	9.67a	67.17a	23.75d	6.89d	2.19c	20.50a	2111.40a
T3 I	7.50b	65.82a	14.44e	17.01c	2.74c	18.44a	366.00d
T13 II	7.17b	28.27c	28.75d	28.65b	14.34a	21.56a	1509.00b
T13 I	8.17a	29.36c	15.25e	47.72a	7.67b	19.61a	1212.00c
T24 I	7.33b	47.32b	33.83c	12.17c	6.68b	20.33a	1378.80c
T7 I	6.00b	63.65a	21.65d	11.58c	3.11c	19.06a	1750.20b
T21 I	9.00a	29.98c	46.18b	21.77b	2.07c	18.44a	1528.80b
Catiguá A. FBS	8.50a	33.88c	60.33a	4.07e	1.72c	20.17a	1852.20b
T5 II	10.00a	62.37a	9.17e	24.28b	4.17c	20.17a	2421.00a
T16 II	8.33a	67.37a	16.83e	14.82c	0.97c	18.50a	2094.00a
Campos Altos	9.16a	42.14b	31.08d	24.54b	2.21c	17.77a	1365.00a
Mean	8.12	49.61	29.47	16.94	3.96	19.45	1496.77
CV%	10.85	9.48	16.05	19.04	24.50	10.44	22.28

Means followed by different letters in the columns belong to the same group by the Scott-Knott test (p> 0.05).

This behavior is influenced by the photoperiod and sporadic rains during the region's dry season (August–December) (DaMatta et al., 2007), explaining the observed maturation patterns of the harvested fruits. Genotype Catiguá Amarelo FBS was the only one to achieve 60% ripe fruits, along with raisin fruit values below 5%, considered ideal. This was followed by genotypes T21 I, T4 I, T1 I, and Paraíso 4 Vermelho, which reached 40% ripe fruits. Ripe fruits are essential for optimal coffee harvest, as green or dry fruits contribute undesirable bitter and acidic flavors to the final product (Arruda et al., 2011). The average Brix of coffee fruits did not differ significantly among the genotypes, ranging from 17.56 (T8 I) to 22.78 (T4 I). These values fall within the ideal range for coffee, typically 15–30, and are an important parameter influencing the drink's flavor quality (Resende et al., 2011). In terms of fruit yield, genotypes T5 II, T16 II, Campos Altos, T15 I, and T8 I performed best, with the highest yields averaging 2,186.16 kg ha^{-1}.

Conversely, genotypes T2 II, Paraíso 4 Vermelho, and T3 I exhibited significantly lower yields, averaging 565.80 kg ha^{-1}.Notably, the highest-yielding genotypes (T5 II, T16 II, Campos Altos, T15 I, and T8 I) surpassed the national average yield of 28.8 bags ha^{-1} (1,728 kg ha^{-1}) (CONAB, 2024), demonstrating that the edaphoclimatic conditions in Areia were highly favorable for these genotypes. Similar results were reported by Silva et al. (2022) in a study of ten coffee progenies and the cultivars Catuái Vermelho IAC 99 and Catuái Vermelho IAC 144 in Vale do Jequitinhonha, Minas Gerais.

They observed yield variations ranging from 20.96 bags ha^{-1} (1,257.60 kg ha^{-1}) to 32.40 bags ha^{-1} (1,944.00 kg ha^{-1}). Analysis by Ward's hierarchical method, based on the Euclidean distance of data referring to the vegetative and yield aspects of the 21 Arabica coffee genotypes, revealed the formation of three groups of genotypes in the first year of cultivation (Figure 1):

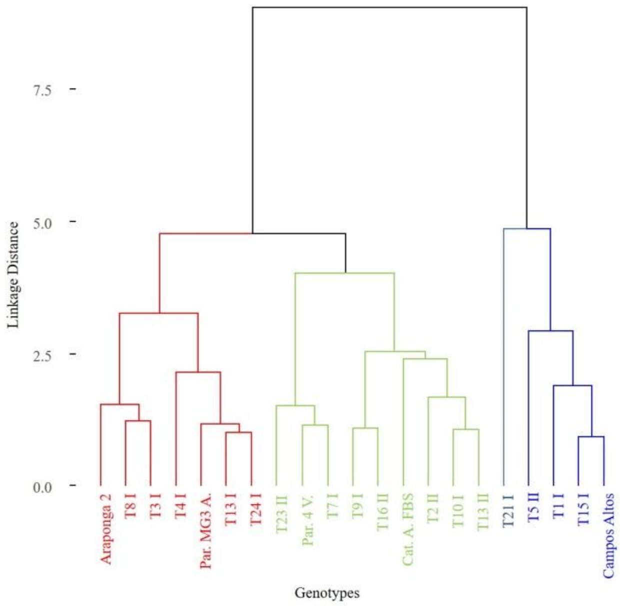

Figure 1. Dendrogram obtained using Ward's hierarchical clustering method, based on Euclidean distances, considering plant height, stem and crown diameter, number of branches, and leaf area during the first year of evaluation of 21 Arabica coffee genotypes in a *brejo de altitude* area in Areia, Paraíba, semi-arid region of Brazil.

Group I comprising five genotypes (T21 I, T5 II, T1 I, T5 I, and Campos Altos); Group II comprising nine genotypes (T23 II, Paraíso 4 Vermelho, T7 I, T9 I, T16 II, Catiguá Amarelo FBS, T2 II, T10 I, and T13 II); and Group III comprising seven genotypes (Araponga 2, T8 I, T3 II, T4 I, Paraíso MG3 Amarelo, T13 I, and T24 I).

In the second year of cultivation, the Arabica coffee genotypes were subdivided into five groups based on morpho-agronomic descriptors (Figure 2): Group I, comprising three genotypes (T5 II, T15 I, and T21 I); Group II, comprising five genotypes (T1 I, Campos Altos, T2 II, T9 I, and T13 I); Group III, comprising six genotypes (T7 I, T23 II, T13 II, Paraíso 4 Vermelho, Paraíso MG3 Amarelo, and T24 I); Group IV, comprising five genotypes (T6 II, Araponga II, T10 I, T8 I, and Catiguá Amarelo FBS); and Group V, comprising two genotypes (T4 I and T3 I). From this perspective, phenotypic divergence was observed among the coffee genotypes, along with differences in the number of groups formed between the first and second year of cultivation.

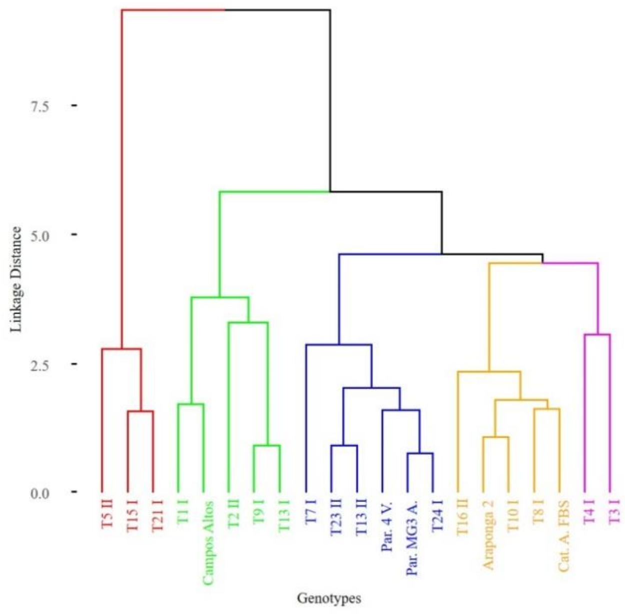

Figure 2. Dendrogram obtained using Ward's hierarchical clustering method, based on Euclidean distances, considering vegetative variables (plant height, stem and crown diameter, number of branches, and leaf area) and yield variables (Brix and grain yield) during the second year of evaluation of 21 Arabica coffee genotypes in a *brejo de altitude* area in Areia, Paraíba, located in the Brazilian semi-arid region.

Genotypes T1 I and Campos Altos, which were part of Group I in the first year, moved to Group II in the second year due to lower values for plant height, crown diameter, and leaf area compared to genotypes T5 II, T15 I, and T21 I, as well as a lower grain yield for genotype T1 I. Consequently, the inclusion of yield data alongside biometric evaluations in the second year was crucial for selecting genotypes that consistently performed well over both years (T5 II, T15 I, and T21 I).

In this scenario, the genotypes in Group I were identified as having the highest yield potential compared to the others, making them the most desirable for coffee cultivation in the Brazilian semi-arid region. Genotypes in Groups II, III, and IV exhibited intermediate values for plant height, stem diameter, crown diameter, number of branches, leaf area, and grain yield. In contrast, genotypes in Group V showed the lowest averages for all morpho-agronomic variables.

4. Conclusions

There is significant genetic variation among the Arabica coffee genotypes studied in terms of growth and yield-related traits. The results indicate that genotypes T5 II, T15 I, and T21 I are promising for cultivation in the *brejos de altitude* of the Brazilian semi-arid region.

However, further assessments of the yield potential of these genotypes are necessary in subsequent years to establish reliable planting recommendations for the edaphoclimatic conditions of the region.

Authors' Contribution

Guilherme Silva de Podestá: Conceptualization, Methodology, Investigation, Writing - original draft. Abraão Targino de Sousa Neto: Methodology, Investigation, Writing - original draft. Valéria Fernandes de Oliveira Sousa: Formal analysis, Data curation, Visualization, Writing - original draft. José Eldo Costa: Methodology, Data curation, Writing - Review. Inara da Silva Araújo: Methodology, Investigation, Writing - original draft. Renato Wanderley Diniz: Writing - Review. Guilherme Romão Silva: Writing - Review. Antônio Carlos Baião de Oliveira: Writing - Review and Editing.

Acknowledgments

The authors would like to thank the Paraíba State Research Foundation (FAPESQ) (Grant No.: 2165/2023) for awarding VFOS author a postdoctoral fellowship.

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