Morphometric and phenotypic characteristics of eight genotypes of *Coffea arabica* L. during vegetative development

Rasgos morfométricos y fenotípicos de ocho genotipos de *Coffea arabica* L. durante el desarrollo vegetativo

Características morfométricas e fenotípicas de oito genotipos de *Coffea arabica* L. durante o desenvolvimento vegetativo

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Abstract

Coffee production represents an important source of employment and economic dynamism for the south of the province of Manabí, so it is appropriate to identify the genotypes with the best morphological behaviour. The objective of the research was to evaluate the morphological and phenotypic variables of eight genotypes of *Coffea arabica* L. ("cafe arabica") in their third year of vegetative development, in order to identify the best morphological attributes for large-scale multiplication. A total of 348 plants of coffee genotypes Acawa, Catimor, Catucaí, Sarchimor, Bourbon yellow, Bourbon red, Manabi and Catuaí were evaluated. For the statistical analysis of the metric variables, a completely randomised design was used and linear regression, and for the analysis of the phenotypic variables, the chi-square statistical analysis was applied. The results showed highly significant differences ($P<0.01$) in all quantitative and qualitative variables. The genotype Acawa showed a better response for leaf length and branch length, Manabí 01 had greater petiole length and stem diameter; Catuaí showed greater number of branches, number of nodes and plant height, Bourbon yellow showed greater length between branches and greater internode length. As for the analysis of the qualitative variables, the colour of young leaves, the Bourbon revealed a reddish brown colour, the other genotypes are green; the leaf shape is oval, except for the Sarchimor that showed obovate leaves.

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Resumen

La producción de café representa una importante fuente de empleo y dinamismo económico para el sur de la provincia de Manabí, por lo que es oportuno identificar los genotipos de mejor comportamiento morfológico. El objetivo de la investigación fue evaluar las variables morfológicas y fenotípicas de ocho genotipos de *Coffea arabica* L. ("café arábigo") en su tercer año de desarrollo vegetativo, a fin de identificar los mejores atributos morfológicos para su multiplicación a gran escala. Se evaluó un total de 348 plantas de genotipos de café: Acawa, Catimor, Catucaí, Sarchimor, Bourbon amarillo, Bourbon rojo, Manabí y Catuaí. Para los análisis estadísticos de las variables métricas, se empleó el diseño completamente al azar y regresión lineal, y para analizar las variables fenotípicas, se aplicó el análisis estadístico chi cuadrado. Los resultados expresaron diferencias altamente significativas (P<0,01) en todas las variables tanto cuantitativas como cualitativas. El genotipo Acawa presentó una mejor respuesta para largo de hoja y longitud de rama, Manabí 01 tuvo mayor largo de pecíolo y diámetro de tallo; Catuaí mostró mayor número de ramas, número de nudos y altura de planta, el Bourbon amarillo mostró mayor longitud entre ramas y mayor longitud entrenudos. En cuanto al análisis de las variables cualitativas, el color de hoja joven, los Bourbon reveló color marrón rojiza, los demás genotipos son de color verde; la forma de hoja es ovada, excepto para el Sarchimor que manifestó hojas obovadas.

Palabras clave: variedad, parámetros de crecimiento, café arábigo, desarrollo vegetal, evaluación agronómica

Resumo

A produção de café representa uma importante fonte de emprego e dinamismo económico para o sul da província de Manabí, pelo que é conveniente identificar os genótipos com melhor comportamento morfológico. O objetivo da investigação foi avaliar as variáveis morfológicas e fenotípicas de oito genótipos de *Coffea arabica* L. ("café arabica") no seu terceiro ano de desenvolvimento vegetativo, a fim de identificar os melhores atributos morfológicos para a multiplicação em grande escala. Foram avaliadas 348 plantas dos genótipos de café Acawa, Catimor, Catucaí, Sarchimor, Bourbon amarelo, Bourbon vermelho, Manabi e Catuaí. Para a análise estatística das variáveis métricas, foi utilizado um delineamento inteiramente casualizado e regressão linear, e para a análise das variáveis fenotípicas, foi aplicada a análise estatística do qui-quadrado. Os resultados mostraram diferenças altamente significativas (P<0,01) em todas as variáveis quantitativas e qualitativas. O genótipo Acawa apresentou melhor resposta para comprimento de folha e comprimento de ramo, Manabí 01 apresentou maior comprimento de pecíolo e diâmetro de caule; Catuaí apresentou maior número de ramos, número de nós e altura de planta, Bourbon amarelo apresentou maior comprimento entre ramos e maior comprimento de entrenó. Quanto à análise das variáveis qualitativas, a cor das folhas jovens, o Bourbon revelou cor castanho-avermelhada, os demais genótipos são verdes; a forma da folha é oval, com exceção do Sarchimor que apresentou folhas obovadas.

Palavras-chave: variedade, parâmetros de crescimento, café arábica, desenvolvimento da planta, avaliação agronómica

Introduction

Coffee (*Coffea arabica* L.) is one of the most widely traded agricultural products in the world, due to its high acceptance as a beverage (Vera-Velásquez *et al*., 2024). The history of the geographical distribution of Arabica coffee cited by Van der Vossen *et al*. (2015) establishes that it originated in Ethiopia and spread to Yemen (6th century) and was then taken to India, Southeast Asia, Latin America and East Africa during the 17th-19th centuries.

Coffee cultivation has an enormous economic impact, especially in developing countries (Villalta-Villalobos and Gatica-Arias, 2019). Approximately 60 tropical and subtropical countries produce coffee on a large scale (Enríquez *et al*., 2020). Around 7.7 million tonnes of green coffee are produced worldwide each year on an area of 10.5 million hectares, with 85 % of the coffee produced in Latin America (Jiménez *et al*., 2023).

Vera-Velásquez *et al*. (2024) cite the prevalence of old coffee plantations with little or no resistance to rust (*Hemileia vastatrix*) and the presence of pests and diseases as the most significant problems affecting Ecuadorian coffee farming. In this regard, Quiroga-Cardona (2021) mentions that there is a wide genetic diversity in coffee cultivation, which is why it is important to identify plants that are resistant to pests and diseases and that are easily adaptable to local climates.

Coffee cultivation, an important agricultural activity in Ecuador, is among the 10 crops with the largest area under cultivation. It is grown in several provinces of the country (Ponce Vaca *et al*., 2018), with production concentrated in the province of Manabí, particularly in the canton of Jipijapa PDOT del Cantón Jipijapa 2019-2023, 2019; Venegas Sánchez *et al*., 2018). Productivity in Ecuador reaches 240,000 ha, with an Arabica coffee yield of 231.8 kg.ha^{-1} (Duicela *et al*., 2018). It is very important for coffee-growing areas, as it is a source of employment for families engaged in this crop (Venegas *et al*., 2018).

Arabica coffee harvesting is still largely based on traditional cultivars developed long ago by selecting lines within the Typica and Bourbon cultivars or from crosses between them (e.g., Mundo Novo, Catuaí (Ferwerda and Der, 1969).

The objective of the research was to evaluate the morphometric and phenotypic characteristics of eight genotypes of *Coffea arabica* L. in order to identify the genotype or genotypes with the best attributes.

Materials and methods

Geographical location of the experimental plots

The research was conducted at the Andil Farm of the Universidad Estatal del Sur de Manabí, 2.5 km from the town of Jipijapa, Manabí, located at 1° 18' 0.0' south latitude and 80° 34' 43.50' west longitude, at an altitude of approximately 280 metres above sea level; with average temperatures between 18 and 23.7 °C. The average annual rainfall is 500 to 1000 mm and the relative humidity in the rainy season is 82 to 84 % and in the dry season it is 76.2 % to 80 % (PDOT Cantón Jipijapa 2019-2023, 2019).

Treatments

The treatments consisted of eight Arabica coffee genotypes whose plants were three years old:

Acawa, Catimor, Catucaí, Sarchimor, Yellow Bourbon, Red Bourbon, Manabí 01, and Catuaí.

Specific research management

For the management of the experimental plots, the plants were supplied with a complete 8-20-20 fertiliser at a dose of 50 g per individual, plus 25 g per individual of urea. Weed control was carried out manually every two months during the dry season and increased monthly during the rainy season. Fifty-seven plants per genotype were evaluated, totalling 456 plants evaluated throughout the experiment, with each plant considered an experimental unit. The data were stored in Excel files, which were subsequently cleaned and analysed using SPSS Statistics version 26 software (Orellana and Cañarte, 2022).

Morphometric characteristics

The following morphometric variables were measured: plant height (PH) cm; stem diameter (SD) mm; leaf blade length (LBL) cm; leaf blade width (LBW) cm; number of branches (NB); branch length (BL) cm; number of knots by branches (NN); leaf petiole length (LPP) mm; internode length (IL) cm, distance between branches (DBB). To collect data on the morphometric variables, the methodology of Ortiz and Ortega (2024) was followed, using a tape measure and a RexBeti Stainless Hardened© digital caliper (measuring range: 5.906 in. Accuracy: 0.1 inch).

Phenotypic characters

The descriptors of the International Plant Genetic Resources Institute (IPGRI) (François and Dussert, 2016) were used as a guide for qualitative data collection. The variables considered were: leaf colour, leaf shape, leaf apex shape, and young shoot colour.

Statistical analysis

Based on the defined model, a completely randomised design was applied, and the comparison of treatment means was performed using Tukey's test (P<0.05). In addition, linear regression was performed to correlate plant height with other variables of interest.

Qualitative variables were analysed using the chi-square test, which allows the behaviour of two qualitative variables to be compared.

Results and discussion

Analysis of morphometric variables

Analysis of the morphometric data prior to applying the parametric statistical model determined that they meet the conditions of normality and homogeneity of variance. The asymmetry coefficient, kurtosis and Kolmogorov-Smirnov test showed that the data had a normal distribution and homogeneous variance, with the exception of the branch length and leaf petiole length variables, which were transformed using logarithms for normalisation.

The analysis of variance (ANOVA), Table 1, revealed highly significant differences (P<0.01) between treatments (genotypes) in each of the variables studied, and the coefficients of variation (CV) are within the range permitted for this type of research (8 to 30) (Gordón-Mendoza and Camargo-Buitargo, 2015).

Table 1. Analysis of variance and comparison of means of the quantitative study variables for each genotype.

Variable	Acawa	Catimor	Catucaí	Sarchimor	Yellow Bourbon	Red Bourbon	Manabí 01	Catuaí	P-value
Leaf Blade length (LBL) (cm)	**19.05±0.01**^{a} (5.84)	18.29±0.03^{ab} (2.73)	18.09±0.01^{b} (4.00)	17.47±0.01^{bc} (5.71)	16.71±0.01^{cd} (4.26)	15.97±0.01^{de} (2.88)	15.56±0.01^{e} (2.43)	15.48±0.01^{f} (4.00)	<0.01
Leaf Blade width (LBW) (cm)	8.33±0.1^{bc} (6.56)	7.94±0.11^{cd} (10.09)	7.67±0.11^{de} (9.85)	**8.81±0. 23a** (13.85)	8.42±0.07^{ab} (6.51)	8.39±0.07^{abc} (6.18)	7.37±0.08^{e} (6.85)	6.45±0.11^{f} (11.03)	<0.01
Number of Branches (NB)	48.16±1.63^{ab} (19.19)	46.69±1.38^{bc} (21.11)	48.50±2.6^{ab} (30.24)	39.07±2.16^{cd} (29.75)	41.91±1.71^{bcd} (33.22)	39.14±1.74^{cd} (30.47)	37.08±1.25^{d} (21.28)	**53.77±2. 6**^{ab} (30.24)	<0.01
Branch Length (BL) (cm)	**71.71±0.02**^{a} (5.17)	63.4±0.01^{bcd} (3.76)	62.63±0.0^{cd} (4.7)	65.81±0.02^{b} (4.59)	63.82±0.01^{bc} (2.8)	66.36±0.01^{bc} (2.64)	56.86±0.01^{d} (2.51)	69.35±0.01^{ab} (4.7)	<0.01
N° Knots by branches (NN)	17.32±0.48^{ab} (15.54)	14.45±0.24^{c} (11.95)	14.99±0.7^{bc} (21.21)	14.79±0.99^{c} (36.11)	17.2±0.46^{ab} (20.2)	12.18±0.42^{d} (25.52)	16.05±0.5^{abc} (19.67)	**17.98±0. 7a** (24.21)	<0.01
Plant height (PH) (cm)	178.31±3.71^{b} (11.78)	189.98±3.66^{b} (13.75)	186.45±5.88^{b} (16.3)	145.8±5.88^{c} (21.73)	189.62±6.55^{b} (26.29)	178.07±8.62^{b} (35.57)	128.40±2.97^{c} (14.61)	**217.23±5. 88a** (16.3)	<0.01
Stem diameter (SD) (mm)	35.63±0.97^{bc} (15.35)	29.11±0.92^{d} (22.47)	28.91±0.87^{d} (17.12)	29.73±0.96^{bc} (17.44)	38.72±1.07^{b} (20.87)	34.89±1.14^{bc} (24.05)	**45.84±1. 35**^{a} (18.56)	31.71±0.87^{cd} (17.12)	<0.01
Leaf Petiole Length (LLP)	1.46±0.02^{b} (18.91)	1.16±0.02^{c} (13.55)	1.16±0.05^{cd} (24.88)	1.3±0.1^{c} (43.24)	1.03±0.03^{d} (19.15)	1.02±0.03^{d} (19.15)	**1.78±0.03**^{a} (11.48)	1.23±0.05^{c} (24.88)	<0.01
Distance between branches (DBB) (cm)	12.07±0.66^{cd} (30.06)	13.88±0.34^{ab} (17.27)	14.23±0.52^{ab} (25.93)	11.34±0.79^{d} (37.62)	**15.27±0. 49**^{a} (24.41)	12.73±0.53^{bcd} (30.52)	7.50±0.47^{e} (39.38)	12.41±0.52^{bcd} (25.93)	<0.01
Length between knots (LBK) (cm)	5.58±0.21b^{c} (21.02)	4.88±0.14^{cd} (20.79)	**7.67±0. 2**^{a} (21.06)	5.93±0.28^{b} (25.18)	**7.34±0. 23**^{a} (23.87)	6.4±0.23^{b} (23.34)	4.61±0.09^{e} (11.94)	5.80±0.2^{b} (21.06)	<0.01

Tukey test results; a, b, c, d for each control, the minimum quadratic means without a common superscript differ significantly (p < 0.05) between groups.

The Catuaí genotype performed best in terms of the AP variables, with an average of 217.23 ± 5.88 cm, NR with an average of 53.77 ± 2.6 branches, and NN per branch of 17.98 ± 0.7. on the other hand, the genotype that presented the lowest height was Manabí 01, with an average of 128.40 ± 2.97 cm, as well as the genotypes Sarchimor with 39.07 ± 2.16 and Manabí 01, with 37.08 ± 1.25, which were those with the lowest NR, and the Catimor genotypes with 14.45 ± 0.24 and Bourbon Rojo with an average of 12.18 ± 0.42 were the genotypes with the lowest number of nodes per branch.

The Acawa genotype showed the best response in LL with an average of 19.05 ± 0.01 cm; in contrast, Catuaí exhibited the shortest length, reaching only 15.48 ± 0.01 cm. Similarly, the Acawa genotype had the highest LR with an average of 71.71 ± 0.02 cm, while the Catucai genotypes with 62.63 ± 0.01 cm and Manabí 01 with an average of 56.86 ± 0.01 cm had the lowest values for this variable.

The Sarchimor genotype stood out for having the highest AL, with an average of 8.81 ± 0.23 cm, and the treatment that showed the lowest response was Catuaí, with an average of 6.45 ± 0.11 cm. In terms of DT, with an average of 45.84 ± 1.35 mm, and LDPF, with an average of 1.78 ± 0.03 mm, the Manabí 01 genotype performed best.

Analysis of the DER variable determined that the Yellow Bourbon genotype had an average of 15.27 ± 0.49 cm, and the lowest averages were for the Sarchimor 11.34 ± 0.79 cm and Manabí 01 7.50 ± 0.47 cm genotypes. With regard to the LEN variable, it was observed that the Catucaí genotypes with 7.67 ± 0.20 cm and Yellow Bourbon with 7.34 ± 0.23 cm had the longest internode lengths.

Enríquez *et al*. (2020) reported that Sarchimor exhibited a greater number of branches and better phenotypic expression compared to other genotypes, specifically in Manabí 01. For their part, Castro *et al*. (2024), in their work with 20 genotypes between hybrids and varieties, observed better performance in the hybrids; likewise, a great deal of variability was observed even among hybrids. In a study conducted by Valverde *et al*. (2024) on the hybrids Sarchimor 4260, Sarchimor 1669 and Manabí 01, it was stated that even among the Sarchimor hybrids there were marked morphological differences, which coincide with our study. The results confirm the findings of Bonomo *et al*. (2004), who pointed out that variability within different genotypes may be greater than in pure varieties due to genetic segregation in early generations.

The variability found in this study is attributed, in self-pollinating species such as *C. arabica*, to evolutionary processes or natural mutations that occur within the population (Olika *et al*., 2011), a view shared by various researchers (Adem, 2020; Alemayehu, 2019; Getachew *et al*., 2017; Mossie *et al*., 2017); Chen (2010) mentioned that morphometric characters interact with the environment and are governed by many genes (polygenic) with small additive effects; this makes it very difficult for the cultivars obtained to behave in the same way in all environments, and according to this, it is due to the allopolyploidy of their genome.

Milla *et al*. (2019), meanwhile, pointed out that the vegetative development of coffee plants is closely linked to the interaction of their components, such as the association of species and coffee variety. These factors directly influence agronomic behaviour, reflecting their growth and adaptation potential. In this regard, Khemira *et al*. (2024) indicated that it is important to conduct morphological studies as a crop sustainability strategy, leading to the creation of new coffee varieties or populations that can better adapt to changing environmental conditions that may threaten different crops.

Linear regression analysis determined that there is a positive correlation between the variable plant height and the variables number of branches, branch length and distance between branches (Figures 1, 2, 3), deducing that at greater heights the probability of having more branches increases, although the distance between them also increases. It should be noted that the Manabí 01 genotype is the most homogeneous in terms of the morphological variables analysed.

With regard to the variables plant height and stem diameter, Figure 4 shows that there is no correlation between stem diameter and plant height among the genotypes. In a study conducted by Espinoza *et al*. (2021), it was noted that stem diameter has a positive correlation with plant height, contrary to our study, where the largest stem diameter is found in the Manabí 01 hybrid, which is the shortest in height. In this regard, Álvarez *et al*. (2024) indicate that certain traits are due to the characteristics of each genetic material.

Valverde *et al*. (2025) compared morphometric characteristics with productive characteristics and identified that both are correlated, asserting that a plant with good morphological characteristics tends to be more productive.

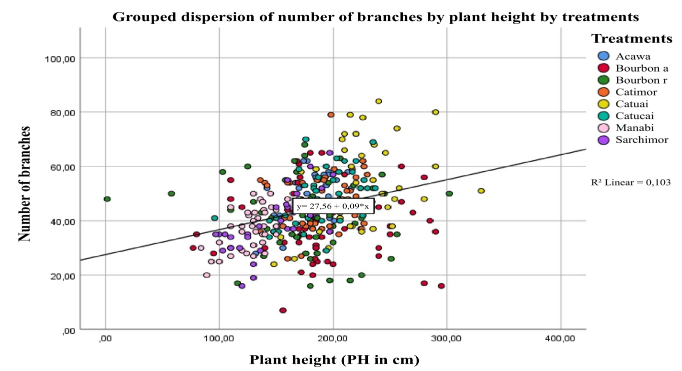

Figure 1. AP - NR linear regression.

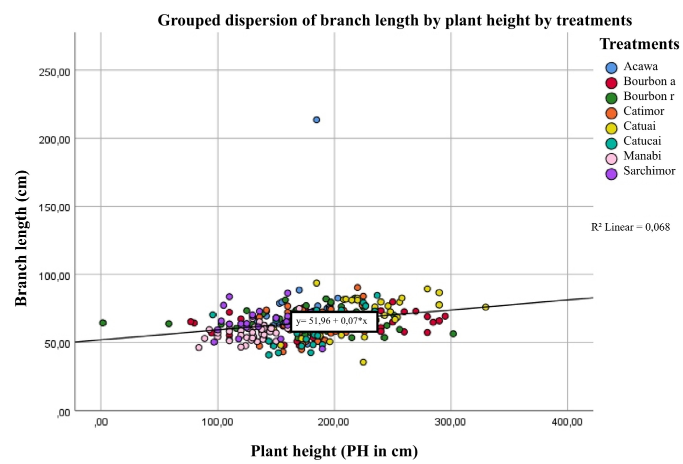

Figure 2. AP - LR linear regression.

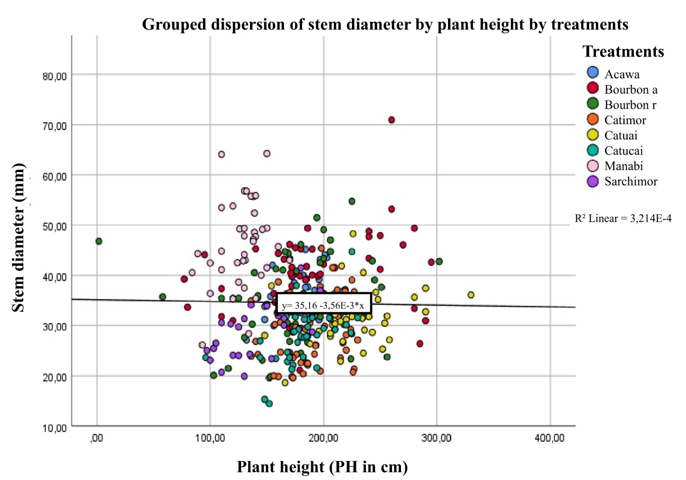

Figure 3. AP - DER linear regression.

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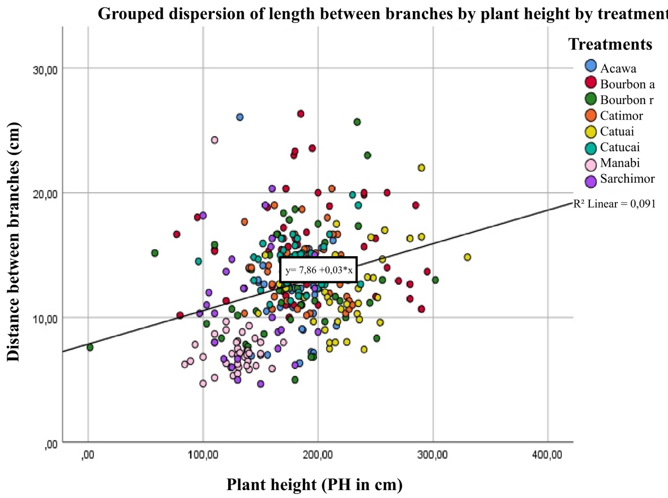

Figure 4. AP - DT linear regression.

Analysis of phenotypic variables

The results of the Chi-square analysis (Table 2) showed statistical differences in all the variables evaluated ($P<0.01$). With regard to the colour of young leaves, it was observed that the Catuaí and Sarchimor genotypes had 100 % green leaves, while the Catucaí, Catimor and Acawa genotypes had green leaves in percentages greater than 86%, and the Bourbon amarillo, Bourbon rojo and Manabí 01 genotypes had an average of between 20 and 26 % greenish leaves; reddish-brown leaves in percentages of 2 to 7 % were only found in the Bourbon genotypes.

In the analysis of young leaf shape, it was observed that the Sarchimor genotype had 100 % obovate leaves, while Catuaí had 100 % ovate leaves. The ovate leaf is also the characteristic shape of the Yellow Bourbon, Red Bourbon, Acawa, Catimor, Manabí 01 and Catucaí genotypes, with a predominance of up to 87 %.

Regarding the shape of the leaf apex, when analysing the results by genotype, it was observed that most of them had an apiculate apex,

Table 2. Analysis of phenotypic traits using the chi-square test.

	Color de la hoja joven (CHJ)				
Treatment	Greenish	Green	Reddish brown	Total	P value
Acawa	2	30	0	32	
Yellow Bourbon	15	42	1	58	
Red Bourbon	10	40	4	54	
Catimor	7	44	0	51	
Catuaí	0	39	0	39	0.01
Catucaí	5	39	0	44	
Manabí 01	8	32	0	40	
Sarchimor 4260	0	30	0	30	
Total	47	296	5	348	

	Shape of young leaf (FHJ)				
Treatement	Obovate	Ovate	Elliptical	Total	
Acawa	0	27	5	32	
Yellow Bourbon	0	53	5	58	
Red Bourbon	0	47	7	54	
Catimor	0	45	6	51	
Catuaí	0	39	0	39	0.01
Catucaí	0	36	8	44	
Manabí 01	2	29	9	40	
Sarchimor 4260	30	0	0	30	
Total	32	276	40	348	

	Shape of the leaf apex (FAH)				
Tratamientos	Acute	Pointy	Apiculated	Total	
Acawa	0	0	32	32	
Yellow Bourbon	16	1	41	58	
Red Bourbon	16	0	38	54	
Catimor	5	0	46	51	
Catuaí	0	0	39	39	0.001
Catucaí	5	0	39	44	
Manabí 01	8	0	32	40	
Sarchimor 4260	0	0	30	30	
Total	50	1	297	348	

** Highly significant statistical differences and the Yellow Bourbon, Red Bourbon, Catimor, Catucaí and Manabí 01 varieties had averages of up to 30 % with an acute apex. In relation to the variable colouration of the young leaf, the analysis by genotype determined that Acawa, Yellow Bourbon, Red Bourbon, Catimor, Catuaí, and Manabí 01 had young leaves with green colouration, while the Catucaí and Sarchimor genotypes were characterised by a predominance of young leaves with dark brown colouration.

Studies conducted by Álvarez *et al*. (2024) with the Sarchimor, Catuaí, Red Bourbon, and Yellow Bourbon genotypes, and work carried out by Valverde *et al*. (2024) with both Sarchimor hybrids and the Manabí 01 hybrid, show that the colour of young leaves is green, which coincides with our study. With regard to leaf shape, these researchers differ from the results obtained, pointing out that in both studies the leaves are elliptical in shape. The variability presented according to Milla *et al*. (2019) is due to the fact that each genotype has different responses to the ecosystem of which it is part, highlighting factors such as climate, solar radiation, and quantity and quality of shade.

For their part, Alvarado-Alvarado and Ochoa-Fonseca (2006) mention that the study of phenotypic variables will allow the incorporation of acceptable materials, in addition to obtaining more harmonious mixtures with a good phenotype and relatively more homogeneity.

Conclusions

The analysis of morphometric characteristics revealed heterogeneity among the various genotypes studied in their third year of vegetative development. With regard to phenotypic characteristics, it was determined that there are genotypes with particular characteristics.

The findings obtained from the study of eight Arabica coffee genotypes determined that genotypes such as Manabí 01 and Sarchimor 4260, with average heights of 128 and 1.45 cm, are the most suitable, as they facilitate harvesting. The stem diameter of Manabí 01, at 45.84 mm, is positive, considering that coffee in our sector is grown on slopes and therefore provides greater firmness; and having a lower DER than the other genotypes means that the difference in NR is not representative with respect to the rest of the genotypes. For these reasons, the Manabí 01 and Sarchimor genotypes would so far be the most promising for multiplication.

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