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Selection of Conilon coffee clones for the Zona da Mata region of Minas Gerais, Brazil

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ABSTRACT

Recently, the cultivation of *Coffea canephora* species has expanded as a consequence of climate change effects and emerging markets that use this coffee as raw material. To meet such demands of production, it is necessary to also improve yield in cultivated areas. Hence, this study aimed to evaluate Conilon coffee clones to identify the most promising fitting material for the Zona da Mata region of Minas Gerais, as well as to analyze the effect of the genotype x biennium interaction and estimate correlation coefficients among evaluated characteristics. Vegetative vigor, yield, main pests and diseases were evaluated in 36 clones from Incaper, ES. The statistical analyses considered the averages of each biennium: Biennium 1 (B1) - 2005/2006; Biennium 2 (B2) - 2007/2008; Biennium 3 (B3) - 2009/2010, and also the average of three biennia (A3B). Univariate and joint statistical analysis were performed, as well as estimates of phenotypic, genotypic and environmental correlation coefficients among assessed characteristics. A wide variability among clones was observed for most of the evaluated characteristics for both each biennium and the average of three biennia. The severities of most diseases have reduced over the years of cultivation. The genotypic correlation coefficients have overcome phenotypic and environmental ones. In general, pests and diseases severities showed significant and negative correlations with vegetative vigor and yield. On the other hand, the last two characteristics were positively correlated. It was also evidenced a certain diversity among clones for most of the evaluated traits. Clone x biennium interaction was significant only for yield and leaf rust severity. There are negative correlations among the characteristics associated with yield and pests and diseases occurrences, which make it possible the use of yield variable as a selection parameter. Clones 24, 23, 28, 26, 21, 29 and 06 MG/ES present a higher potential for cultivation in the Zona da Mata of Minas Gerais.

Key words: Breeding; *coffea canephora*; correlations; genotype-environment interaction.

1 INTRODUCTION

The coffee culture holds great importance in the national and world economy with only two species presenting commercial value - *Coffea arabica* and *Coffea canephora.* The species *C. canephora* represents approximately 35 to 40% of world coffee production, and Brazil ranks second as the largest producer. This species originates from the low, warm and humid equatorial regions of the African continent, being highly adapted to regions with average annual temperatures ranging from 22 to 26 °C (Ferrão et al., 2019). It is composed of different genetic materials, such as Conilon, the most cultivated in Brazil, followed by Robusta, which comprises about 23% of the coffee traded in the country (Companhia Nacional De Abastecimento - CONAB, 2020).

The appreciation and notability of the *C. canephora* species have changed the world coffee production scenario, either as the main raw material for soluble coffees or as a component of blends with Arabica coffee. Such emergence of special coffees has changed paradigms and creating new market opportunities. Moreover, *C. canephora* has been pointed out as a viable alternative for the replacement of Arabica coffee in areas that are becoming unsuitable for its cultivation due to climate change effects. Thus, a growing interest in cultivating Conilon coffee has been observed in the country.

However, to meet such demands, it is necessary to invest in technologies that provide the base for the expansion to new areas. Some research has been developed to evaluate, introduce and recommend clones of Conilon or Robusta coffee in different regions of the country (Moraes et al., 2020; Rodrigues et al., 2015; Silva et al., 2017; Spelline et al., 2018).

The state of Minas Gerais, the largest producer of Arabica coffee, also holds suitable conditions for Conilon species. According to a study carried out by Emater-MG, there are 291 counties the present suitable conditions for Conilon coffee cultivation, of which 185 can be irrigated or upland; in counterpart to 107 irrigated only (Pereira; Guimarães; Carvalho, 2020). Despite this, the production of Minas Gerais does not match the state's potential, in which only 309.8 thousand bags were produced in 2020, for instance, being concentrated in low and warm regions, such as Zona da Mata, Jequitinhonha, Mucuri, Rio Doce, Central (CONAB, 2020). Therefore, for the expansion of these crops, it is necessary to foster and fund new studies.

Despite being considered more rustic than Arabica, Conilon coffee is also susceptible to pests and diseases, such as leaf rust (*Hemileia vastatrix*), brown eye spot (*Cercospora coffeicola*) and dieback (Ventura et al., 2019). Regarding leaf rust, as the main disease of coffee trees, it can cause losses of up to 50% in production (Capucho et al., 2012). On the other hand, the presence of lesions on the leaves and defoliation caused by the attack of leaf miners (*Leucoptera coffeella*), reduces the photosynthetic capacity and favours malformation of floral buds and, consequently, low fruit set, thereby impairing overall coffee production (Fornazier et al., 2019).

Production is also influenced by genetic signature, as there is variability among genotypes concerning vegetative vigor, recovery capacity from one season to another, fruit set and yield (Giles et al., 2018; Rodrigues et al., 2012). This diversity can also be affected by the biennial production characteristic of this species, in which is observed the occurrence of genotypes with high yields, but with accentuated biennality effects - as well as genotypes with low yields, but with stability in the production over the years (Rocha et al., 2015a). In this sense, it is important to consider evaluations based on biennium to reduce the effect of biennality during the selection process of genetic materials.

Breeding programs of Conilon coffee seek to select and recommend genotypes that have suitable characteristics, such as resistance to main pests and diseases, uniform maturation, high vegetative vigor and yield (Ferrão et al., 2019). However, for this, it is important to bear in mind the associations between evaluated characteristics to reduce the number of individuals via indirect selection and optimize current programs. In this sense, the study of correlations is an important approach, which can be divided into three ways: phenotypic, genotypic and environmental traits. However, only the genotypic correlation holds a real value, as it involves associations of inheritable nature (Cruz; Regazzi; Carneiro, 2012).

Therefore, this study aimed to evaluate Conilon coffee clones to identify the most promising fitting material for cultivation in the Zona da Mata of Minas Gerais region, as well as to analyze the effect of the genotype x biennium interaction and estimate the correlation coefficients among the evaluated characters.

2 MATERIAL AND METHODS

The experiment started in 2003 at the Experimental Farm of the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) in Leopoldina - MG, at 21°28'51.26" latitude and 42°43'17.00" longitude, 187 m above the sea. The soil is classified as Yellow Latosol (Santos et al., 2018). The region's climate is tropical (type Aw, according to Köppen) with dry, mild winters and rainy summers, and moderately high temperatures. The evaluations were performed from 2005 to 2010, in which annual averages of precipitation and temperatures were about 1,700 mm, 30 °C and 16.8 °C (maximum and minimum, respectively). Data were analyzed considering three biennia from May to October Figure 1.

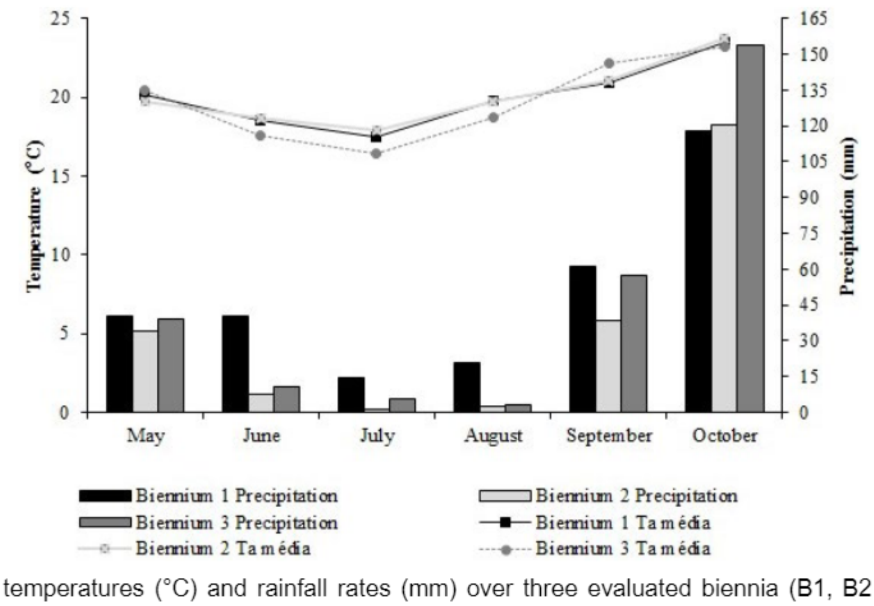

Figure 1: Average of temperatures (°C) and rainfall rates (mm) over three evaluated biennia (B1, B2 and B3) during coffee cultivation in the Zona da Mata region of Minas Gerais.

The experimental design was in randomized blocks with three replicates, in which 36 Conilon coffee clones with different fruit maturation cycles were evaluated. The experimental plot consisted of nine plants, spaced 1.0 x 2.5 m, plants and rows, respectively. Clones were obtained from the Conilon coffee genetic breeding program of the Capixaba Institute for Research, Technical Assistance and Rural Extension, Incaper (Ferrão et al., 2019).

Both soil correction and planting fertilization was performed based on soil analysis and as previously recommended by Prezotti et al. (2007). Planting furrows of 40 cm in depth and width were prepared, in which dolomitic limestone and 100 g of simple superphosphate were added.

Cover fertilizations were accomplished annually during the wet season as estimated by the soil analysis. Simple superphosphate was used as a phosphate source in a single application. As nitrogen source, ammonium sulphate, and potassium chloride as potassium source were applied three times over intervals of 30 days. On these same occasions, foliar fertilization was carried out with zinc sulphate, copper sulphate, boric acid, potassium chloride and adhesive spread for fertilizers.The weed control was done by weeding and mowing periodically the area around coffee trees. The residues of this activity were used as mulch. Pests and diseases control was not performed. Coffee trees were managed to keep four productive branches per plant, and they were sprouted whenever necessary. When the coffee trees reached two years of age (in 2005), evaluations were started in six consecutive seasons using a methodology adapted from (Ferrão et al., 2021) for the following characteristics:

a) Leaf rust severity - LRS (*Hemileia vastatrix*) was based on infection ratings as follows: 1, no leaf rust; 2, few leaf pustules; 3, moderate leaf infection; 4, high infection and abundant pustules in leaves; 5, high infection, abundant pustules in leaves and defoliation occurrence;

b) Brown eye spot severity - BES (*Cercospora coffeicola*) was based on infection ratings as follows: 1, no symptoms; 2, mild severity in some leaves; 3, moderate severity in leaves; 4, severe infection in leaves; 5, intense severity in both leaves and fruits; c) Leaf miner attack intensity - LMI (*Leucoptera cofeella*) was composed of five rates, namely: 1, no symptoms; 2, few lesions covering some leaves; 3, moderate lesions; 4, many coalesced lesions; 5, many coalesced lesions and defoliation; d) Dieback intensity (DBI) was performed based on attributed grades from 1 to 4, as follows: 1, no symptoms; 2, few symptoms; 3, moderate intensity; 4, severe symptoms; e) Vegetative vigor (VIG), ranged from 1 to 10, namely: 1, low vigor; and 10, high vigor; f) Yield (YLD), expressed in liters and converted into bags (60 kg) of processed coffee ha^{-1}.

The evaluations regarding vegetative vigor, pests and diseases were carried out from May to August, since it is a period of at least one peak of population growth of biotic agents (Fanton; Queiroz, 2020; Zambolim et al., 2016). On the other hand, depending on the year/seasons, the evaluation of yield was extended to October due to the different cycles of maturation among studied clones.

Data were analyzed considering the outcomes from the following seasons: Biennium 1 (B1) - 2005/2006; Biennium 2 (B2) - 2007/2008 and Biennium 3 (B3) - 2009/2010. They were then submitted to a joint analysis of variance. Regardless of significant interaction, or not, the means were compared using the Scott-Knott at 5% probability level. Regarding the average of three biennia (A3B), analysis of variance was performed in randomized blocks with 36 clones and three replications.

Coefficients of phenotypic, genotypic and environmental correlation among evaluated traits were estimated using the average products with GENES software (Cruz, 2016). Based on such analyses, estimates of genotypic, phenotypic and environmental covariance between two-by-two characteristics and correlation coefficients were obtained by Equations 1, 2 and 3:

$$\text{Genotypic correlation coefficient } (r_g) = \frac{C\hat{o}v_g(X,Y)}{\sqrt{\hat{\sigma}_g^2(X)\hat{\sigma}_g^2(Y)}} \quad (1)$$

$$\text{Phenotypic correlation coefficient } (r_p) = \frac{C\hat{o}v_p(X,Y)}{\sqrt{\hat{\sigma}_p^2(X)\hat{\sigma}_p^2(Y)}} \quad (2)$$

$$\text{Environmental correlation coefficient } (r_e) = \frac{C\hat{o}v_e(X,Y)}{\sqrt{\hat{\sigma}_e^2(X)\hat{\sigma}_e^2(Y)}} \quad (3)$$

which: $C\hat{o}v_g(X,Y)$, $C\hat{o}v_p(X,Y)$ and $C\hat{o}v_e(X,Y)$, as estimators of genotypic, phenotypic and environmental covariance, respectively, between two characteristics X and Y; $\hat{\sigma}_g^2(X)$, $\hat{\sigma}_p^2(X)$ and $\hat{\sigma}_e^2(X)$ as genotypic, phenotypic and environmental variance estimators, respectively, of X trait; and $\hat{\sigma}_g^2(Y)$, $\hat{\sigma}_p^2(Y)$ and $\hat{\sigma}_e^2(Y)$ as genotypic, phenotypic and environmental variance estimators, respectively, of the Y trait.

3 RESULTS

Among evaluated characteristics, only leaf rust severity and yield showed significant interactions between clones x biennia (Table 1). This demonstrates the difference in the behaviour of clones concerning such characteristics along the evaluated period.

Regarding leaf rust severity, variability was observed among clones at B1, B2 and A3B. The first biennium showed the highest variability for this characteristic - in manner that the clones were classified into five groups (Table 2). When the average of three biennia was considered, clones 13, 34, 14, 12, and 10 were the most affected by leaf rust. On the other hand, clones 24, 23, 28, 21, 01, 05, 11, 19, 20, and 32 were the fewest ones to be infested by leaf rust (Table 2). Nine clones did not present biennality responses over the disease development (24, 21, 25, 01, 05, 22, 11, 09 and 20), and only one clone (10) was progressively affected by biennality (Table 2).

The variability among clones for the severity of brown eye spot occurred only at B1 and A3B, in which they were thus clustered into two groups, ranging from no symptoms of leaf rust to some leaf pustules (Table 2). For the intensity of dieback, variability among clones occurred at the B1, B2 and A3B, in which they were thus clustered into two groups. In this vein, 36% of the clones were common among groups with fewer symptoms - and 39% among the most affected (Table 2). Concerning the intensity of leaf miners attack, no significant differences were observed among clones regardless of the evaluated time (Table 3). In general, the averages were relatively low, and four types of responses were evidenced among the clones: most clones showed little symptoms of pests at the first biennium; increases of symptoms were observe at the second one and such behaviour was maintained constant at the third; 11% of clones were unaffected over time; only one clone evolved gradually over the years and four showed a severe increase in attacks at the last biennium.

Clones were grouped in two ways for vegetative vigor, a fact that was observed at each evaluated biennium as well as by the average of three biennia (Table 3). Clones 15, 09, 29, 04, 36, 03, 31, 17, 24, 23, 28, 21, 01, 05 and 11 were the most vigorous, with an average of 7.87.

Variability among clones was observed for yield at all considered times, which increased over the biennia (Table 3). Based on M3B, it was possible to classify them into four groups (Table 3). The first one was formed only by the clone 24, which presented the highest yield. The second group consisted of clones 23, 29, 21, 28, 06 and 26 with an average of 97.47 bags of processed coffee ha^{-1}. The third group, formed by most evaluated clones, showed an average of 71.92 bags of processed coffee ha^{-1}, and the fourth group, the least productive (average of 52.18 bags of processed coffee ha^{-1}), was composed by 36% of the clones.

Coefficients of genotypic, phenotypic and environmental correlation are shown in Table 4. It was observed that the values of genotypic correlation coefficients were higher than their counterparts for all estimated combinations among six evaluated characteristics. Yield showed positive and significant correlations with vegetative vigor, which were negatively correlated with disease severities. The intensity of the leaf miners did not present significant correlations with the other evaluated characteristics.

4 DISCUSSION

4.1 Pest and disease severity

The weather conditions interfere in the development of leaf rust by providing adequate conditions for the development of the pathogen *H. vastatrix*. Average temperatures between 21.6 and 23.6 °C with high relative humidity (>80%) are highly favorable for the leaf rust development in Conilon coffee (Capucho et al., 2012). Thus, it was observed that the weather conditions during the period from May to August (Figure 1) interfered with the severity of this disease over the evaluated biennia (Table 2). From the second biennium, there was a reduction in the variability among clones (Table 2), which may be associated with environmental conditions, that have disfavoured the development of leaf rust, as well as genetic factors and the development of coffee trees. This fact corroborates the interaction between clones x environment affecting the leaf rust severity (Table 1).

Table 1: Summary of the analysis of variance for severities of leaf rust (LRS) and brown eye spot (BES); intensities of leaf miners attack (LMI) and dieback (DBI) occurrence; vegetative vigor (VIG) and yield as 60 kg of processed coffee ha^{-1} (YLD) of Conilon coffee clones cultivated in Zona da Mata region of Minas Gerais.

Source of variation	DF[1/]	LRS	BES	LMI	DBI	VIG	YLD
Block/ Biennium	6	0.61	1.04	0.73	2.37**	2.35	1370.81
Clones	35	0.78**	0.38**	0.14*	0.51**	2.43**	3344.66**
Biennia	2	25.83**	1.56**	10.65**	6.84**	26.31**	62565.38**
Clones x Biennia	70	0.35**	0.13	0.08	0.17	0.48	1156.07**
Residuals	210	0.10	0.14	0.09	0.16	0.45	439.28
CV (%)		18,58	24.48	14.79	18.38	9.11	29.70

[1/] Degree of freedom

** and * Significant at 1 and 5 % probability, respectively, by the F test.

Table 2: Leaf rust[1] (LRS) and brown eye spot (BES) severities; the intensity of dieback (DBI) at each B1, B2, B3 biennium and the average of these variables over three biennia (A3B) in Conilon coffee clones cultivated in the Zona da Mata region of Minas Gerais.

Clones	LRS				BES				DBI			
	B1	B2	B3	A3B	B1	B2	B3	A3B	B1	B2	B3	A3B
13 MG/ES	3.17 Ba	2.00 Ab	1.67Ab	2.28 A	1.67 Ba	1.33 Aa	1.33 Aa	1.44 B	2.67 Aa	2.17 Aa	2.00 Aa	2.28 A
15 MG/ES	2.33 Da	1.83 Ab	1.50 Ab	1.89 B	1.33 Ba	1.17 Aa	1.33 Aa	1.28 B	2.17 Ba	2.00 Aa	2.00 Aa	2.06 B
25 MG/ES	2.00 Da	1.67 Aa	1.50 Aa	1.72 C	1.33 Ba	1.50 Aa	1.33 Aa	1.39 B	2.00 Ba	1.83 Ba	2.33 Aa	2.06 B
02 MG/ES	2.50 Ca	1.50 Bb	1.17 Ab	1.72 C	1.67 Ba	2.00 Aa	1.50 Aa	1.72 A	2.33 Ba	2.17 Aa	2.17 Aa	2.22 A
19 MG/ES	2.00 Da	1.17 Bb	1.33 Ab	1.50 D	2.25 Aa	2.00 Aa	1.83 Aa	2.02 A	2.50 Aa	1.67 Bb	1.83 Ab	2.00 B
33 MG/ES	2.00 Da	1.33 Bb	1.33 Ab	1.55 C	2.00 Aa	1.83 Aa	1.67 Aa	1.83 A	2.67 Aa	2.00 Aa	2.33 Aa	2.33 A
17 MG/ES	2.50 Ca	1.83 Ab	1.50 Ab	1.94 B	1.50 Ba	1.67 Aa	1.17 Aa	1.44 B	2.50 Aa	1.83 Ba	2.00 Aa	2.11 B
21 MG/ES	1.67 Ea	1.17 Ba	1.17 Aa	1.33 D	1.50 Ba	1.33 Aa	1.50 Aa	1.44 B	2.17 Ba	1.67 Ba	1.67 Aa	1.83 B
03 MG/ES	2.33 Da	1.17 Bb	1.50 Ab	1.67 C	1.33 Ba	1.50 Aa	1.33 Aa	1.39 B	1.83 Ba	1.83 Ba	2.00 Aa	1.89 B
07 MG/ES	2.33 Da	1.83 Aa	1.33 Ab	1.83 B	1.33 Ba	1.17A a	1.33 Aa	1.28 B	2.33 Ba	2.50 Aa	2.17 Aa	2.33 A
26 MG/ES	3.00 Ba	1.33 Bb	1.83 Ab	2.05 B	1.67 Ba	1.50 Aa	1.33 Aa	1.50 B	2.50 Aa	1.67 Bb	2.00 Ab	2.06 B
36 MG/ES	2.17 Da	1.50 Bb	1.50 Ab	1.72 C	1.67 Ba	1.50 Aa	1.67 Aa	1.61 A	2.00 Ba	1.67 Ba	2.00 Aa	1.89 B
05 MG/ES	1.67 Ea	1.17 Ba	1.33 Aa	1.39 D	1.33 Ba	1.33 Aa	1.17 Aa	1.28 B	2.00 Ba	1.50 Ba	2.17 Aa	1.89 B
34 MG/ES	3.17 Ba	2.00 Ab	1.50 Ab	2.22 A	1.67 Ba	1.17 Aa	1.67 Aa	1.50 B	2.67 Aa	2.50 Aa	2.00 Aa	2.39 A
32 MG/ES	2.00 Da	1.33 Bb	1.00 Ab	1.44 D	1.83 Aa	1.33 Aa	1.83 Aa	1.67 A	2.67 Aa	2.17 Aa	2.00 Aa	2.28 A
27 MG/ES	1.33 Eb	2.17 Aa	1.33 Ab	1.61 C	1.67 Ba	1.17 Aa	1.67 Aa	1.50 B	2.33 Ba	2.00 Aa	2.17 Aa	2.17 A
31 MG/ES	2.67 Ca	1.83 Ab	1.50 Ab	2.00 B	2.00 Aa	1.83 Aa	1.33 Aa	1.72 A	2.83 Aa	2.17 Ab	2.17 Ab	2.39 A
29 MG/ES	2.25 Da	1.33 Bb	1.50 Ab	1.70 C	1.50 Ba	1.33 Aa	1.00 Aa	1.28 B	2.50 Aa	1.33 Bb	1.83 Ab	1.89 B
23 MG/ES	2.00 Da	1.17 Bb	1.17 Ab	1.44 D	1.50 Ba	1.50 Aa	1.17 Aa	1.39 B	2.17 Ba	1.50 Bb	2.17 Aa	1.94 B
30 MG/ES	3.00 Ba	1.67 Ab	1.50 Ab	2.05 B	2.67 Aa	1.50 Ab	1.50 Ab	1.89 A	3.17 Aa	2.00 Ab	2.00 Ab	2.39 A
08 MG/ES	2.83 Ca	1.33 Bb	1.50 Ab	1.89 B	1.83 Aa	1.50 Aa	1.33 Aa	1.55 A	2.50 Aa	2.17 Aa	2.33 Aa	2.33 A
01 MG/ES	1.33 Ea	1.17 Ba	1.33 Aa	1.28 D	1.50 Ba	1.33 Aa	1.50 Aa	1.44 B	1.83 Ba	1.50 Ba	2.00 Aa	1.78 B
11 MG/ES	1.50 Ea	1.17 Ba	1.50A a	1.39 D	1.50 Ba	1.00 Aa	1.50 Aa	1.33 B	2.17 Ba	2.00 Aa	2.17 Aa	2.11 B
14 MG/ES	3.50 Aa	1.83 Ab	1.50 Ab	2.28 A	2.17 Aa	1.33 Ab	1.67 Ab	1.72 A	3.17 Aa	2.50 Ab	2.33 Ab	2.67 A
12 MG/ES	3.67 Aa	1.50 Bb	1.33 Ab	2.17 A	2.00 Aa	1.33 Aa	1.67 Aa	1.67 A	3.00 Aa	2.50 Ab	2.00 Ab	2.50 A
16 MG/ES	2.83 Ca	1.50 Bb	1.50 Ab	1.94 B	1.83 Aa	1.83 Aa	1.67 Aa	1.78 A	3.00 Aa	2.17 Ab	2.33 Ab	2.50 A
10 MG/ES	3.00 Ba	2.17 Ab	1.50 Ac	2.22 A	1.67 Ba	1.67 Aa	1.33 Aa	1.55 A	2.83 Aa	2.00 Ab	2.33 Ab	2.39 A
04 MG/ES	2.25 Da	1.33 Bb	1.67 Ab	1.75 C	1.75 Ba	1.67 Aa	1.33 Aa	1.58 A	2.00 Ba	1.50 Ba	1.83 Aa	1.78 B
18 MG/ES	2.17 Da	1.50 Bb	1.50 Ab	1.72 C	1.00 Ba	1.17 Aa	1.00 Aa	1.05 B	2.50 Aa	1.83 Bb	2.50 Aa	2.28 A
06 MG/ES	2.50 Ca	1.17 Bb	1.33 Ab	1.67 C	1.67 Ba	1.50 Aa	1.67 Aa	1.61 A	2.00 Ba	1.50 Bb	2.33 Aa	1.94 B
24 MG/ES	1.50 Ea	1.17 Ba	1.33 Aa	1.33 D	1.33 Ba	1.00 Aa	1.33 Aa	1.22 B	2.00 Ba	1.67 Ba	2.00 Aa	1.89 B
28 MG/ES	1.67 Ea	1.17 Bb	1.00 Ab	1.28 D	1.33 Ba	1.00 Aa	1.50 Aa	1.28 B	2.67 Aa	2.00 Ab	2.00 Ab	2.22 A
22 MG/ES	1.83 Ea	1.50 Ba	1.67 Aa	1.67 C	1.67 Ba	1.33 Aa	1.33 Aa	1.44 B	2.17 Ba	1.83 Ba	2.00 Aa	2.00 B
35 MG/ES	2.33 Da	1.33 Bb	1.17 Ab	1.61 C	1.83 Aa	1.33 Aa	1.50 Aa	1.55 A	2.67 Aa	2.00 Ab	2.00 Ab	2.22 A
09 MG/ES	1.83 Ea	1.50 Ba	1.50 Aa	1.61 C	1.33 Ba	1.33 Aa	1.33 Aa	1.33 B	1.83 Ba	1.50 Ba	2.00 Aa	1.78 B
20 MG/ES	1.83 Ea	1.17 Ba	1.50 Aa	1.50 D	1.33 Ba	1.50 Aa	1.50 Aa	1.44 B	2.67 Aa	2.33 Aa	2.17 Aa	2.39 A
Overall Average	2.3	1.49	1.43	1.73	1.64	1.43	1.44	1.5	2.42	1.92	2.09	2.14
CV (%)	18.58				24.48				11.03			

[1]Groups of means with the same uppercase letter in the column and lowercase letter do not differ by Scott-Knott at 5% probability level.

Table 3: Leaf miners attack intensity (LMI), vegetative vigor (VIG) and yield (YLD) at each B1, B2, B3 biennium and the average of these variables over three biennia (A3B) in Conilon coffee clones cultivated in the Zona da Mata region of Minas Gerais.

Clones	LMI				VIG				YLD (scs.ha^{-1})			
	B1	B2	B3	A3B	B1	B2	B3	A3B	B1	B2	B3	A3B
13 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	1.89 A	6.83 Aa	8.17 Aa	7.67 Aa	7.55 A	41.78 Bb	56.21 Bb	108.55 Ba	68.85 C
15 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	1.89 A	7.00 Aa	8.00 Aa	7.33 Ba	7.44 A	33.10 Bb	61.51 Ba	74.98 Da	56.53 D
25 MG/ES	1.83 Ab	2.00 Ab	2.83 Aa	2.22 A	7.17 Aa	7.50 Ba	7.50 Ba	7.39 B	36.51 Bb	76.07 Aa	102.92 Ba	71.83 C
02 MG/ES	1.33 Ab	2.00 Aa	2.17 Aa	2.02 A	6.50 Ba	7.33 Ba	7.00 Ba	6.94 B	47.67 Bb	75.27 Aa	87.91 Ca	70.28 C
19 MG/ES	2.00 Aa	2.17 Aa	2.50 Aa	2.22 A	6.25 Bb	7.17 Ba	8.00 Aa	7.14 B	40.17 Ba	57.26 Ba	74.67 Da	57.37 D
33 MG/ES	2.00 Ab	2.00 Ab	2.67 Aa	2.22 A	6.50 Ba	7.50 Ba	6.67 Ba	6.89 B	33.16 Bb	41.74 Cb	80.05 Ca	51.65 D
17 MG/ES	1.83 Aa	2.00 Aa	2.17 Aa	2.00 A	7.67 Aa	8.33 Aa	8.17 Aa	8.05 A	48.15 Bb	64.84 Bb	97.99 Ca	70.33 C
21 MG/ES	1.67 Aa	2.00 Aa	2.17 Aa	1.94 A	7.67 Aa	8.33 Aa	8.17 Aa	8.05 A	77.90 Ab	87.21 Ab	123.50 Ba	96.21 B
03 MG/ES	1.67 Ab	2.17 Aa	2.17 Aa	1.88 A	6.83 Aa	8.17 Aa	7.50 Ba	7.50 A	44.59 Bb	78.52 Aa	96.51 Ca	73.20 C
07 MG/ES	1.83 Aa	2.00 Aa	2.17 Aa	2.00 A	6.17 Ba	7.17 Ba	7.00 Ba	6.78 B	38.75 Ba	56.66 Ba	72.25 Da	55.88 D
26 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	1.89 A	6.00 Bb	8.00 Aa	7.83 Aa	7.28 B	60.22 Ab	89.30 Ab	151.67 Aa	100.40 B
36 MG/ES	1.67 Aa	2.00 Aa	2.00 Aa	1.89 A	7.33 Ab	8.83 Aa	8.00 Ab	8.05 A	40.66 Bc	75.95 Ab	115.97 Ba	77.52 C
05 MG/ES	1.67 Ab	2.00 Aa	2.33 Aa	2.00 A	7.17 Aa	8.17 Aa	8.00 Aa	7.78 A	56.25 Ab	36.24 Cb	108.18 Ba	66.89 C
34 MG/ES	1.67 Aa	2.00 Aa	2.00 Aa	1.89 A	7.00 Aa	6.67 Ba	7.33 Ba	7.00 B	54.70 Aa	52.56 Ba	50.51 Da	52.59 D
32 MG/ES	1.67 Aa	2.00 Aa	2.00 Aa	1.89 A	5.67 Bb	8.00 Aa	7.50 Ba	7.05 B	23.96 Ba	54.36 Ba	59.79 Da	46.03 D
27 MG/ES	1.67 Ab	2.00 Aa	2.33 Aa	2.00 A	7.67 Aa	7.67 Ba	6.67 Ba	7.33 B	80.75 Aa	34.55 Cb	55.08 Db	56.79 D
31 MG/ES	1.67 Ab	2.00 Aa	2.33 Aa	2.00 A	7.33 Aa	8.00 Aa	7.17 Ba	7.50 A	65.08 Aa	61.66 Ba	86.64 Ca	71.12 C
29 MG/ES	2.50 Aa	2.00 Aa	2.33 Aa	2.28 A	7.25 Ab	8.33 Aa	8.67 Aa	8.08 A	62.82 Ab	76.27 Ab	134.29 Ba	91.13 B
23 MG/ES	1.83 Ab	2.00 Ab	2.50 Aa	2.11 A	8.33 Aa	9.50 Aa	8.67 Aa	8.83 A	86.87 Ab	59.92 Bb	173.31 Aa	106.70 B
30 MG/ES	1.33 Ab	2.17 Aa	2.00 Aa	1.83 A	5.83 Bb	7.33 Ba	7.50 Ba	6.89 B	32.82 Bb	64.99 Bb	117.48 Ba	71.76 C
08 MG/ES	1.50 Ab	2.00 Aa	2.33 Aa	1.94 A	6.83 Aa	7.50 Ba	7.17 Ba	7.17 B	65.46 Aa	78.94 Aa	69.59 Da	71.33 C
01 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	2.05 A	7.00 Ab	8.00 Aa	8.33 Aa	7.78 A	42.90 Bb	37.48 Cb	126.19 Ba	68.86 C
11 MG/ES	1.50 Ab	1.83 Ab	2.17 Aa	1.83 A	7.17 Ab	8.50 Aa	8.67 Aa	8.11 A	42.98 Bb	21.36 Cb	114.04 Ba	59.46 D
14 MG/ES	1.67 Ab	2.00 Aa	2.33 Aa	2.00 A	6.33 Ba	6.83 Ba	6.17 Ba	6.44 B	40.29 Ba	26.06 Ca	49.73 Da	38.70 D
12 MG/ES	1.67 Aa	2.00 Aa	2.17 Aa	1.94 A	6.67 Ba	6.83 Ba	6.83 Ba	6.78 B	43.96 Ba	27.72 Ca	62.51 Da	44.73 D
16 MG/ES	1.50 Ac	2.17 Ab	2.67 Aa	2.11 A	5.83 Bb	7.50 Ba	6.50 Bb	6.61 B	52.65 Bb	89.07 Aa	97.58 Ca	79.77 C
10 MG/ES	1.50 Ab	2.17 Aa	2.50 Aa	2.05 A	6.50 Ba	7.50 Ba	7.00 Ba	7.00 B	55.75 Ab	68.16 Ab	112.15 Ba	78.69 C
04 MG/ES	1.75 Ab	2.17 Aa	2.33 Aa	2.08 A	6.50 Bb	7.83 Aa	8.33 Aa	7.55 A	65.38 Aa	82.02 Aa	88.44 Ca	78.61 C
18 MG/ES	1.33 Ab	2.00 Aa	2.33 Aa	1.89 A	7.00 Aa	7.33 Ba	6.83 Ba	7.05 B	59.83 Ab	38.44 Cb	100.07 Ca	66.11 C
06 MG/ES	1.83 Ab	2.33 Aa	2.50 Aa	2.22 A	6.67 Bb	7.83 Aa	6.67 Bb	7.05 B	66.95 Aa	94.02 Aa	91.98 Ca	84.32 B
24 MG/ES	1.67 Aa	2.00 Aa	2.17 Aa	1.94 A	7.00 Ab	8.50 Aa	8.00 Aa	7.83 A	75.64 Ac	129.15 Ab	174.98 Aa	126.59 A
28 MG/ES	1.83 Aa	2.00 Aa	2.00 Aa	1.94 A	7.17 Aa	8.17 Aa	7.67 Aa	7.67 A	64.99 Ac	105.15 Ab	147.94 Aa	106.03 B
22 MG/ES	1.33 Ab	2.00 Aa	2.33 Aa	1.89 A	6.67 Ba	7.33 Ba	6.83 Ba	6.94 B	43.76 Ba	67.38 Aa	85.44 Ca	65.53 C
35 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	1.89 A	6.50 Ba	7.50 Ba	7.00 Ba	7.00 B	42.82 Ba	57.63 Ba	57.79 Da	52.75 D
09 MG/ES	1.50 Ab	2.00 Aa	2.17 Aa	1.89 A	7.17 Aa	8.33 Aa	8.17 Aa	7.89 A	35.71 Bb	17.99 Cb	107.18 Ba	53.62 D
20 MG/ES	1.50 Ab	2.00 Aa	2.33 Aa	1.94 A	7.00 Aa	7.33 Ba	7.17 Ba	7.17 B	42.14 Ba	60.67 Ba	53.90 Da	52.24 D
Overall Average	1.65	2.03	2.27	1.99	6.84	7.8	7.49	7.38	51.31	62.84	97.55	70,57
CV(%)		14.79				9.11				29.7		

[1]Groups of means with the same uppercase letter in the column and lowercase letter do not differ by Scott-Knott at 5% probability level.

Table 4: Phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlation coefficients among six variables evaluated in 36 clones of Conilon coffee cultivated in the Zona da Mata region of Minas Gerais.

Variables	Correlations	VIG	LRS	BES	DBI	LMI	YLD
VIG	r_p	1	-0.485^{++}	-0.467^{++}	-0.703^{++}	0.250^{NS}	0.526^{++}
	r_g	1	-0.573^{++}	-0.653^{++}	-0.933^{++}	0.297^{NS}	0.669^{++}
	r_e	1	-0.171^{NS}	-0.023^{NS}	-0.183^{+}	-0.203^{+}	0.020^{NS}
LRS	r_p		1	0.289^{+}	0.600^{++}	-0.069^{NS}	-0.288^{NS}
	r_g		1	0.371^{NS}	0.673^{++}	-0.143^{NS}	-0.355^{+}
	r_e		1	0.011^{NS}	0.415^{++}	-0.018^{NS}	-0.105^{NS}
BES	r_p			1	0.371^{++}	0.200^{NS}	-0.299^{+}
	r_g			1	0.479^{+}	0.517^{NS}	-0.365^{NS}
	r_e			1	0.142^{NS}	-0.010^{NS}	-0.091^{NS}
DBI	r_p				1	-0.119^{NS}	-0.450^{++}
	r_g				1	-0.192^{NS}	-0.561^{++}
	r_e				1	-0.087^{NS}	-0.124^{NS}
LMI	r_p					1	0.156^{NS}
	r_g					1	0.350^{NS}
	r_e					1	0.008^{NS}
YLD	r_p						1
	r_g						1
	r_e						1

$^{++}$ e $^{+}$ Significant at 1 and 5 % probability, respectively, by the bootstrap method with 5.000 simulations. ^{NS} not significant.
LRS - Leaf rust severity; BES -Brown eye spot severity; DBI – Dieback intensity; LMI - Leaf miner attack intensity; VIG – Vegetative vigor and YLD – yield.

In *Coffea canephora*, resistance to leaf rust (*H. vastatrix*) is governed by SH type genes, simple or in association, which both vertical and horizontal resistances can be observed (Ventura et al., 2019). Because it is characterized as quantitative, horizontal resistance presents a longer durabilty, which make it of utmost importance for genetic breeding programs aimed at resistance to leaf rust. This fact is corroborated by the different intensities of leaf rust symptoms observed in the 36 clones cultivated in this study (Table 2), as well as in a population of C. canephora cultivated at the field level (Rodrigues et al., 2012; Rodrigues et al., 2015), and under controlled conditions (Zambolim et al., 2016; Mendonça et al., 2019).

Based on the average of the three biennia, clone 13 were the most affected by leaf rust (Table 2). This clone has been identified as susceptible to race II of the *H. vastatrix* pathogen (Zambolim, et al., 2016). On the other hand, the clones 23 e 28, less infested by leaf rust (Tabela 2), were classified as moderate and high genetic resistance, respectively, to the main leaf rust races present in the country (Zambolim, 2016). The degree of resistance to leaf rust also depends on several components of fungus development. Clones of Conilon coffee classified as resistant to this disease did not show sporulation of the pathogen; however, those ones that present moderate resistance showed an increase in the incubation and latency periods, in addition to decreases in the number of fungal spores, which reduced the development of the disease (Mendonça et al., 2019).

Thus, the results observed in this study may contribute to the selection of leaf rust-resistant clones (Table 2), since when composing cultivars, hence contributing to more efficient management of this disease by preventing and/or reducing the spread of this pathogen in the field (Mendonça et al., 2019). Consequently, a higher sustainability in the cultivation and production process is observed.

In general, low brown eye spot severity was observed during the evaluation period and the clones showed no disease alterations over the biennia (Table 2). Higher values for this disease were demonstrated in Apoatã cultivar and Robusta IAC 1653-7 progeny when evaluated in younger leaves of coffee trees growing under controlled environment, a condition that favors fungus occurrence (Patrício; Braghini; Fazuoli, 2010). Several clones of Conilon coffee have also shown low severities for brown eye spot as a result of previous selection in breeding programs (Ventura et al., 2019). Despite this, few studies concerning genetic resistance to this pathogen have been conducted, mainly due to the fact that this disease is associated with the nutritional status of coffee trees and environmental conditions - especially temperature and precipitation.

The occurrence of temperatures below 20 °C, from May to August (Figure 1), as observed in the average of three biennia, may have also hindered the development of brown eye spot, even during a dry period. According to Ventura et al. (2019), temperatures between 20 and 25 °C associated with water deficit favor the incidence of this disease. The nutritional imbalance, mainly of nitrogen and potassium, lead to a higher incidence of brown eye spot (Silva et al., 2020). The results evidenced in this study (Table 2) suggest that the fertilization was conducted in a balanced way.

Another aspect to consider is the fruit maturation cycle, as it was observed among 60 conilon coffee genotypes in the state of Espírito Santo (Rodrigues et al., 2015), that earlier clones showed resistance to brown eye spot, which reinforces the importance of of this characteristic as an important management strategy in the control of this disease. This fact was also observed in this study for clones 03, 01, 13, 05, 11, 15, 07 and 09 (Table 2).

The relationship with other diseases is also important, clones with few symptoms of brown eye spot severity, especially clones 24, 23, 28, 01, 05, 18, 22, 11 and 20, which also showed few symptoms of leaf rust (Table 2). On the other hand, in addition to a higher susceptibility to brown eye spot, clones 10, 12 and 14 were the most affected by leaf rust (Table 2), which suggests a relationship between the severity of both diseases.

Similar to the severities of leaf rust and brown eye spot (Table 2), the intensity of dieback was higher at the first biennium, and may be associated with the climate and water deficit observed in the evaluation period (Figure 1). Dieback is an abiotic disease that can be related to several factors, including adverse environmental conditions, nutritional deficiency, genetic signatures and an excessive fruit production that, combined with a low leaf area will affect the production of photoassimilates, causes twigs, branches, shoots death (Ventura et al., 2019). The association between the intensity of dieback and other diseases must also be considered. Clones 24, 23, 01, 05, 22, and 11 showed fewer symptoms of this disease and a higher resistance to the severities of leaf rust and brown eye spot (Table 1) - whereas the opposite was observed in 10, 12, and 14.

Regarding the severity of leaf miners attack, no significant differences were observed among clones in all evaluated biennia (Table 3). The opposite of what was observed by Rodrigues et al. (2015), which demonstrated a wide diversity concerning the attack of this pest among 40 clones of Conilon coffee. The response of variability observed among clones over the years may be related to genetic causes. Although clones with some resistances have been found, there is still little information about them. According to Guerreiro Filho (2007), although resistance to leaf miners is associated with two complementary and dominant genes, it seems to be influenced by smaller genes, which is determined in crosses between Arabica x Racemosa coffee.

The environmental conditions, in the period from May to August (Figure 1), must also be considered, as they may have favored the lower severity of the attack of this pest since elevated temperatures and low air humidity hinders its development (Fornazier et al., 2019).

4.2 Vegetative vigor

The lowest averages of vegetative vigor were observed at the first biennium, which coincides with the highest occurrences of leaf rust, brown eye spot and dieback, except for clones 26, 06, 13 and 02 (Tables 2 and 3). However, the opposite was observed at the second and third biennia. Less vigorous coffee plants may be related to leaf development, crop yield and evolution of leaf rust.

As for the average of three biennia, the vegetative vigor was 7.38 higher than the average reported by Bergo, Pereira and Sales (2008). Among the most vigorous clones, with an average of 7.87 (Table 3), it was observed that seven also showed the highest resistance to rust and brown eye spot (Table 2), which may have contributed to the improvement in the vigor of these coffee trees.

The vegetative vigor also depends on the fruiting and recovery rate of coffee trees. Plants with high yield and high recovery rate may show high vigor; while others may show a reduction in vigor due to the metabolic stress caused by high fruit set (charge), even with a slow recovery rate of these plants; however, they may be able to show satisfactory yield (Rodrigues et al., 2012). Thus, the selection of genotypes based on greater vegetative vigor can be a strategy to achieve increased yields.

4.3 Grain yield

The productive potential of the clones was influenced by environmental conditions during the cultivation period (Table 1). Significant interactions between plant fitting and years of cultivation were also demonstrated by Spinelli et al. (2018). The average yield of three evaluated biennia, 70.57 bags of processed coffee ha^{-1} was much higher than the values estimated in different regions of the country that cultivate this species (Rocha et al., 2015b, Silva et al al., 2017, Spinelle et al., 2018). Therefore, this characterizes an important variability and favourable condition for selection.

Coffee yield and variability among clones increased over the biennia (Table 3). These differences are expected since the expression of this trait is determined by genetic potential and also influenced by environmental factors such as soil fertility, management practices, edaphoclimatic conditions and incidence of pests and diseases (Rocha et al., 2015a). According to these authors, the production variability of coffee over time grounds the selection of clones by considering the highest average production with less fluctuation over years. Thus, it was demonstrated that the yield increased in response to the progress of the biennium in 8% of the clones; while 17% of the clones reached production stability from the second biennium. Moreover, 39% showed an increase in yield only at the third biennium, and 36% presented production stability (Table 3). Clones 24, 28, 26, 21, 29, 10 and 04 were the most productive regardless of the evaluated biennium.

Yield variability may be related to differences in genetic productive potential, as well as the occurrence of pests and diseases, which affect vegetative vigor of coffee trees (Tables 2 and 3). The vegetative vigor and leaf rust severity influenced the yield of Conilon coffee trees in the south of Espírito Santo state, with the vegetative vigor being more limiting to yield than the leaf rust severity (Rodrigues et al., 2012). The characteristics associated with yields presented the highest contributions to the diversity among Conilon coffee genotypes (Giles et al., 2018). Hence, this evidences the importance of this feature in the process of selecting superior clones.

4.4 Phenotypic, genotypic and environmental correlations

The genotypic correlation coefficients overcome phenotypic and environmental correlation coefficients for all combinations of six evaluated characteristics, which demonstrates that genetic factors influenced more than environmental factors. This fact can also be verified by the sign agreement of the phenotypic (r_p) and genotypic (r_g) correlation coefficients (Table 4).

Dieback intensity, leaf rust and brown eye spot severity were positively correlated (Table 4), which suggests that the increase or decrease in the incidence of one of these diseases contributes in the same extent to the incidence of other diseases. Equivalent results were obtained by Silva et al. (2018) by evaluating 71 Conilon coffee genotypes.

The vegetative vigor showed negative genotypic and phenotypic correlations with the intensity of dieback and severity of leaf rust and brown eye spot (Table 4). Negative correlations between vegetative vigor and severities of such diseases were also observed among 71 Conilon coffee genotypes (Silva et al., 2018). On the other hand, vegetative vigor showed a high genotypic and positive correlation with yield (Table 4). Related results were observed in studies with Arabica coffee (Severino et al., 2002) and Conilon genotypes (Silva et al., 2018), which points out this characteristic as a parameter of productive capacity estimation of coffee trees.

Coffee yield showed positive genotypic correlations with vegetative vigor, and negative correlations with the evaluated diseases (Table 4). Altogether, such results corroborate with what previously reported by Silva et al. (2018). Therefore, the most productive clones were the most vigorous and presented the lowest both leaf rust and brown eye spot severities, as well as dieback intensity.

5 CONCLUSIONS

1. There is Clone x Biennium interaction for yield and severity of leaf rust characteristics.

2. There are negative correlations between the yield characteristics and those related to the occurrence of pests and diseases.

3. Clones 24, 23, 28, 26, 21, 29 and 06 present higher yields, high vigor and lower severity of pests and diseases, with potential for cultivation in the Zona da Mata region of Minas Gerais.

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7 AUTHORS' CONTRIBUTIONS

WMM wrote the manuscript, supervised the experiments, conducted statistical analyses, review and approved the final version of the work, AWP and RLO co-worked the manuscript, review and approved the final version of the work, PRC conducted all statistical analyses, review and approved of the final version of the work, RGF, MAGF and ACV Filho supervised the experiments, review and approved of the final version of the work.

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