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Intercropping with dwarf coconut: vegetative, reproductive and nutritional traits of *Coffea canephora* genotypes recommended to monoculture

Consórcio com coqueiro-anão: características vegetativas, reprodutivas e nutricionais de genótipos de *Coffea canephora* recomendados para monocultura

Cultivo intercalado con coco enano: características vegetativas, reproductivas y nutricionales de genotipos de *Coffea canephora* recomendados para monocultivo

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ABSTRACT
The aim of this study was to quantify vegetative, reproductive and nutritional characteristics of conilon coffee genotypes intercropped with dwarf coconut, in order to verify the possibility of identifying genotypes with promising performance for consortium systems between genotypes recommended for monoculture. The experiment was developed in a consortium system, following a completely randomized design, testing eight genotypes of *C. canephora* randomly distributed along the lines of consortium with dwarf coconut trees, using six replications. Twelve characters were evaluated to describe vegetative, reproductive and nutritional aspects of plants. It was possible to identify differences in vegetative, reproductive and nutritional characteristics between genotypes of *C. canephora* in consortium with dwarf coconut. The phenotypic and genetic variability expressed, even in a limited group of eight genotypes improved and adapted for monoculture, seems to be sufficient to allow a selection of genotypes more suitable for the consortium. Considering the conditions evaluated, genotypes 83, 48, 02 and 153 stand out for this consortium, because their selection could promote gains in several of the characteristics used in this research.

Keywords: Coconut. Coffee. Land Use. Mitigation. Shading.

RESUMO
O objetivo deste estudo foi quantificar características vegetativas, reprodutivas e nutricionais de genótipos de café conilon consorciados com coqueiro-anão, a fim de verificar a possibilidade de identificar genótipos com desempenho promissor para sistemas de consórcio entre genótipos recomendados para monocultura. O experimento foi desenvolvido em sistema de consórcio, seguindo delineamento inteiramente casualizado, testando oito genótipos de *C. canephora* distribuídos aleatoriamente ao longo das linhas de consórcio com coqueiros-anões, utilizando seis repetições. Foram avaliados doze caracteres para descrever aspectos vegetativos, reprodutivos e nutricionais das plantas. Foi possível identificar diferenças de características vegetativas, reprodutivas e nutricionais entre genótipos de *C. canephora* em consórcio com coqueiro-anão. A variabilidade fenotípica e genética expressa, mesmo em um grupo limitado de oito genótipos melhorados e adaptados para monocultura, parece ser suficiente para permitir uma seleção de genótipos mais adequados para o consórcio. Considerando as condições avaliadas, os genótipos 83, 48, 02 e 153 se destacam para este consórcio, pois sua seleção pôde promover ganhos em diversas das características utilizadas nesta pesquisa.

Palavras-chave: Coco. Café. Mitigação. Uso da Área. Sombreamento.

RESUMEN
El objetivo de este estudio fue cuantificar las características vegetativas, reproductivas y nutricionales de genotipos de café conilon intercalados con coco enano, con el fin de verificar la posibilidad de identificar genotipos con desempeño prometedor para sistemas de consorcio entre genotipos recomendados para monocultivo. El experimento se desarrolló en un sistema de consorcio, siguiendo un diseño completamente al azar, probando ocho genotipos de *C. canephora* distribuidos aleatoriamente según las líneas de consorcio con cocoteros enanos, utilizando seis repeticiones. Se evaluaron doce caracteres para describir aspectos vegetativos, reproductivos y nutricionales de las plantas. Fue posible identificar diferencias en las características vegetativas, reproductivas y nutricionales entre genotipos de *C. canephora* en consorcio con coco enano. La variabilidad fenotípica y genética expresada, incluso en un grupo limitado de ocho genotipos mejorados y adaptados para monocultivo, parece suficiente para permitir una selección de genotipos más adecuados para el consorcio. Considerando las condiciones evaluadas, los genotipos 83, 48, 02 y 153 se destacan para este consorcio, porque su selección podría promover ganancias en varias de las características utilizadas en esta investigación.

Palabras clave: Coco. Café. Uso de la Tierra. Mitigación. Sombreado.

1 INTRODUCTION

The climate change has created a scenario of uncertainty for the sustainability of the agriculture. The increasing occurrence of extreme weather phenomena has challenged the agriculture to adapt towards techniques to resist abiotic stresses that can compromise the development and productivity of plants. Intercropping systems have become an interesting alternative in order to cultivate coffee (*Coffea* spp.), with the possibility of mitigating the harmful effects of many of these environmental stresses (DaMatta, 2004; DaMatta; Ramalho, 2006; DaMatta *et al.*, 2007a; Pezzopane *et al.*, 2011; Rodríguez-López *et al.*, 2013).

The use of arboreal or high-canopy species in an intercropping system allows the coffee plants to be cultivated in the lower stratum of the agroecosystem, partially protected from the direct action of stresses caused by excessive incident radiation, mechanical damage from high wind speed, or even thermal stresses caused by the wide oscillation of temperature along the day (DaMatta; Ramalho, 2006; Pezzopane *et al.*, 2010). The cultivation of coffee in consortium can also generate other benefits, such as improvements in the conservation of soil moisture and its fertility, in particular due to the modification of the pattern of exploration of the soil by the roots of the different species present in the system, favoring the recovery and recycle of nutrients (Vaast; Zasoski; Bledsoe, 2005).

The intercropping of coffee with dwarf coconut (*Cocus nucifera* L.) has already been successfully used in commercial crops. In these systems, it has been observed that the dwarf coconut palms are able to modify the patterns of incidence of photosynthetically active radiation over the canopy of coffee plants, in addition to promoting a decrease in wind speed and changing the thermal and relative humidity regime of the air inside the plantation (Pezzopane *et al.*, 2011).

The high variability among genotypes of conilon coffee (*Coffea canephora* Pierre ex Froehner), which naturally occurs due to the gametophytic self-incompatibility mechanism that promotes a high rate of allogamy for the species (Berthaud, 1980), makes it possible to observe distinctions for several agronomic traits in populations of this species. Research results have already shown that this variability is sufficient to identify genotypes with superior behavior for intercropping, shaded or agroforestry systems (Christo *et al.*, 2018, 2023; Senra *et al.*, 2022, 2024).

In this context, it is believed that this high variability for the expression of phenotypic traits can be exploited to help identifying genotypes of conilon coffee that are best adapted to intercropping systems. Within this theme, although studies describe the variability for mineral nutrition of genotypes of this species of coffee (Colodetti *et al.*, 2015; Martins *et al.*, 2016), there is still a lack of scientific knowledge regarding the nutritional efficiency of these plants in intercropping systems. This knowledge is required in order to explore the genetic potential of the species for the rational exploration of consortium agroecosystems (DaMatta *et al.*, 2007a).

The objective of this study was to quantify vegetative, reproductive and nutritional traits of genotypes of conilon coffee intercropping with dwarf coconut, in order to verify the possibility to identify genotypes with promising performance for intercropping systems among genotypes which were already recommended for monoculture.

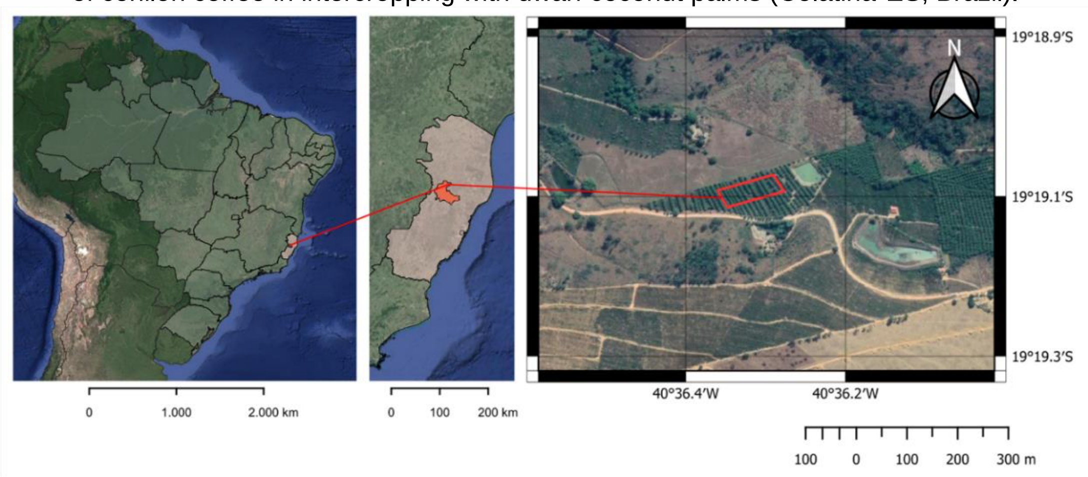
2 MATERIAL AND METHODS

The article was based on descriptive research, using data collection from an experimental field to test the hypothesis.

2.1 LOCAL CHARACTERIZATION

The experiment was developed in an intercropping system cultivated in the municipality of Colatina, Northwest region of the Espírito Santo state, located in Southeast Region of Brazil, at latitude 19°19'5.61"S and longitude 40°36'13.64"W (Figure 1), being located at 116 m above sea level. This region is located in a zone classified as suitable for cultivating conilon coffee, according to the agroclimatic zoning for agriculture aptitude (Pezzopane *et al.*, 2012).

Figure 1. Map of the geographic location of the experimental field used to study the genotypes of conilon coffee in intercropping with dwarf coconut palms (Colatina-ES, Brazil).

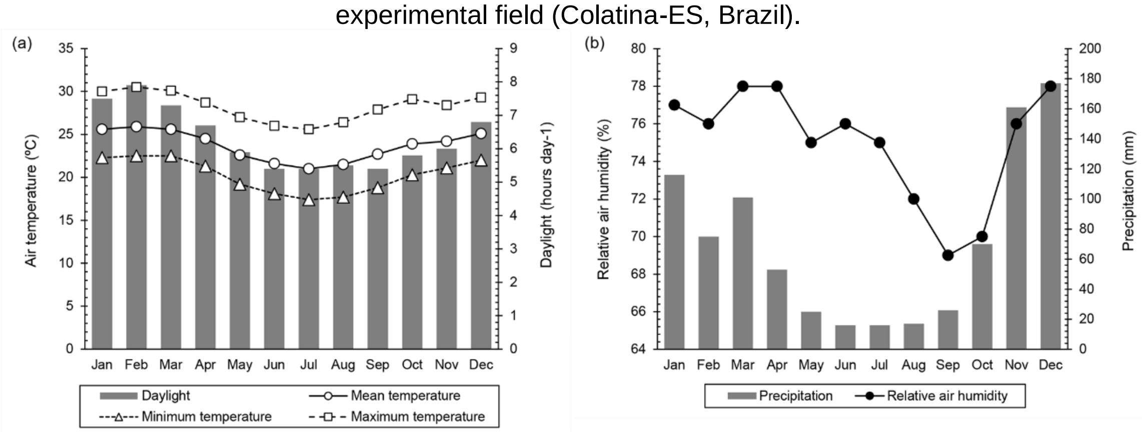


Source: the authors.

The soil is classified as Oxisol, being annually sampled for analysis to correct its acidity and increase its fertility to the levels considered adequate for the crops. The nutritional management was established using the current recommendations for the State where the research was developed (Prezotti *et al.*, 2007).

The climate of the region is classified as "*Aw*" type, according to the Köppen classification (Alvares *et al.*, 2013), presenting two well defined seasons: hot and rainy from November to February, and cold and dry from March to September. The weather conditions were monitored using an automatic meteorological station localized near the intercropping field (Figure 2).

Figure 2. Mean values of (a) daily maximum, mean and minimum air temperature and daylight length, and (b) daily relative air humidity and accumulated monthly precipitation in the experimental field (Colatina-ES, Brazil).

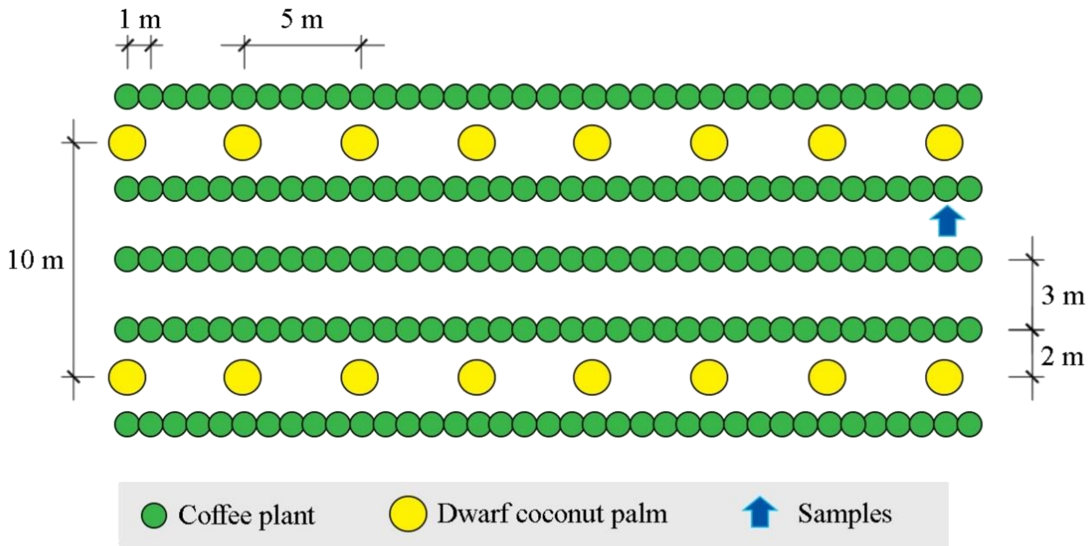


Source: the authors.

2.2 INTERCROPPING CHARACTERIZATION

The coffee plants were spaced by 3 × 1 m and cultivated with four orthotropic stems each. The dwarf coconut palms (*Cocos nucifera* L. var. nana) were cultivated in a 10 x 5 m spacing. The coffee lines were placed 2 m away from the coconut lines. The system was composed by the sequential distribution of three lines of coffee and one line of coconut (Figure 3).

Figure 3. Design and spacing of the intercropping with sequential lines of coffee plants and dwarf coconut palms, with indication of the place where the data were sampled for the coffee plants (Colatina-ES, Brazil).



Source: the authors.

The photosynthetically active radiation over each species of the intercrop system was measured during a day with clear sky, at midday, using a portable irradiance bar of 1 linear meter of length (Li-cor, Li-250A). By comparing the irradiance incident on the system and the irradiance quantified over the canopy of coffee plants, it was noted that the dwarf coconut crop promoted a decrease of approximately 40% of the incident irradiance.

The plants were cultivated in rainfed conditions and managed following the recommendations for growing coffee in the region, considering the weed and phytosanitary management as needed and adopting the traditional pruning scheme for renewing the canopy (Ferrão *et al.*, 2019a).

2.3 EXPERIMENTAL DESIGN

The experiment followed a completely randomized design, testing eight genotypes of *C. canephora* randomly distributed along the intercrop lines, using six repetitions. The randomized placement of genotypes is also used as a strategy to promote cross-pollination (Conagin; Mendes, 1961; Ferrão *et al.*, 2019b).

The genotypes were selected to sample different groups regarding ripening cycle. The genotypes used in this study were: 02, 03 and 48 of early cycle; 16, 76 and 83 of intermediate cycle; and 100 and 153 of late cycle. These genotypes are improved and adapted to cultivation in the region, being part of clonal cultivars widely used for monoculture in the Espírito Santo state (Ferrão *et al.*, 2019b).

2.4 CULTIVATION AND DATA COLLECTION

The intercrop was cultivated until the stabilization of the reproductive phenological cycles of both species and evaluated during its eighth year. The vegetative, reproductive and nutritional traits of the coffee plants were evaluated during the end of the phase of fruit ripening. Plants of each genotype were randomly sampled from adjacent lines from the dwarf coconut palms (Figure 2). The data were collected from one of the orthotropic stems and from plagiotropic branches selected at the medium portion of the canopy, selecting branches which represented the overall growth and yield of the current cycle.

Fruits from the plagiotropic branches were harvested and separated in paper bags, taken to drying in a laboratory oven with forced air circulation, at a temperature of 65 °C, until they reached constant mass. The dry matter of fruits (DMF) was determined by weighing in an electronic analytical scale (precision of 0.01 g). The remaining structures of the same plagiotropic branches were subjected to the same drying process, in order to obtain the total dry matter of all structures of the plagiotropic branch (DMP), considering the biomass of fruits, leaves and stem.

The dried leaf tissues were ground in a knife mill (Wiley type, 20 mesh) to obtain a homogeneous powder. Sub-samples were used to quantify the concentration of nitrogen, phosphorus and potassium, according to the methodology for chemical analysis of plant tissues described by Embrapa (1997). Using the concentration of these macronutrients and the biomass of leaves, the nitrogen, phosphorus and potassium contents available in the leaves of each plagiotropic branch were calculated (NCP, PCP, KCP, respectively).

The total chlorophyll index (CHL) from the leaves were determined using a portable chlorophyll meter (Falker, ClorofiLOG FL1030). The total leaf area (TLA) per plagiotropic branch was quantified using the method of leaf dimensions (Barros *et al.*, 1973).

The plant height (PHE) was measured with a graduated ruler, from the soil level up to the apex of the selected orthotropic steam. The number of plagiotropic branches (NPB) grown per orthotropic steam was counted. The length of plagiotropic branches (LPB) were measured with a graduated ruler, from the insertion on the orthotropic steam to the apex of the branch. The number of reproductive buds (NRB) (*i.e.*, rosettes) per branch were counted. The average length of internodes (LIN) from the plagiotropic branches were measured using a graduated ruler.

2.5 STATISTIC ANALYSES

The data were subjected to analysis of variance, assisted by the software GENES (Cruz, 2013) and Selegen (Resende, 2016), using the statistical model $Y_{ij}=\mu+G_i+e_{ij}$, where Y_{ij} represents the observed value of the i^{th} genotype in j^{th} repetition, μ represents the overall mean and e_{ij} represents the random error in the i^{th} genotype and j^{th} observation. This model was used to estimate the genetic parameters for each analyzed trait: coefficient of genetic variation (CV_g), phenotypic variance ($\hat{\sigma}_p^2$), genotypic variance ($\hat{\sigma}_g^2$) and coefficient of genotypic determination (H^2). The the coefficient of repeatability ($\hat{r}$) were estimated using the method of analysis of variance.

According to the significance of the source of variation, the Scott-Knott criterion was applied to identify homogeneous groups among genotypes. The correlation coefficients for each pair of traits were obtained and their statistical significance was tested by t-test. A correlogram was created to visualize the data, using the package *ggcorrplot* (Kassambara; Patil, 2023) in R-Studio (R Core Team, 2021).

In order to help selecting the genotypes with superior response to the intercropping, the selection index was calculated using the Mulamba-Rank. This index classifies the performance of the genotypes for each trait, considering the objective to increase or decrease the values, and uses the average rank of each genotype to estimate the gains based on the predicted genotypic values (Resende, 2007).

3 RESULTS AND DISCUSSIONS

The overall means observed for the traits indicates that the coffee plants were not negatively influenced by the level of shading caused by the dwarf coconut palms (Table 1). This fact can be accessed by the magnitude of chlorophyll levels and by the balance between vegetative (DMP, TLA, PHE, NPB, LPB) and reproductive (DMF, NRB) growth, especially noted for the allocation of biomass with a ratio of 2.2:1 between fruits and vegetative structures.

The climatic conditions during the evaluated cycle were not as favorable for the crops, as it matched an atypical period for the region, marked by a decreased water availability (*i.e.*, drought). The adequate vegetative, reproductive and nutritional status of the coffee plants show the benefits of the mitigation caused by the intercropping. The water crisis caused by the lack of rain caused a yield loss in the region of nearly 26.4% in this period (Galeano *et al.*, 2016).

Furthermore, the nutritional status of the coffee plants for N showed medium to high availability even at the end of the reproductive cycle (after the reallocation of nutrients to flowering and fruitification). This fact shows possible benefits of the intercropping over nutritional stresses and reaffirms that the adopted spacing didn’t cause competition for this nutrient. The roots from the dwarf coconut palms may be exploring the soil in different regions and depths, and the organic matter added by the fallen plant structures could be promoting the recycling of N, facilitating the acquisition of this macronutrient by the coffee plants.

A significant effect for the source of variation represented by the different genotypes was observed for most traits (Table 1). Differences among the evaluated genotypes were only not observed for the chlorophyll index and plant height. The precision of the methods used to measure the traits can be accessed by the low coefficients of variation observed for all the traits, the highest value (25.20%) being observed for the leaf area. The values of CV_g surpassed the CV_e for several traits (DMF, DMP, NCP, PCP, KCP, LPB and LIN), showing a desirable potential for improvement in breeding programs.

Table 1. Overall mean (μ), mean square of genotypes (MS_g), coefficient of variation (CV_e), coefficient of genetic variation (CV_g), phenotypic variation ($\hat{\sigma}_p^2$), genotypic variation ($\hat{\sigma}_g^2$), coefficient of genotypic determination (H^2) and coefficient of repeatability ($\hat{r}$) for vegetative, reproductive and nutritional traits of the genotypes of C. canephora in intercropping with dwarf coconut palms (Colatina-ES, Brazil).

Trait	Parameter							
	μ	MS_g	$CV_e(\%)$	$CV_g(\%)$	$\hat{\sigma}_p^2$	$\hat{\sigma}_g^2$	H^2	$\hat{r}$
DMF[1]	18.77	188.76**	17.06	29.06	31.46	29.75	94.57	0.75
DMP[2]	27.26	423.15**	14.62	30.23	70.53	67.88	96.25	0.84
NCP[3]	165.33	31671.22**	13.46	43.60	5278.53	5196.04	98.44	0.91
PCP[4]	3.68	9.72**	13.59	34.11	1.62	1.58	97.42	0.86
KCP[5]	45.18	1263.43**	11.23	31.79	210.57	206.28	97.96	0.88
CHL[6]	55.40	49.76ns	12.67	-	-	-	-	-
TLA[7]	564.02	104195.60**	25.20	20.98	17365.93	13997.34	80.60	0.44
PHE[8]	215.52	1066.88ns	12.19	-	-	-	-	-
NPB[9]	44.31	108.50*	15.28	7.29	18.08	10.44	57.72	0.21
LPB[10]	56.60	941.43**	16.84	21.03	156.90	141.76	90.35	0.63
NRB[11]	8.25	17.92**	23.60	18.40	2.93	2.30	78.48	0.39
LIN[12]	3.53	3.50**	12.61	21.02	0.58	0.54	94.34	0.72

1Dry matter of fruits (g); 2Dry matter of plagiotropic branches (g); 3Nitrogen content per plagiotropic branch (mg); 4Phosphorus content per plagiotropic branch (mg); 5Potassium content per plagiotropic branch (mg); 6Chlrorophyll index (icf); 7Total leaf area per plagiotropic branch (cm2); 8Plant height (cm); 9Number of plagiotropic branches per orthotropic stem; 10Length of plagiotropic branches (cm); 11Number of reproductive buds; 12Length of internodes (cm). **Significant at 1%, *significant at 5% and nsnot significant at 5%, by the F-test.
Source: the authors.

The genetic variance ($\hat{\sigma}_g^2$) was the main component of the observed phenotypic variation ($\hat{\sigma}_p^2$) among genotypes for most traits, resulting in high estimate values of H^2, following the decrescent order: NCP > KCP > PCP > DMP > DMF > LIN > LPB > TLA > NRB > NPB (Table 1).

Several studies suggest that cultivating coffee under shade, as is the case in the present consortium with coconut palms, is an important alternative to manage the crop, to diversify the production, and to mitigate the microclimatological fluctuations inside the agroecosystem (Cavatte *et al.*, 2013; Christo *et al.*, 2018; DaMatta, 2004; Pezzopane *et al.*, 2010, 2011). Intercropping coffee with arboreous or larger shading species can increase the viability of cultivation by attenuating adverse conditions and decreasing the stresses suffered due to excess radiation, frost, high velocity winds and extremes of temperature (Pezzopane; Pedro Júnior; Gallo, 2003; DaMatta, 2004; DaMatta; Ramalho, 2006; Pezzopane *et al.*, 2010, 2011).

The variability observed among coffee genotypes, including within selections of improved materials that are already found as components of cultivars in Brazil (Martins *et al.*, 2013; Colodetti *et al.*, 2014; Rodrigues *et al.*, 2017; Partelli *et al.*, 2020, 2021), corroborates the possibility of identifying genotypes capable of taking advantage of the nitrogen absorbed in their metabolic processes with higher conversion rate to growth. Other authors, working with growth parameters and nutritional efficiency of *C. canephora*, also identified different responses among genotypes (Colodetti *et al.*, 2015; Martins *et al.*, 2016).

The coefficient of repeatability for DMF, DMP, NCP, PCP, KCP, LPB and LIN can be classified as high (Resende, 2002). Lower coefficients were observed for TLA, NPB and NRB, which indicates that it may be necessary to increase the number of measurements to achieve high precision for these traits (Table 1).

It was possible to identify four homogeneous groups of genotypes for DMF, DMP, PCP and KCP; three groups of genotypes for NCP; and only two groups for TLA, NPB, LPB, NRB and INT (Table 2).

Table 2. Means for vegetative, reproductive and nutritional traits of the genotypes of C. canephora in intercropping with dwarf coconut palms (Colatina-ES, Brazil).

Genotype	02	03	16	48	76	83	100	153
DMF[1]	17.89C	11.85D	20.47C	23.29B	11.30D	28.25A	17.45C	19.64C
DMP[2]	25.07C	18.95D	26.80C	33.04B	17.84D	44.31A	24.65C	27.39C
NCP[3]	139.09C	165.26B	118.28C	164.34B	117.84C	338.57A	124.48C	154.83B
PCP[4]	3.23C	4.03B	2.05D	3.04C	3.08C	6.38A	3.45C	4.19B
KCP[5]	30.47D	64.89A	24.82D	46.76B	44.74B	65.51A	38.97C	45.26B
CHL[6]	57.55A	52.78A	52.68A	59.25A	55.38A	58.03A	51.30A	56.20A
TLA[7]	443.41B	679.97A	409.15B	554.91B	571.97B	805.00B	460.07B	587.71B
PHE[8]	226.33A	197.67A	214.83A	231.83A	215.50A	229.67A	197.67A	210.67A
NPB[9]	40.83B	49.33A	45.17A	43.00B	49.17A	47.83A	41.33B	37.83B
LPB[10]	52.50B	43.50B	53.50B	59.50B	47.33B	84.50A	59.67B	52.33B
NRB[11]	10.00A	6.67B	8.50A	11.00A	6.50B	9.00A	6.33B	8.00B
LIN[12]	2.77B	2.92B	3.63B	3.13B	3.29B	4.54A	4.84A	3.10B

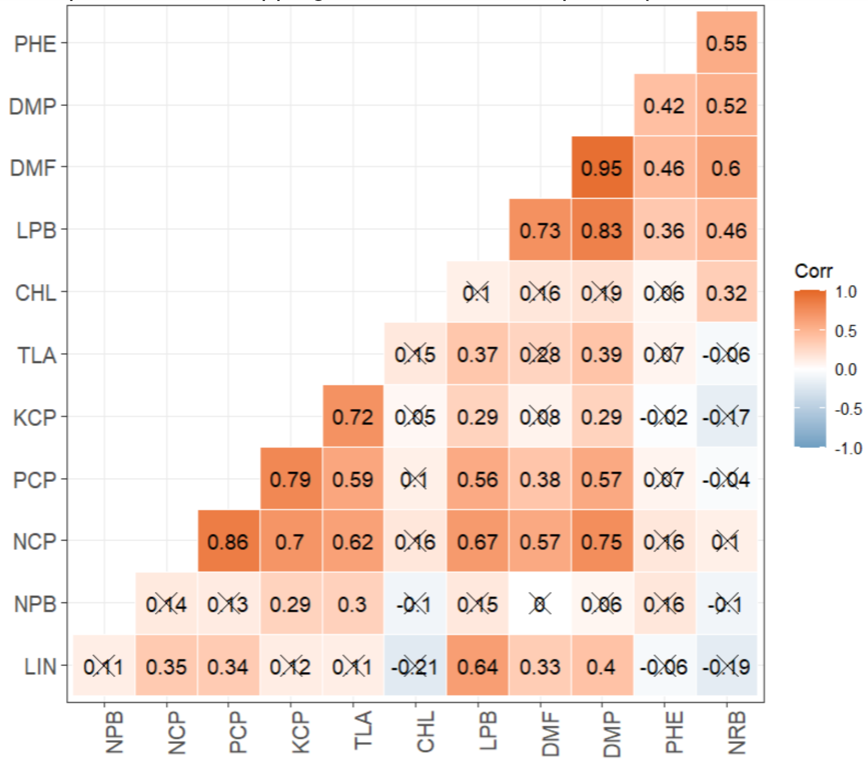
1Dry matter of fruits (g); 2Dry matter of plagiotropic branches (g); 3Nitrogen content per plagiotropic branch (mg); 4Phosphorus content per plagiotropic branch (mg); 5Potassium content per plagiotropic branch (mg); 6Chlrorophyll index (icf); 7Total leaf area per plagiotropic branch (cm2); 8Plant height (cm); 9Number of plagiotropic branches per orthotropic stem; 10Length of plagiotropic branches (cm); 11Number of reproductive buds; 12Length of internodes (cm). Means followed by the same uppercase letter per each row doesn't differ by the Scott-Knott (5% of probability).
Source: the authors.

The genotype 83 stood out for its higher dry matter of fruits, higher dry matter and length of plagiotropic branches, and higher content of N and P. The genotype 03 presented the higher leaf area per branch. Both these genotypes together formed the group with higher mean for K content (Table 2).

The evaluated nutritional contents are parameters of availability of N, P and K in the structures that are considered as metabolic sources (leaves) to sustain the anabolic processes of the plant (DaMatta *et al.*, 2007b). It is important to mention that all genotypes received the same amount of nutrients during the fertilization, therefore, the differences reported here reinforce the need to identify genotypes capable of acquiring, translocating and using the nutrients with higher efficiency.

The matrix of phenotypic correlation was used to study the interrelation between traits (Figure 4). Changes in the biomass per plagiotropic branch were very strongly and positively correlated with changes in the branch length and fruit biomass. Changes in nutritional content for P and N were also very strongly and positively correlated.

Figure 4. Correlogram for 12 vegetative, reproductive and nutritional traits of eight genotypes of C. canephora in intercropping with dwarf coconut palms (Colatina-ES, Brazil).



Crossed values represent non-significant correlations (p-values > 0.05).
Source: the authors.

The nutritional contents for the primary macronutrients presented positive and strong correlations with other traits (Figure 4), which reinforce the possibility to select genotypes that could explore better agronomic traits together with improvements of nutritional efficiency. The N content was strongly correlated with the K content, leaf area, branch length and biomass. The K content was strongly correlated with P content and leaf area.

The estimated gains using the Mulamba-Rank were calculated considering the effects for plant height and chlorophyll index as null; aiming to increase biomass allocation on fruits and branches, nutritional contents, leaf area, number and length of plagiotropic branches and number of reproductive buds per branch, and to decrease the internode length. The predicted gain using this parameter if the four best-ranked genotypes (83, 48, 02 and 153) were selected would reach nearly 23% (Table 3).

Table 3. Classification based on the Mulamba-Rank; considering 12 vegetative, reproductive and nutritional traits; of the genotypes of C. canephora in intercropping with dwarf coconut palms (Colatina-ES, Brazil).

Rank	Genotype	Mulamba-Rank	Gain (%)	Rank	Genotype	Mulamba-Rank	Gain (%)
1	83	2.0	125.0	5	16	5.1	14.2
2	48	3.6	60.7	6	03	5.3	8.0
3	02	4.3	36.4	7	76	5.5	3.3
4	153	4.7	23.3	8	100	5.5	0.0

Source: the authors.

These results show that it may be possible to explore a selection of genotypes that are able to take advantage of the conditions generated by the intercropping agroecosystem to make better use of available resources, making it possible to identify genotypes with higher efficiency to growth both vegetative and reproductive structure and better nutritional status under these conditions. Exploring the genetic variability expressed among genotypes which are already improved for crop yield and adaptation to monoculture may contribute to advance the breeding programs focused on intercropping, making these systems increasingly more viable for coffee production.

4 CONCLUSION

It is possible to identify differences of vegetative, reproductive and nutritional traits among genotypes of *C. canephora* in an intercropping with dwarf coconut. The phenotypic and genetic variability expressed, even in a limited group of eight genotypes improved and adapted for monoculture, seems to be enough to allow a selection of genotypes more suitable for intercropping.

There are strong correlations between nutritional contents for N, P and K and vegetative traits which could be used to obtain simultaneous gains in plant breeding programs.

Considering the evaluated conditions, the genotypes 83, 48, 02 and 153 stand out for this intercropping, as they could be selected to promote gains in several of the traits used in this research.

This research for intercropping with dwarf coconut describe the conditions of a period of development of both species, which have long life cycles, therefore, longer researches are important to keep evaluating these conditions in order to enhance the scientific knowledge about this agroecosystem. The variability and desirable responses among the genotypes used in this research also creates the interest in widening the samples for future researches, adding more genotypes, different environments and other species to be used in the intercropping.

The data presented in this study is helpful to aggregate scientific knowledge about coffee intercropping. The description about vegetative, reproductive and nutritional traits can be used to better select descriptors for studies of genetic variability for *C. canephora*, as well as to understand which genotypes have better performance in these agroecosystems and also work as basic knowledge for academic discussions involving the interaction between these traits.

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REFERENCES

ALVARES, C. A. *et al.* Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, Karlsruhe, v. 22, n. 6, p. 711-728, 2013.

BARROS, R. S. *et al.* Determinação de área de folhas do café (*Coffea arabica* L. cv. 'Bourbon Amarelo'). **Revista Ceres**, Viçosa-MG, v. 20, n. 107, p. 44–52, 1973.

BERTHAUD, J. L'incompatibilité chez *Coffea canephora*: méthode de test et déterminisme génétique. **Café Cacao Thé**, Paris, v. 24, n. 4, p. 167-174, 1980.

CAVATTE, P. C. *et al.* Arborização em café conilon: aspectos microclimáticos, fisiológicos e nutricionais. *In*: TOMAZ, M. A. *et al.* (orgs.). **Tópicos Especiais em Produção Vegetal IV**. Alegre: Caufes, 2013. p. 421–444.

CHRISTO, B. F. *et al.* Caracterização nutricional e exportação de nutrientes de genótipos de cafeeiro conilon consorciado com coqueiro-anão. **Desarrollo Local Sostenible**, Curitiba, v. 16, n. 46, p. 2403-2415, 2023.

CHRISTO, B. F. *et al.* Morpho-agronomic characterization of genotypes of Conilon coffee intercropped with dwarf coconut palms. **Australian Journal of Crop Science**, Queensland, v. 12, n. 9, p. 1479-1485, 2018.

COLODETTI, T. V. *et al.* Differential tolerance between genotypes of conilon coffee (*Coffea canephora*) to low availability of nitrogen in the soil. **Australian Journal of Crop Science**, Queensland, v. 8, n. 12, p. 1648-1657, 2014.

COLODETTI, T. V. *et al.* Nitrogen availability modulating the growth of improved genotypes of *Coffea canephora*. **African Journal of Agricultural Research**, Lagos, v. 10, n. 32, p. 3150-3156, 2015.

CONAGIN, C. H. T. M.; MENDES, A. J. T. Pesquisas citológicas e genéticas em três espécies de *Coffea*: auto-incompatibilidade em *Coffea canephora*. **Bragantia**, Campinas, v. 20, p. 787-804, 1961.

CRUZ, C. D. GENES: a software package for analysis in experimental statistics and quantitative genetics. **Acta Scientiarum. Agronomy**, Maringá, v. 35, n. 3, p. 271-276, 2013.

DaMATTA, F. M. Ecophysiological constraints on the production of shaded and unshaded coffee: a review. **Field Crops Research**, v. 86, n. 2-3, p. 99-114, 2004.

DaMATTA, F. M. *et al.* Ecophysiology of coffee growth and production. **Brazilian Journal of Plant Physiology**, Campos dos Goytacazes, v. 19, n. 4, p. 485-510, 2007b.

DaMATTA, F. M. *et al.* O café conilon em sistemas agroflorestais. *In*: FERRÃO, R. G. *et al.* (eds.). **Café Conilon**. Vitória: Incaper, 2007a. p. 375-389.

DaMATTA, F. M.; RAMALHO, J. D. C. Impacts of drought and temperature stress on coffee physiology and production: a review. **Brazilian Journal of**

Plant Physiology, Campos dos Goytacazes, v. 18, n. 1, p. 55-81, 2006.

EMBRAPA – EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Manual de métodos de análises de solos**. 2. ed. Brasília-DF: Embrapa, 1997.

FERRÃO, R. G. *et al.* **Conilon coffee**. 3. ed. Vitória: Incaper, 2019a.

FERRÃO, R. G. *et al.* Cultivars of conilon coffee. *In*: FERRÃO, R. G. *et al.* (org.). **Conilon coffee**. 3. ed. Vitória: Incaper, 2019b. p. 255-287.

GALEANO, E. A. V. *et al*. Estimativa de perdas na produção agrícola capixaba em 2015. **Incaper em Revista**, Vitória, v. 6-7, n. 4, p. 26-41, 2016.

MARTINS, L. D. *et al.* Alterações morfológicas em clones de cafeeiro conilon submetidos a níveis de fósforo. **Scientia Plena**, São Cristóvão, v. 9, n. 4, p. 1-11, 2013.

MARTINS, L. D. *et al.* Genotypes of conilon coffee can be simultaneously clustered for efficiencies of absorption and utilization of N, P and K. **African Journal of Agricultural Research**, Lagos, v. 11, n. 38, p. 3633-3642, 2016.

PARTELLI, F. L. *et al.* Monte Pascoal: first clonal conilon coffee cultivar for southern Bahia-Brazil. **Functional Plant Breeding Journal**, Campos dos Goytacazes, v. 3, n. 2, p.107-112, 2021.

PARTELLI, F. L. Tributun: a coffee cultivar developed in partnership with farmers. **Crop Breeding and Applied Biotechnology**, Viçosa-MG, v. 20, n. 2, e30002025.

PEZZOPANE, J. E. M. *et al.* **Agrometeorologia**: aplicações para o Espírito Santo. Alegre: Caufes, 2012.

PEZZOPANE, J. R. M. *et al.* Alterações microclimáticas em cultivo de café conilon arborizado com coqueiro-anão-verde. **Revista Ciência Agronômica**, Benfica, v. 42, n. 4, p. 865-871, 2011.

PEZZOPANE, J. R. M. *et al.* Condições microclimáticas em cultivo de café conilon a pleno sol e arborizado com nogueira macadâmia. **Ciência Rural**, Santa Maria, v. 40, n. 6, p.1257-1263, 2010.

PEZZOPANE, J. R. M.; PEDRO JÚNIOR, M. J.; GALLO, P. B. Caracterização microclimática em cultivo consorciado café/coqueiro-anão verde. **Revista Brasileira de Agrometeorologia**, Santa Maria, v. 11, n. 2, p. 293-302, 2003.

PREZOTTI, L. C. *et al.* **Manual de recomendação de calagem e adubação para o estado do Espírito Santo**. Vitória: SEEA/INCAPER/CEDAGRO, 2007.

R CORE TEAM. **R**: a language and environment for statistical. Vienna: R Foundation for Statistical Computing, 2021.

RESENDE, M. D. V. **Genética biométrica e estatística no melhoramento de plantas perenes**. Brasília-DF: Embrapa, 2002.

RESENDE, M. D. V. **Matemática e estatística na análise de experimentos e**

no melhoramento genético. Colombo: Embrapa, 2007.

RESENDE, M. D. V. Software Selegen-REML/BLUP: a useful tool for plant breeding. **Crop Breeding and Applied Biotechnology**, Viçosa-MG, v. 16, n. 4, p. 330-339, 2016.

RODRIGUES, W. N. *et al.* Genetic variability for sprout growth among genotypes of Coffea canephora led by bending of orthotropic stems. **Genetics and Molecular Research**, Ribeirão Preto, v.16, n. 4, p. 1-12, 2017.

RODRÍGUEZ-LÓPEZ, N. F. *et al.* (2013). Physiological and biochemical abilities of robusta coffee leaves for acclimation to cope with temporal changes in light availability. **Physiologia Plantarum**, Lund, v. 149, n. 1, p. 45-55, 2013.

SENRA, J. F. de B. *et al.* Promising conilon coffee trees clones for agroforestry and intercropping systems. **Agroforestry Systems**, Montpellier, v. 98, n. 6, p. 1759-1770, 2024.

SENRA, J. F. de B. *et al.* Seleção de genótipos de cafeeiro conilon para sistemas agroflorestais ou consorciados. **Conjecturas**, Caxias do Sul, v. 22, n. 1, p. 1-17, 2022.

VAAST, P.; ZASOSKI, R. J.; BLEDSOE, C. S. Effects of solution pH, temperature, nitrate/ammonium rates and inhibitors on ammonium and nitrate uptake by Arabica coffee in short term solution culture. **Journal of Plant Nutrition**, Athens, v. 21, n. 7, p. 1551-1564, 1998.