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Genetic Variability for Sprout Growth among Genotypes of *Coffea canephora* Led by Bending of Orthotropic Stems

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ABSTRACT. The multi-stem aspect of crop systems using *Coffea canephora* makes it necessary to correctly establish the number of orthotropic stems per plant during the crop formation. The present study was developed to study the variability of responses among improved genotypes of *C. canephora* to the technique of bending orthotropic stems as a mean of promoting the sprout growth, allowing producing an adequate number of vigorous sprouts that will be conducted to create the multi-stem canopies. The experiment studied 27 improved genotypes of *C. canephora*, following a randomized block design, with four replications and six plants per experimental plot. The results show that growth pattern and responsiveness varies among genotypes, and that parameters of biomass allocation and leafiness seems to be good describers to study of genetic variability. The observed variability was enough to cluster the genotypes regarding their response to this technique and to identify groups of genotypes with higher similarity and

homogeneous behavior. It is important to identify genotypes from groups of slower growth (e.g., 102, 103 and 301) or lesser emission of new sprouts (e.g., 207 and 301), since these may require additional treatments to develop the adequate number of orthotropic stems in the multi-stem architecture.

Keywords: Coffee; Bending; Multivariate Analysis; Orthotopic Stems; Crop Management; Diversity.

INTRODUCTION

Brazil is the country with the largest coffee production worldwide, producing both Coffea arabica Lineu and *Coffea canephora* Pierre ex A. Froehner. Great scientific advances have been made in the genetic improvement for both coffee species in Brazil due to the great economic importance of this agricultural product (Borém and Miranda, 2005). The species *C. canephora* have been constantly improved for several agronomic aspects such as crop yield, pruning management, productive stability, resistance to major phytosanitary problems, beverage quality and drought tolerance; which allow the recommendation of new cultivars of conilon coffee based on sets of improved genotypes (Ferrão et al., 2007; Carvalho, 2008; Verdin Filho et al., 2014).

Currently, for conilon coffee crops, the newer system of management of pruning is the programmed cycle pruning (Verdin Filho et al., 2008), which may allow average decrease of 32% of labor operations required in the crop and increase near 20% of average yield, improving the canopy architecture and facilitating other crop operations.

The success of this pruning system is based on the correct establishment of the number of orthotropic stems per plant during the crop formation. In order to promote the emission and growth of new orthotropic stems, the single original orthotropic stem may be bent (forming a semi arch towards the soil). The bending of young orthotropic stems for this end is a technique that is recommended for conilon coffee during the first 90 days of cultivation, it may improve the initial growth of new stems and is widely recommended in combination with the programed cycle pruning (Morais et al., 2012; Partelli et al., 2006, 2013).

The establishment of the number of stems per area required in the pruning management also is depend on the genetic variability. The cultivars of conilon coffee are composed by combinations of different improved genotypes and, since different genotypes may present different initial vegetative development, special attention may be required to achieve a homogeneous final number of stems per plant.

The high heterogeneity in populations of *Coffea canephora* is due to the high phenotypic and genotypic variability of this species (Fonseca et al., 2006; Ferrão et al., 2008; Rodrigues et al., 2012, 2013), which may be enough to express differences in the growth of new sprouts after the implementation of the bending technique.

The present study was developed to study the variability of responses among improved genotypes of *Coffea canephora* to the technique of bending orthotropic stems as a mean of promoting the sprout growth, allowing producing an adequate number of vigorous sprouts that will be conducted to create the multi-stem canopies. In addition, this study aims to identify genotypes that may require especial management during the crop implantation, due to an emission of lesser number of vigorous sprouts.

MATERIAL AND METHODS

Experimental setup

The experiment was developed in competition field installed in the countryside of the municipality of Alegre, Espírito Santo State, Southeast Region of Brazil (20°52'07"S and 41°28'43"W). The area has elevation of 642 m over sea level, the average air temperature of the region during the study was 20.85°C and annual accumulated rainfall was 1290 mm, with the rainy season from October to April and the dry season from May to September. The site is located in the mountain region (Carapaó-ES), and even if could be considered marginally fit for crops of *Coffea canephora* Pierre ex Froehner (due to its elevation), this species is already being used in commercial crops in the region.

The experiment studied 27 improved genotypes of *C. canephora*, following a randomized block design, with four replications and six plants per experimental plot. The plants were spaced 3.00 x 1.00 m, aiming to grow four orthotropic stems per plant and achieve a total population of 13.332 orthotropic branches per hectare.

The bending of orthotropic stems was made 50 days after planting, using standardized segments of bamboo culm (Bambusa vulgaris) to bend the plantlet stem towards the east-west direction.

The agricultural practices were established in accordance with those normally employed in the region, according to their need and following the current recommendations for the cultivation of conilon coffee in Brazil (Ferrão et al., 2007). The experimental field was irrigated since planting using localized dripping system.

Selected genotypes

The 27 genotypes of *Coffea canephora* Pierre ex A. Froehner used in this study are the group of genotypes that compose the three most recent clonal cultivars certified in Brazil by SNPC (Serviço Nacional de Proteção de Cultivares) for conilon coffee. Nine genotypes are from the cultivar "Diamante ES8112" (SNPC Certification number: 20140103), and will be referred in this study as 101, 102, 103, 104, 105, 106, 107, 108 and 109. Nine genotypes are from the cultivar "Jequitibá ES8122" (SNPC Certification number: 20140104), referred as 201, 202, 203, 204, 205, 206, 207, 208 and 209. And the last nine genotypes are components of the cultivar "Centenária ES8132" (SNPC Certification number: 20140102), referred as 301, 302, 303, 304, 305, 306, 307, 308 and 309. These clonal cultivars were developed and registered by the Instituto Capixaba de Pesquisa, Assistência Técnica e Extensão Rural (INCAPER), and are results of compatible arrangements characterized by high crop yield and quality.

Parameters of sprout growth

The plants were cultivated and 140 days after the bending of their stems, the new grown sprouts were evaluated and selected to form the multi-stem canopies with four stems each. These evaluations were performed to quantify: the total number of sprouts emitted per plant (TNS) and number of leaves per sprout (NLF), both obtained by direct counting; the average sprout height (ASH) and average stem diameter (ASD), measured with a ruler and a digital caliper, respectively; the length of orthotropic stem available for the growth of each sprout (OLS), obtained by the ratio between the length of the bent orthotropic stem and TNS; and the total leaf area per sprout (TLA), obtained using the non-destructive method of linear dimensions developed by Barros et al. (1973); and used for conilon coffee as tested by Brinate et al. (2015).

After these evaluations, the sprouts were cut and separated in leaves and stems, which were dried in laboratory oven, with forced air circulation at 65℃ (±2℃), until the mass achieve constant weight. The dried material was weighted in analytic scale (0.0001 g of precision). The results were expression in leaf dry mater (LDM), stem dry matter (SDM), total dry matter (TDM, as sum of LDM and SDM), leaf mass ratio (LMR, as ratio between LDM and TDM), stem mass ratio (SMR, as ratio between SDM and TDM), and leaf area ratio (LAR, as ratio between TLA and TDM).

Data analyses

The collected data were subjected to analysis of variance, using the F-test in order to identify the existence of differences between treatments for each variable. The genetic parameters were estimated based on analyses for each farming system, using the individual model:

$Yij=\mu + Bj + Gi + \varepsilon ij$ (Equation 1).

where Yij represents the phenotypic value of the ijth observation, Bj represents the effect of the jth block, Gi is the fixed effect of the ith genotype, and εij is the random error related to the ijth observation.

Means were analyzed using the Scott-Knott criterium (at 5% probability). The genetic parameters for each variable were estimated using the methods described by Cruz and Carneiro (2003), whereby the values for mean phenotypic variances (σ^_p^2), mean environmental variances (σ^_e^2), mean genotypic variances (σ^_g^2), coefficient of genotypic determination (H2), coefficient of genetic variation (CVg), and variation index (CVg/CV) were estimated.

The genetic divergences between genotypes were estimated by multivariate analysis techniques. The Mahalanobis distance (D2) was used as dissimilarity measure to cluster the genotypes using the UPGMA method, applied as described by Cruz and Carneiro (2006). Analyses were performed using the statistical software GENES (Cruz, 2013).

RESULTS AND DISCUSSION

Genetic parameters

The estimative of genetic parameters shows a considerable variability among genotypes regarding the emission of sprouts and the characteristics of their growth, showing that is possible to differentiate the response of the genotypes to the technique of bending the orthotropic stems. High genetic variability in *C. canephora* is naturally caused by the gametophytic self-incompatibility of the species (Lashermes et al., 1996), which promotes high cross breeding and increase the chance of finding genotypes with several heterogenous descriptors (Fonseca, 1999).

The existence of genotypic differences has been reported for many agronomic traits, such as plant biometry (Fonseca, 1999; Rodrigues et al., 2012), crop yield and its oscillation (Rodrigues et al., 2013), ripening cycle (Rodrigues et al., 2012, 2015), nutritional efficiency (Martins et al., 2013, 2016), resistance to plant diseases (Belan et al., 2015), tolerance to nutritional stresses (Colodetti et al., 2014), drought tolerance (DaMatta et al., 2003).

Different sprout growth patterns could be observed among the genotypes, as observed in Table 1, by the significance of the mean squares (MSgenotypes) for all variables but the biomass ratios (allocation of dry matter in leaves and stems), which were homogeneous among the genotypes.

Table 1. Estimative of phenotypic and genetic parameters of 12 morphological traits of sprouts, from young plants conducted with bending of orthotropic stems, from 27 genotypes of *Coffea canephora*, cultivated in mountain region (Alegre, Espírito Santo, Brazil, 2014-2015).

Parameters	**TNS**[9]	**ASH**[10]	**ASD**[11]	**NLF**[12]
$MS_{genotypes}$[1]	3,060**	80,22**	1,42**	59,05**
Overall mean	5,18	25,41	5,71	17,27
CV(%)[2]	19,79	14,86	12,79	16,26
$\hat{\sigma}^2_p$[3]	0,76	20,06	0,36	14,76
$\hat{\sigma}^2_e$[4]	0,26	3,56	0,13	1,97
$\hat{\sigma}^2_g$[5]	0,50	16,49	0,22	12,79
H^2[6]	65,58	82,23	62,55	86,65
CV_g(%)[7]	13,66	15,98	8,26	20,71
CV_g/CV[8]	0,69	1,08	0,65	1,27
Parameter	OLS[13]	TLA[14]	LDM[15]	SDM[16]
$MS_{genotypes}$[1]	8,63**	198495,94**	10,55**	10,51**
Overall mean	8,10	903,78	5,85	2,31
CV(%)[2]	19,79	19,25	18,50	19,94
$\hat{\sigma}^2_p$[3]	2,16	49623,98	2,64	0,56
$\hat{\sigma}^2_e$[4]	0,64	7571,39	0,29	0,05
$\hat{\sigma}^2_g$[5]	1,52	42052,59	2,34	0,50
H^2[6]	70,22	84,74	88,88	90,48
CV_g(%)[7]	15,19	22,69	26,16	30,74
CV_g/CV[8]	0,77	1,18	1,41	1,54
Parameter	TDM[17]	LMR[18]	SMR[19]	LAR[20]
$MS_{genotypes}$[1]	22,09**	13,62^{ns}	13,63^{ns}	2066,41**
Overall mean	8,16	71,74	28,26	116,12
CV(%)[2]	17,21	4,85	12,32	24,87
$\hat{\sigma}^2_p$[3]	5,52	-	-	516,60
$\hat{\sigma}^2_e$[4]	0,49	-	-	208,52
$\hat{\sigma}^2_g$[5]	5,03	-	-	308,08
H^2[6]	91,06	-	-	59,63
CV_g(%)[7]	27,47	-	-	15,11
CV_g/CV[8]	1,60	-	-	0,61

*Significant by the F-test and ^{ns}non-significant by the F-test, at 5% of probability; [1]mean square of genotypes; [2]coefficient of variation; [3]mean phenotypic variance; [4]mean environmental variance; [5]mean genotypic variance; [6]coefficient of genotypic determination; [7]coefficient of genetic variation; [8]variation index; [9]total number of sprouts; [10]average sprout height (cm); [11]average sprout diameter (mm); [12]number of leaves; [13]orthotropic length available per sprout (cm); [14]total leaf area (cm^2); [15]leaf dry matter (g); [16]stem dry matter (g); [17]total dry matter (g); [18]leaf mass ratio (%); [19]stem mass ratio (%); [20]leaf area ratio (cm^2/g).

The mean phenotypic variances (σˆ_p^2) for the 10 variables which presented significant differences among genotypes were mostly determined by the contribution of the high genotypic variances (σˆ_g^2), which exceeded the estimate values for the mean environmental variances (σˆ_e^2). As result, the coefficients of genotypic determination (H2) for these traits presented high values, showing genotypic contributions over 85% in the observed variation for number of leaves and accumulation of biomass (both LDM and SDM). Additionally, the variation indexes from these previously cited variables ranged from 0.61 to 1.60, being higher than 1.00 in six of them (TDM > SDM > LDM > NLF > TLA > ASH).

The before mentioned results show a certain favorability of using leafiness and biomass parameters to identify differences among genotypes regarding the growth pattern of their sprouts after bending. As well as indicate a higher contribution of genetic over environmental factors in the determination of the actual differences in this study.

Differences in sprout growth after bending

Analyzing the response of the different genotypes regarding the 12 growth traits, it is possible to observe the variability among them being enough to identify phenotypic differences and to group the genotypes in homogeneous groups for each trait, with the exception of LMR and SMR (Table 2).

Table 2. Comparison of means of 12 morphological traits of sprouts, from young plants conducted with bending of orthotropic stems, from 27 genotypes of *Coffea canephora*, cultivated in mountain region (Alegre, Espírito Santo, Brazil, 2014-2015).

Gen	TNS[(1)]	ASH[(2)]	ASD[(3)]	NLF[(4)]	OLS[(5)]	TLA[(6)]
101	5.50[a]	30.33[b]	5.96[a]	20.29[a]	7.18[b]	1038.27[a]
102	6.63[a]	21.54[c]	4.91[b]	12.54[c]	5.98[b]	523.21[c]
103	5.48[a]	19.94[c]	5.17[b]	12.46[c]	7.70[b]	654.04[c]
104	4.81[b]	25.52[b]	5.75[b]	19.38[a]	8.03[b]	870.11[b]
105	4.15[b]	22.46[c]	5.38[b]	18.38[a]	9.95[a]	922.69[b]
106	4.44[b]	25.56[b]	5.41[b]	19.25[a]	7.60[b]	891.19[b]
107	6.38[a]	33.25[a]	5.75[b]	24.00[a]	7.24[b]	1255.73[a]
108	5.71[a]	27.96[b]	7.19[a]	20.54[a]	7.10[b]	1032.86[a]
109	6.06[a]	36.13[a]	6.95[a]	22.25[a]	6.62[b]	1154.48[a]
201	5.06[b]	22.50[c]	6.14[a]	17.25[b]	7.95[b]	955.58[b]
202	6.31[a]	30.56[b]	5.61[b]	14.00[b]	5.64[b]	846.65[b]
203	4.69[b]	22.19[c]	6.18[a]	15.75[b]	8.92[a]	788.60[b]
204	4.77[b]	19.98[c]	4.71[b]	13.75[b]	9.10[a]	644.19[c]
205	4.63[b]	25.88[b]	5.84[b]	19.50[a]	8.25[b]	936.66[b]
206	4.21[b]	21.56[c]	5.39[b]	16.35[b]	9.87[a]	844.27[b]
207	3.50[b]	20.38[c]	5.38[b]	9.50[c]	11.31[a]	567.58[c]
208	6.54[a]	29.25[b]	5.28[b]	16.58[b]	6.72[b]	956.92[b]
209	5.88[a]	29.31[b]	5.94[a]	21.19[a]	7.13[b]	1239.70[a]
301	3.69[b]	20.08[c]	4.76[b]	10.77[c]	10.57[a]	549.79[c]
302	5.58[a]	28.31[b]	6.53[a]	15.67[b]	7.18[b]	942.33[b]
303	5.50[a]	26.88[b]	5.27[b]	15.88[b]	8.12[b]	842.76[b]
304	4.00[b]	21.06[c]	5.66[b]	14.13[b]	10.00a	697.69[c]
305	6.08[a]	28.23[b]	6.23[a]	23.67[a]	6.92[b]	1303.64[a]
306	5.21[a]	20.56[c]	5.46[b]	14.79[b]	6.89[b]	681.77[c]
307	4.60[b]	25.33[b]	6.21[a]	21.63[a]	9.72[a]	1173.45[a]
308	5.00[b]	29.27[b]	5.67[b]	16.69[b]	9.66[a]	892.67[b]
309	5.60[a]	22.04[c]	5.41[b]	20.17[a]	7.39[b]	1195.28[a]
Gen	LDM[(7)]	SDM[(8)]	TDM[(9)]	LMR[(10)]	SMR[(11)]	LAR[(12)]
101	5.28[c]	2.42[d]	7.70[c]	68.67[a]	31.33[a]	136.24[a]
102	3.23[d]	1.40[e]	4.63[d]	69.34[a]	30.66[a]	114.78[a]
103	3.89[d]	1.42[e]	5.31[d]	73.18[a]	26.82[a]	122.75[a]
104	5.50[c]	2.14[d]	7.64[c]	72.20[a]	27.80[a]	117.21[a]
105	5.56[c]	2.08[d]	7.64[c]	72.84[a]	27.16[a]	122.26[a]
106	5.73[c]	2.03[d]	7.76[c]	73.73[a]	26.27[a]	123.72[a]
107	7.45[b]	2.93[c]	10.38[b]	71.68[a]	28.32[a]	123.55[a]
108	7.69[b]	3.44[b]	11.13[b]	69.02[a]	30.98[a]	92.21b
109	10.67[a]	4.63[a]	15.30[a]	70.02[a]	29.98[a]	75.66b
201	5.60[c]	2.00[d]	7.60[c]	73.79[a]	26.21[a]	127.57[a]
202	6.10[c]	2.43[d]	8.53[c]	71.52[a]	28.48[a]	99.07[b]
203	5.32[c]	1.87[e]	7.19[c]	73.52[a]	26.48[a]	112.78[a]
204	3.33[d]	1.33[e]	4.65[d]	70.92[a]	29.08[a]	141.25[a]
205	5.87[c]	2.53[d]	8.40[c]	69.68[a]	30.32[a]	115.92[a]
206	6.02[c]	2.13[d]	8.14[c]	73.54[a]	26.46[a]	104.37[b]
207	6.25[c]	2.44[d]	8.69[c]	71.84[a]	28.16[a]	65.74[b]
208	4.91[c]	2.19[d]	7.10[c]	69.02[a]	30.98[a]	141.35[a]
209	7.19[b]	2.79[c]	9.98[b]	71.69[a]	28.31[a]	125.77[a]
301	3.24[d]	1.22[e]	4.46[d]	72.73[a]	27.27[a]	123.41[a]
302	7.91[b]	3.46[b]	11.37[b]	69.85[a]	30.15[a]	87.25[b]
303	7.18[b]	2.46[d]	9.65[b]	74.39[a]	25.61[a]	89.07[b]
304	4.95[c]	1.80[e]	6.75[c]	73.45[a]	26.55[a]	105.33[b]
305	7.25[b]	2.88[c]	10.13[b]	71.21[a]	28.79[a]	131.99[a]
306	4.37[d]	1.67[e]	6.03[d]	72.26[a]	27.74[a]	115.53[a]
307	6.44[c]	2.52[d]	8.96[c]	71.88[a]	28.12[a]	132.69[a]
308	5.82[c]	2.51[d]	8.33[c]	69.68[a]	30.32[a]	109.73[a]
309	5.24[c]	1.66[e]	6.90[c]	75.37[a]	24.63[a]	178.15[a]

Means followed by the same letter in the column do not differ by the Scott-Knott criterium (5% of probability); [(1)]total number of sprouts; [(2)]average sprout height (cm); [(3)]average sprout diameter (mm); [(4)]number of leaves; [(5)]orthotropic length available per sprout (cm); [(6)]total leaf area (cm^2); [(7)]leaf dry matter (g); [(8)]stem dry matter (g); [(9)]total dry matter (g); [(10)]leaf mass ratio (%); [(11)]stem mass ratio (%); [(12)]leaf area ratio (cm^2/g).

Only two different groups of means were formed for the number of sprouts per bent stem (TNS), diameter of the grown sprouts (ASD), the linear length available per sprout (OLS) and for leaf area ratio (LAR). Three different groups were formed for the average height of the sprouts (ASH), number of leaves per sprout (NLF) and for total leaf area (TLA). The dry matter of the plant organs allowed to identify a higher number of different groups: four different groups were identified for leaf dry matter (LDM) and total dry matter (TDM), and five groups for

stem dry matter (SDM). These results showed initial evidences of the accumulation of biomass being a valuable parameter to study diversity for genotypes of conilon coffee, regarding the growth of their sprouts (Table 2).

The genotypes 101, 102, 103, 107, 108, 109, 202, 208, 209, 302, 303, 305, 306 and 309 presented higher number of sprouts emitted per plant. The genotypes with higher vertical growth was 107 and 109, while the slower vertical growth was observed for 102, 103, 105, 201, 203, 204, 206, 207, 301, 304, 306 and 309. The genotypes 101, 108, 109, 201, 203, 209, 302, 305 and 307 presented thicker stems (Table 2).

Regarding the leafiness pf the sprouts, the genotypes 101, 104, 105, 106, 107, 108, 109, 205, 209, 305, 307 and 309 presented higher number of leaves; while the genotypes 102, 103, 207 and 301 developed less leaves. However, not all genotypes with more leaves resulted in higher total leaf area, which is due a morphological variation among genotypes of conilon coffee that results in slight differences in the leaf blade dimensions and, therefore, in the leaf size (Brinate et al., 2015). Larger leaf areas were observed for the genotypes 101, 107, 108, 109, 209, 305, 307 and 309, while smaller areas were obtained from the sprouts of the genotypes 102, 103, 204, 207, 301, 304 and 306 (Table 2). The development of greater leaf area implicates in a higher capacity to intercept the solar radiation, contributing to the photosynthetic rate and, ultimately, to the overall growth of the plants (Carvalho et al., 2001). The leaf area ratio for the genotypes 108, 109, 202, 206, 207, 302, 303 and 304 were smaller than all the others (Table 2).

The genotype 109 presented sprouts with the higher accumulation of biomass on leaves (LDM), stems (SDM), as well as the higher mean for total dry matter (TDM); while the genotypes 102, 103, 204, 301 and 306 produced less biomass for leaves and total, with addition of the genotypes 203, 304 and 309 for lesser biomass on stems (Table 2).

Overall, the results for growth and leafiness of the sprouts after the bending technique show that the genotypes 109, 107, 108, 101, 209, 307 and 305 responded with faster growth; while the genotypes 102, 103, 207 and 301 present grow slower and develop smaller leafiness. For biomass accumulation, the results show the genotype 109 with the higher means for dry matter, followed by the genotypes 107, 108, 209, 302 and 305 (Table 2).

The bending of orthotropic stems in conilon coffee plantlets promotes the emission of new sprouts in the initial stages of the crop formation (Schmidt et al., 2015), allowing a better standardization of the population of stems kept per area (Morais et al., 2012; Partelli et al., 2013), which has considerable effect over the crop yield and the sustainability of the plantation.

The promotion of development of sprouts and the new aerial part of the plants of conilon coffee with the use of the bending technique may be explained by the alterations caused in the hormonal balance, mainly caused by auxin and cytokinin, which promotes the break of the apex dominancy and stimulate the growth of lateral buds and, therefore, the development of new sprouts (Taiz and Zeiger, 2013).

The diversity for growth and biomass production among genotypes of conilon coffee are resulted from the high genetic variability of the species (Fonseca et al., 2006; Ferrão et al., 2008, 2009; Rodrigues et al., 2012). But it is noteworthy that the growth rate in coffee plants is highly dependent of environmental conditions, e.g., photoperiod, temperature, radiation, water availability, soil fertility (Ronchi and DaMatta, 2007). Therefore, studies that allow identifying and quantifying the alterations in the growth patterns of genotypes of *Coffea canephora* in response to different crop conditions are very important to select genotypes with best response to different crop techniques or with higher crop yield for different conditions (Fonseca et al., 2006; Rodrigues et al., 2016).

The act of bending the stems to promote the emission of new sprouts may have favored the growth of a group of genotypes more than others, which may be result of a higher level of responsiveness of some genotypes to external stimulation. Both intrinsic and extrinsic factors are determinant to the metabolic performance of coffee plants and are capable of modifying their growth (Larcher, 2000; Dardengo et al., 2010).

Diversity among genotypes

Using the characteristics of sprout growth in response to the bending of the orthotropic branches to estimate the dissimilarity measures between pairs of genotypes made possible to observe a complex pattern of the similarity between genotypes, regardless of their classification of ripening cycle (early ripening cycle: 101, 102, 103, 104,

Table 3. Dissimilarity measures between pairs of genotypes obtained by Mahalanobis distance and estimated from the study of 12 characteristics of sprouts from young plants conducted with bending of orthotropic stems (Alegre, Espírito Santo, Brazil, 2014-2015).

Gen	102	103	104	105	106	107	108	109	201	202	203	204	205	206	207	208	209	301	302	303	304	305	306	307	308	309
101	29	26	6	10	9	11	22	58	14	17	17	24	4	12	36	6	6	30	24	11	20	11	18	12	8	22
102		16	24	26	30	60	57	129	26	40	22	13	29	26	52	23	39	22	61	35	26	44	11	42	37	32
103			16	15	24	52	43	112	8	32	7	9	22	12	24	20	35	8	38	22	7	40	5	28	24	19
104				4	4	20	23	66	7	26	8	14	1	5	31	13	11	21	26	9	12	13	10	8	11	14
105					8	24	26	73	7	32	7	12	5	2	27	16	13	15	29	11	8	16	11	7	11	11
106						24	32	65	15	25	16	18	6	10	36	17	15	23	32	12	18	20	13	18	19	17
107							35	58	32	30	38	49	16	25	54	16	7	62	36	15	46	9	47	15	16	33
108								30	20	39	21	52	18	24	39	35	22	55	8	27	27	23	31	23	24	45
109									76	76	78	110	57	72	85	76	56	115	27	58	81	63	92	70	59	96
201										28	2	15	9	4	23	17	16	18	21	13	6	18	7	10	15	11
202											29	44	25	26	23	13	23	36	28	19	31	36	29	39	26	48
203												13	10	4	18	19	21	13	21	13	3	25	6	14	14	17
204													19	12	38	19	34	9	49	22	13	39	10	27	22	14
205														6	31	12	7	27	21	8	15	9	14	7	9	17
206															18	15	13	14	24	7	5	18	9	8	9	14

207	31	43	22	26	24	16	53	30	37	27	52
208		12	26	30	10	23	19	20	20	10	21
209			44	25	10	28	3	27	8	12	20
301				48	28	7	55	11	37	27	29
302					19	25	33	33	29	19	45
303						17	17	21	14	6	21
304							36	6	21	16	24
305								32	6	19	19
306									26	24	19
307										12	14
308											26

D^2 maximum: 129.15 (102 and 109); D^2 minimum: 1.38 (104 and 205).

105, 106, 107, 108 and 109; intermediate ripening cycle: 201, 202, 203, 204, 205, 206, 207, 208 and 209; late ripening cycle: 301, 302, 303, 304, 305, 306, 307, 308 and 309). The dissimilarity measures ranged from 1.38 to 129.15 and are presented on Table 3.

A greater distance was observed between the genotypes 102 and 109 (D2=129.15), while smaller dissimilarity was observed between the genotypes 104 and 205 (D2=1.38). It is possible that the duration of ripening cycle, which was the criteria to separate the studied genotypes in the three cultivars which they are part of, is resulted of a genetic combination that is not fully linked to the sprout growth parameters used in this study. However, the genotype 109, regardless of the classifications for ripening cycle, is a highly dissimilar genotype in terms of sprout growth response, participating of all the 10 largest distances observed in this experiment. Taking these 10 largest distances as sample, it is possible to observe greater dissimilarities of the genotype 109 to genotypes of late (301, 304, 306 and 309) and intermediate (201, 203, 204 and 207) ripening cycles, as well as some others genotypes of early maturation cycle (102 and 103). As result of this larger dissimilarity measures, the genotype 109 was isolated in the clustering presented in Figure 1.

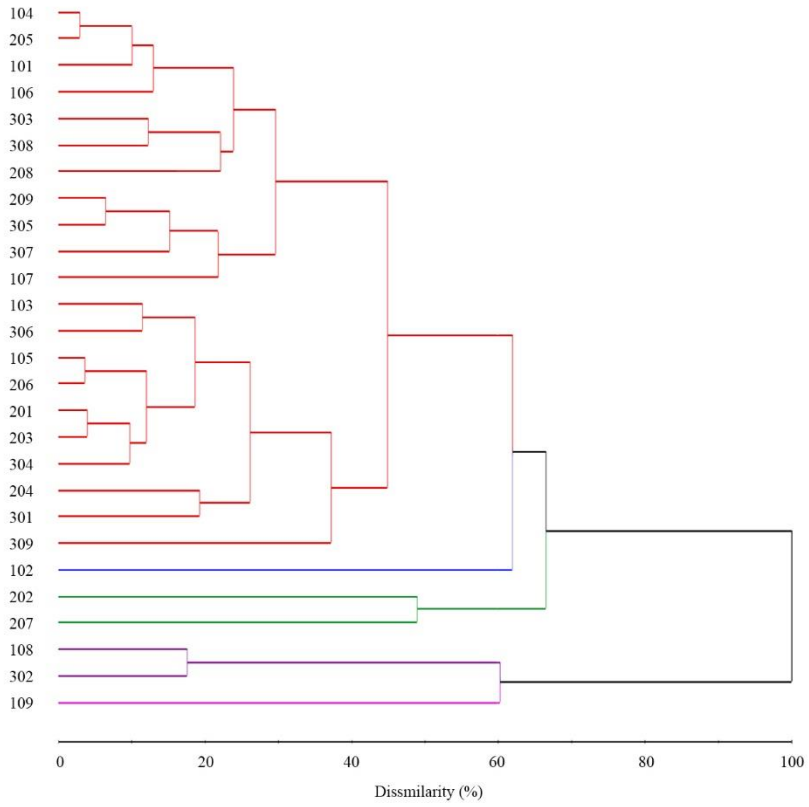

Figure 1. Dendogram showing the clustering (Mahalanobis distance, UPGMA method) of 27 genotypes of *Coffea canephora* based on 12 morphological traits of sprouts, from young plants conducted with bending of orthotropic stems, cultivated in mountain region (Alegre, Espírito Santo, Brazil, 2014-2015).

The cluster analysis, based on the multivariate dissimilarity measures, revealed the formation of five groups when a cutoff of 59.91 was used in the distance scale ($p>0.95$).

The first group was formed by the genotypes 101, 103, 104, 105, 106, 107, 201, 203, 204, 205, 206, 208, 209, 301, 303, 304, 305, 306, 307, 308, and 309. The genotype 102 presented some level of similarity with this group, but was isolated in the clustering. This fact may be occurred due to the plants of this genotype responding to the bending by emitting a large number of sprouts, but these sprouts growing slowly (smaller sprouts, with lesser leaf area and biomass).

Another group was formed by the genotypes 202 and 207, which presented similar pattern of biomass accumulation. These genotypes are similar regarding the amount of dry matter accumulated in the sprouts and in the partition of the biomass between leaves and steams, as well as the same behavior for the leaf area grown per accumulated biomass (Table 2).

The genotypes 108 and 302 were clustered in another group. Besides presenting high similarity in the biomass production and allocation, these genotypes also presented similarity regarding the emission of new sprouts. Plants from these genotypes developed high number of sprouts, with thicker stems, associated with a larger spatial separation between sprouts along the bent orthotropic stem.

The genotype 109 was singled out in the clustering, which may be due to its peculiar pattern of biomass accumulation. This genotype alone was able to produce sprouts with the highest means for biomass among all others.

CONCLUSION

Bending young orthotropic stems to promote the sprout growth and to produce an adequate number of stems in multi-stem plantations is a common technique used for Coffea canephora. The growth pattern and responsiveness varies among genotypes and it is possible to observe high variability among improved genotypes of *C. canephora* for sprout growth after bending the stems. Parameters of biomass allocation and leafiness seems to be good describers to study of genetic variability among genotypes of *C. canephora*, regarding the response to the bending technique.

It is possible to cluster the genotypes regarding their response to this technique and to identify groups of genotypes with higher similarity and homogeneous behavior. It is important to identify genotypes from groups of slower growth (e.g., 102, 103 and 301) or lesser emission of new sprouts (e.g., 207 and 301), since these may require additional treatments to develop the adequate number of orthotropic stems in the multi-stem architecture.

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