Original Article

PHENOTYPIC AND GENOTYPIC CHARACTERIZATION OF BASIL HYBRIDS AND CULTIVARS

CARACTERIZAÇÃO FENOTÍPICA E GENOTÍPICA DE HÍBRIDOS E CULTIVARES DE MANJERICÃO

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ABSTRACT: This study aimed to evaluate the phenotypic and genotypic performance of basil (*Ocimum basilicum* L.) hybrids and cultivars, grown in four crop years, in the municipality of São Cristóvão, state of Sergipe. The following variables were evaluated: dry weight of aerial part; essential oil content and yield; and the contents of linalool, 1,8-cineol, neral, geranial, and methyl cinnamate. Five hybrids ('Sweet Dani' x 'Maria Bonita', 'Genovese' x 'Maria Bonita', 'Cinnamon' x 'Maria Bonita', 'Sweet Dani' x 'Cinnamon', and 'Sweet Dani' x 'Genovese') and four parent cultivars ('Maria Bonita', 'Sweet Dani', 'Genovese', and 'Cinnamon') of basil were evaluated. The essential oils were obtained from dried leaves by hydrodistillation. The chemical composition of essential oils was analyzed by GC/MS-FID. Means were clustered, and the genetic and phenotypic parameters were estimated. Linalool was the main compound of most genotypes. Hybrids 'Cinnamon' x 'Maria Bonita', 'Sweet Dani' x 'Cinnamon', and 'Sweet Dani' x 'Maria Bonita' had methyl cinnamate (41.93 %), methyl cinnamate (60.15 %), geranial (15.20 %), and neral (11.46 %), respectively, as major compounds. The sources of variation were significant at the 1 % probability level, according to the F tests for all variables, confirming the differences in the performance of genotypes in the different years. Most of the variation among the studied variables resulted from the genetic variation.

KEYWORDS: *Ocimum basilicum.* Genetic variability. Essential oil. Chemical compounds.

INTRODUCTION

Basil (*Ocimum basilicum* L.) is an autogamous plant of the family Lamiaceae, grown in various countries, including Brazil. The species may be used for raw consumption or essential oils production. Cross-pollination can frequently occur, especially in the presence of bees. The goal of breeding programs is to produce cultivars adapted to the planting regions and which present enhanced aroma and high contents of active ingredients of the essential oil. This way, new cultivars can meet the demand of the pharmaceutical, cosmetic, and perfume industries for good-quality raw material.

Environmental factors may affect genotypes evaluation and cultivars recommendation. They may also affect the identification of superior genotypes by equating disparate and differentiating identical genotypes (CRUZ, 2005), as well as by resulting in the production of compounds at levels higher or lower than those expected.

Furthermore, the wide chemical variability of the species hinders its characterization. Thus, the genetic and phenotypic parameters, including the genotypic coefficient of determination, coefficient of genetic variation, coefficient of environmental variation, ratio between the coefficients of genetic and environmental variation, and the coefficient of phenotypic and genotypic correlations must be estimated. The study of these parameters aims to analyze the genetic variability and whether they may be maintained in future generations.

The parameter genotypic coefficient of determination, analogous to broad-sense heritability, predicts how much the observed variability results from the genotype. However, heritability is not a fixed measurement, and it may vary depending on the conditions, genotype, year, and site (genotype x environment interaction) (CRUZ 2005, BLANK et al. 2010, VERARDI et al. 2012). The coefficient of genetic variation enables comparisons of the levels of genetic variability in different genotypes, environments, and variables (FERRÃO et al. 2008).

The knowledge of correlations between variables helps to identify the best genotypes and genetic gains, and thus allows the selection of new cultivars to meet commercial and agronomic goals (FERREIRA et al. 2007). Furthermore, indirect selection of two variables may generate gains when these variables are highly correlated genetically,

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even when the variable of higher economic value shows low heritability, comparing with the other variable (SOUZA et al. 2012).

Studies on genetic variation and relationships between production variables in basil based on genetic parameters are still scarce. Blank et al. (2010) observed high broad-sense heritability for the essential oil content and yield and linalool content. The authors also detected low heritability for the leaves dry mass combined with dried inflorescences. Khan et al. (2012) studied *Ocimum* spp. genotypes and also recorded high broad-sense heritability (> 70 %) for the variables plant height, number of primary branches plant^{-1}, number of secondary branches plant^{-1}, leaf length, leaf width, number of inflorescences plant^{-1}, inflorescence length, days to maturity, and fresh herb yield plant^{-1}.

Therefore, this study aimed to evaluate the phenotypic and genotypic performance of basil hybrids and cultivars grown in four crop years in the municipality of São Cristóvão, state of Sergipe, Brazil.

MATERIAL AND METHODS

Localization, plant material, and experiment details

The four experiments were conducted in the summer, from December to February of the crop years of 2009/2010, 2010/2011, 2011/2012, and 2012/2013, at the "Campus Rural da UFS" Research Farm, Federal University of Sergipe (UFS), located in the municipality of São Cristóvão, state of Sergipe, Brazil. This region is located in the central part of the physiographic region of the Coast of the state of Sergipe, at 15 km from Aracaju (lat. 10° 55' 27" S; long. 37° 12' 01" W; alt. 46 m asl). The climate of the region is classified as As type (tropical rainy, with dry summer, according to the Köppen's climate classification), with an average annual temperature of 25.2°C (SANTOS et al. 2009).

Five hybrids ('Sweet Dani' x 'Maria Bonita', 'Genovese' x 'Maria Bonita', 'Cinnamon' x 'Maria Bonita', 'Sweet Dani' x 'Cinnamon', and 'Sweet Dani' x 'Genovese') and four parent cultivars ('Maria Bonita', 'Sweet Dani', 'Genovese', and 'Cinnamon') of basil were evaluated. The phenotypic characterization of the cultivars can be seen in Blank et al. (2004) and Pinto et al. (2018). 'Sweet Dani' and 'Genovese' were acquired from the company Richters, whereas 'Cinnamon' and 'Maria Bonita' were acquired from the companies Johnny's Selected Seeds and UFS, respectively. The five experimental hybrids were generated from artificial crosses between parents. Emasculation and pollination were performed as described by Blank et al. (2012).

Seedlings were generated in a protected environment with 50 % black shade screen and irrigation, in 162-cell polypropylene trays. The substrate was cattle manure, coconut coir dust, sand, and soil, at a 1:1:1:2 ratio, supplemented with 1 g of limestone and 6 g of Hortosafra® fertilizer (6 % N, 24 % P_2O_5, 12 % K_2O, 5.1 % Ca, 4.9 % S, 0.189 % Zn, 0.06 % B, and 0.09 % Mn) per liter of substrate. Seedlings were transplanted in December of the respective year when they exhibited three fully-expanded leaves.

Plowing, liming, and fertilization were performed according to the soil analysis. Liming was conducted in the experimental area, using 2 t ha^{-1} of limestone, applied thirty days before planting to increase the base saturation to 70 %. Conventional tillage was performed after liming by dividing the area into five 1.00 x 15 m seedbeds and adding 800 kg ha^{-1} of mono-ammonium phosphate (MAP), 300 kg ha^{-1} of potassium chloride (KCl), and 5 t ha^{-1} of cattle manure to the soil (PINTO et al., 2018).

The experimental design consisted of randomized blocks, with three replications. The three inner seedbeds composed the blocks. Each useful plot consisted of two rows with three plants, totaling six plants, spaced at 0.60 x 0.50 m. The two outer seedbeds were used as border rows with the commercial cultivar Maria Bonita, which was also planted at the ends of the three blocks, using one plant per row.

Crop management was performed according to Blank et al. (2004). Plants were drip-irrigated based on the crop's needs. Harvests were performed at sixty days after transplanting, in February of the respective year, upon full bloom of the plants of each plot. The six plants from each plot were cut at 20 cm from the soil surface.

Samples of leaves and the inflorescences from each plot were dried in a forced air circulation oven at 40º C for five days, to obtain the dry weight of the aerial part. The results are expressed as g plant^{-1}.

The following agronomic variables were evaluated: dry weight of the aerial part and essential oil content and yield. The essential oils had the contents of the following chemical compounds evaluated: linalool, 1,8-cineol, neral, geranial, and methyl cinnamate.

Essential oil distillation

The essential oils of dry leaves (samples of 50 g) with inflorescences from each plot were obtained by hydrodistillation, using a Clevenger apparatus for 140 min (Ehlert et al. 2006). The content was expressed in % (ml per 100 g of dry leaves). The essential oil yield was calculated by the following formula:

$$Yield\ in\ ml\ plant^{-1} = \frac{essential\ oil\ content\ (\%)}{100} \cdot weight\ of\ dry\ leaves\ per\ plant\ (g)$$

Essential oils analysis

The chemical composition of essential oils was analyzed by gas chromatography using a Gas Chromatography/Mass Spectrometry-Flame ionization detector (GC/MS-FID; QP2010 Ultra, Shimadzu Corporation, Kyoto, Japan) equipped with an AOC-20 i autosampler (Shimadzu). Separations were accomplished using an Rtx®-5MS Restek fused silica capillary column (5%-diphenyl–95%-dimethyl polysiloxane) of 30 m × 0.25 mm i.d., 0.25 μm film thickness, at a constant helium (99.999 %) flow rate of 1.2 ml min^{-1}. An injection volume of 0.5 μL (5 mg ml^{-1}) was employed, with a split ratio of 1:10. The oven temperature was programmed from 50 °C (isothermal for 1.5 min), with an increase of 4° C/min, to 200° C, then 10° C/min to 250° C, ending with a 5 min isothermal, at 250° C.

The MS and FID data were simultaneously acquired by employing a Detector Splitting System; the split flow ratio was 4:1 (MS:FID). A 0.62 m x 0.15 mm i.d. restrictor tube (capillary column) was used to connect the splitter to the MS detector; a 0.74 m x 0.22 mm i.d. restrictor tube was used to connect the splitter to the FID detector. MS data (total ion chromatogram, TIC) were acquired in the full scan mode (m/z of 40–350), at a scan rate of 0.3 scan/s, using the electron ionization (EI) with an electron energy of 70 eV. The injector temperature was 250° C, and the ion-source temperature was 250° C. The FID temperature was set to 250º C, and the gas supplies for the FID were hydrogen, air, and helium, at flow rates of 30, 300, and 30 ml min^{-1}, respectively. Quantification of each constituent was estimated by FID peak-area normalization (%). Compound concentrations were calculated from the GC peak areas and arranged in order of GC elution.

Individual compounds of the essential oil were identified by computerized matching of the acquired mass spectra with those stored in the NIST21, NIST107, and WILEY8 mass spectral library of the GC-MS data system. A mixture of hydrocarbons (C_9H_{20}–$C_{19}H_{40}$) was injected under these same conditions, and compounds were identified by comparing the spectra obtained with those of the equipment data bank. The Kovats index was also calculated for each compound, as previously described (Adams 2007). Retention indices were obtained using the equation proposed by Van Den Dool and Kratz (1963).

Statistical analysis

Data were subject to individual and joint analyses of variance (F tests), and means were clustered by the Scott-Knott test at a 5 % probability level, using the statistical software SISVAR®. The joint analysis of variance followed the model proposed by Vencovsky and Barriga (1992), considering the year effect as random and the population effect as fixed. The following mathematical model was used: $Y_{ij} = m + G_i + A_j + GA_{ij} + \varepsilon_{ij}$, where-in Y_{ij} is the mean phenotypic value of variable Y, measured in the genetic material i, in the year j; m is the overall parametric mean of the study data; G_i is the effect of the i^{th} population (fixed); A_j is the effect of the j^{th} year (random); GA_{ij} is the effect of the interaction between the i^{th} population and the j^{th} year (random); ε_{ij} is the standard error of the mean associated with the observation Y_{ij} (random).

The genotypic quadratic component $(\hat{\phi}_g)$ and residual variance $(\hat{\sigma}^2)$ of all variables studied were estimated from the expected mean squares. The phenotypic and genotypic correlation analyses were performed based on the Pearson's correlation coefficients (*r*). Phenotypic and genetic parameters, broad-sense heritability (h^2), coefficient of genetic variation (CV_g), coefficient of environmental variation (CV_e), and CV_g/CV_e ratio were also estimated, using the GENES® software.

$$\hat{\phi}_g = (MSG - MSR) / ar$$

$$\sigma^2 = MSR$$

$$h^2 = \left[\frac{\hat{\phi}_g}{(MSG/ar)}\right] \times 100$$

$$CV_g = \left(100\sqrt{\hat{\phi}_g}\right) / m$$

$$CV_e = \left(100\sqrt{\hat{\sigma}^2}\right) / m$$

Where-in *MSG* is the mean square of the genotype; *MSR* is the mean square of the residuals; *ar* is the number of replicates; and m is the overall experimental mean.

Heterosis (H) was estimated by the following equation:

H (%) = [(F_1 – mean of parents) / (mean of parents)] x 100

RESULTS AND DISCUSSION

The combined analysis of variance revealed the genetic variability between the means of the genotypes, which was calculated based on the different replications and the four years analyzed (Table 1).

The sources of variation (genotypes, environments, and genotype x environment interactions) were significant at the 1 % probability level, according to the F tests, for all variables. These results confirm the differences between genotypes for the variables analyzed in the years evaluated and the performance of the genotypes in the different years (Table 1). This result is expected when assessing a series of genotypes in an "experimental network" (Squilassi 2003).

Table 1. Summary of the combined analysis of variance of all variables, dry weight of the aerial part (DWA g plant^{-1}), essential oil content (OC %) and yield (OY ml plant^{-1}), 1,8-cineol (EUC %), linalool (LI %), neral (NER %), geranial (GER %), and methyl cinnamate (MC %), from four cultivars and five hybrids of basil (*Ocimum basilicum* L.) grown in four crop years.

FV	GL	Mean Square (MS)							
		DWA	OC	OY	CIN	LI	NER	GER	MC
Genotypes (G)	8	4369.38**	11.15**	6.98**	80.65**	7783.63**	1338.31**	2280.88 **	7735.56**
Years (A)	3	45814.13**	1.23**	38.67**	23.92**	61.22**	25.11**	8.17**	28.88**
G x A	24	2202.64**	0.69**	2.14**	9.06**	23.04**	11.66**	17.08**	21.09**
Block/Year	8	117.58*	0.34**	0.02^{ns}	1.11^{ns}	2.79^{ns}	2.83*	0.59^{ns}	0.37^{ns}
Error	64	50.37	0.09	0.02	0.57	2.37	1.38	0.74	0.56
Mean		57.77	2.64	1.56	4.87	43.56	6.92	8.58	16.64
CV (%)		12.29	11.27	9.32	15.51	3.53	16.96	9.99	4.50

**, *: significant at the 1 % and 5 % probability levels, respectively, according to the F test. ^{ns}: non-significant. CV: coefficient of variation.

In the test for the comparison of means, the yield of dry weight of aerial part showed the highest mean value in the hybrid 'Cinnamon' x 'Maria Bonita' (90.72 g plant^{-1}), which stood out from other genotypes in most years. This hybrid showed better performance than its parents, 'Cinnamon' and 'Maria Bonita', which are in the group with the lowest mean values of dry weight of aerial part, with 34.03 and 49.94 g plant^{-1}, respectively (Table 2). The dry mass values found for the genotypes during the years evaluated are higher than those reported by Blank et al. (2010), who found dry mass values ranging from 12.51 g plant^{-1} (genotype PI 197442-S3-Bulk 8) to 21.91 g plant^{-1} (cultivar Osmin Purple) and from 9.06 g plant^{-1} (genotype PI 197442-S3-Bulk 3) to 14.36 g plant^{-1} (cultivar Osmin Purple), in the crop years of 2004/05 and 2005/06, respectively. The better performance of the hybrids can be explained by the existence of heterosis (Table 2).

The highest essential oil content during the years evaluated was detected in the cultivar Maria Bonita, with 4.33 %. The best performance among hybrids was found in 'Sweet Dani' x 'Cinnamon' (3.79 %), which had lower essential oil content than cultivar Maria Bonita, although this hybrid was more stable during the evaluated years. Cultivar Sweet Dani showed the lowest essential oil content (1.46 %) (Table 2).

Table 2. Means and heterosis (H) of dry weight of aerial part, essential oil content, and essential oil yield of four cultivars and five hybrids of basil (*Ocimum basilicum* L.) grown in four crop years.

Genotypes	Crop years				Mean	H (%)
	2009/2010	2010/2011	2011/2012	2012/2013		
	Dry weight of aerial part (g plant^{-1})					
'Sweet Dani'	32.68 aB	51.27 fA	38.87 dB	32.68 cB	38.87 e	-
'Genovese'	22.64 bC	69.81 eA	37.45 dB	19.91 dC	37.45 e	-
'Cinnamon'	25.14 bB	47.69 fA	34.03 dB	29.27 cB	34.03 e	-
'Maria Bonita'	41.33 aB	88.82 dA	49.94 cB	19.66 dC	49.94 d	-
'Sweet Dani' x 'Genovese'	29.18 aC	135.68 cA	64.12 bB	27.51 cC	64.12 c	68.03
'Sweet Dani' x 'Maria Bonita'	26.28 bC	136.34 cA	62.79 bB	25.76 cC	62.79 c	41.40
'Cinnamon' x 'Maria Bonita'	30.25 aD	195.82 aA	90.72 aB	46.09 bC	90.72 a	116.08
'Genovese' x 'Maria Bonita'	21.76 bC	135.69 cA	73.98 bB	64.48 aB	73.98 b	69.31

'Sweet Dani' x 'Cinnamon'	10.65 cC	182.66 bA	67.99 bB	10.65 dC	67.99 c	86.53
Mean	26.66 D	115.98 A	57.77 B	30.67 C	57.77	
CV (%)	20.93	8.17	7.62	25.52	12.29	
			Essential oil content (%)			
'Sweet Dani'	1.22 eB	1.93 cA	1.46 dB	1.22 eB	1.46 f	-
'Genovese'	1.45 eB	1.50 cB	1.71 dB	2.17 dA	1.71 e	-
'Cinnamon'	1.89 dB	1.00 dC	1.74 dB	2.33 dA	1.74 e	-
'Maria Bonita'	3.18 bC	5.00 aA	4.33 aB	4.80 aA	4.33 a	-
'Sweet Dani' x 'Genovese'	2.03 dB	2.93 bA	2.49 cA	2.50 dA	2.49 d	57.10
'Sweet Dani' x 'Maria Bonita'	2.51 cA	3.20 bA	2.85 cA	2.83 cA	2.85 c	-1.55
'Cinnamon' x 'Maria Bonita'	3.27 bA	2.47 bB	2.91 cA	3.00 cA	2.91 c	-4.12
'Genovese' x 'Maria Bonita'	1.59 eB	2.73 bA	2.44 cA	3.00 cA	2.44 d	-19.21
'Sweet Dani' x 'Cinnamon'	4.22 aA	2.93 bB	3.79 bA	4.22 bA	3.79 b	136.88
Mean	2.37 C	2.63 B	2.64 B	2.90 A	2.64	
CV (%)	17.23	8.42	6.84	11.10	11.27	
			Essential oil yield (ml plant^{-1})			
'Sweet Dani'	0.39 cB	0.99 fA	0.59 cB	0.40 eB	0.59 f	-
'Genovese'	0.30 cB	1.02 fA	0.58 cB	0.42 eB	0.58 f	-
'Cinnamon'	0.46 cA	0.48 gA	0.54 cA	0.67 dA	0.54 f	-
'Maria Bonita'	1.30 aC	4.44 cA	2.23 aB	0.95 cD	2.23 b	-
'Sweet Dani' x 'Genovese'	0.55 cC	3.98 dA	1.74 bB	0.69 dC	1.74 e	197.44
'Sweet Dani' x 'Maria Bonita'	0.63 cC	4.38 cA	1.91 bB	0.73 dC	1.91 d	35.46
'Cinnamon' x 'Maria Bonita'	0.96 bD	4.83 bA	2.37 aB	1.33 bC	2.37 a	71.12
'Genovese' x 'Maria Bonita'	0.29 cC	3.72 eA	1.98 bB	1.93 aB	1.98 d	40.93
'Sweet Dani' x 'Cinnamon'	0.43 cC	5.36 aA	2.08 bB	0.44 eC	2.08 c	268.14
Mean	0.59 D	3.24 A	1.56 B	0.84 C	1.56	
CV (%)	20.42	4.51	9.55	19.31	9.32	

Means followed by the same lowercase letters in columns and uppercase letters in rows show no significant difference from each other, according to the Scott-Knott's test ($p \leq 0.05$). CV: coefficient of variation.

The hybrid 'Cinnamon' x 'Maria Bonita' had the highest mean essential oil yield (2.37 ml plant^{-1}) in all the years tested. The lowest values of essential oil yield were observed in cultivars 'Sweet Dani' (0.59 ml plant^{-1}), 'Genovese' (0.58 ml plant^{-1}), and 'Cinnamon' (0.54 ml plant^{-1}) (Table 2). The highest values of essential oil yield were observed in hybrids, and this result can be attributed to the heterosis or hybrid vigor (Tabela 2). A significant oscillation of the analyzed variables in relation to the years can be justified by differences in temperature, humidity, and rainfall during the cropping period in the years (Table 2).

The highest mean linalool content was reported for cultivar Maria Bonita (74.85 %) in all years evaluated. This result corroborates the findings of Blank et al. (2012). The genotype with the second highest mean linalool content in the years evaluated was 'Genovese' (67.32 %). Hybrids 'Sweet Dani' x 'Maria Bonita' (58.83 %) and 'Genovese' x 'Maria Bonita' (59.05 %) showed the best performance in the years evaluated. The only cultivar that did not contain any detectable linalool was 'Sweet Dani' (Table 3).

Table 3. Means and heterosis (H) of the linalool, 1,8-cineol, neral, geranial, and methyl cinnamate contents of four cultivars and five hybrids of basil (*Ocimum basilicum* L.) grown in four crop years.

Genotypes	**Crop years**				**Mean**	**H (%)**
	2009/2010	**2010/2011**	**2011/2012**	**2012/2013**		
			Linalool (%)			
'Sweet Dani'	0.00 hA	0.00 fA	0.00 hA	0.00 gA	0.00 h	-
'Genovese'	67.33 bB	63.60 bC	67.32 bB	71.05 bA	67.32 b	-
'Cinnamon'	27.25 fA	27.38 dA	25.99 fA	23.34 eB	25.99 f	-
'Maria Bonita'	75.40 aA	73.33 aA	75.51 aA	75.18 aA	74.85 a	-
'Sweet Dani' x 'Genovese'	51.25 dC	54.97 cB	55.05 dB	58.94 cA	55.05 d	63.55
'Sweet Dani' x 'Maria Bonita'	60.14 cA	56.29 cB	58.83 cA	60.07 cA	58.83 c	57.19

'Cinnamon' x 'Maria Bonita'	32.19 eC	28.16 dD	34.92 eB	44.42 dA	34.92 e	-30.74
'Genovese' x 'Maria Bonita'	60.24 cA	55.59 cB	59.05 cA	61.30 cA	59.04 c	-16.94
'Sweet Dani' x 'Cinnamon'	15.30 gA	17.42 eA	16.01 gA	15.30 fA	16.01 g	23.20
Mean	43.24 B	41.86 C	43.63 B	45.51 A	43.56	
CV (%)	4.57	3.62	2.41	3.24	3.53	
			1,8-Cineol (%)			
'Sweet Dani'	0.00 eA	0.00 dA	0.00 dA	0.00 bA	0.00 e	-
'Genovese'	10.43 aB	8.42 aC	15.99 aA	5.43 aD	10.07 a	-
'Cinnamon'	3.49 dB	1.69 cC	4.34 cB	6.44 aA	3.99 d	-
'Maria Bonita'	5.24 cA	4.82 bA	4.28 cA	5.15 aA	4.87 c	-
'Sweet Dani' x 'Genovese'	7.61 bA	4.00 bC	6.61 bA	5.47 aB	5.92 b	17.58
'Sweet Dani' x 'Maria Bonita'	4.23 dA	3.50 bA	3.96 cA	4.07 aA	3.94 d	61.81
'Cinnamon' x 'Maria Bonita'	5.38 cB	4.20 bB	6.85 bA	5.13 aB	5.39 b	21.67
'Genovese' x 'Maria Bonita'	7.06 bA	3.63 bB	4.22 cB	4.96 aB	4.97 c	-33.47
'Sweet Dani' x 'Cinnamon'	4.35 dB	3.28 bB	6.82 bA	4.35 aB	4.70 c	135.59
Mean	5.31 B	3.73 D	5.90 A	4.56 C	4.87	
CV (%)	13.21	13.99	13.27	20.93	15.51	
			Neral (%)			
'Sweet Dani'	31.68 aA	32.65 aA	31.72 aA	32.75 aA	32.20 a	-
'Genovese'	0.00 eA	0.00 cA	0.00 dA	0.00 dA	0.00 f	-
'Cinnamon'	0.00 eA	0.00 cA	0.00 dA	0.00 dA	0.00 f	-
'Maria Bonita'	0.00 eA	0.00 cA	0.00 dA	0.00 dA	0.00 f	-
'Sweet Dani' x 'Genovese'	6.02 cC	13.08 bA	8.16 bB	5.38 cC	8.16 d	-49.32
'Sweet Dani' x 'Maria Bonita'	11.73 bA	12.82 bA	9.08 bB	12.22 bA	11.46 b	-28.82
'Cinnamon' x 'Maria Bonita'	0.00 eA	0.00 cA	0.00 dA	0.00 dA	0.00 f	-*
'Genovese' x 'Maria Bonita'	3.01 dD	14.27 bA	8.26 bC	11.77 bB	9.33 c	-*
'Sweet Dani' x 'Cinnamon'	0.58 eA	0.88 cA	2.11 cA	0.90 dA	1.12 e	-93.04
Mean	5.89 C	8.19 A	6.59 B	7.00 B	6.92	
CV (%)	22.90	7.67	14.05	22.31	16.96	
			Geranial (%)			
'Sweet Dani'	41.40 aB	43.11 aA	42.00 aB	41.48 aB	42.00 a	-
'Genovese'	0.00 eA	0.00 eA	0.00 cA	0.00 dA	0.00 e	-
'Cinnamon'	0.00 eA	0.00 eA	0.00 cA	0.00 dA	0.00 e	-
'Maria Bonita'	0.00 eA	0.00 eA	0.00 cA	0.00 dA	0.00 e	-
'Sweet Dani' x 'Genovese'	8.56 cC	15.87 cA	10.68 bB	7.61 cC	10.68 c	-49.14
'Sweet Dani' x 'Maria Bonita'	15.97 bA	17.34 bA	11.50 bB	15.99 bA	15.20 b	-27.62
'Cinnamon' x 'Maria Bonita'	0.00 eA	0.00 eA	0.00 cA	0.00 dA	0.00 e	-*
'Genovese' x 'Maria Bonita'	4.35 dC	4.52 dC	10.34 bB	15.29 bA	8.63 d	-*
'Sweet Dani' x 'Cinnamon'	0.84 eA	0.57 eA	0.75 cA	0.84 dA	0.75 e	-96.43
Mean	7.91 B	9.05 A	8.36 B	9.02 A	8.58	
CV (%)	9.35	10.96	10.32	9.06	9.99	
			Methyl cinnamate (%)			
'Sweet Dani'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-
'Genovese'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-
'Cinnamon'	51.94 bA	47.17 bB	44.87 bC	46.70 bB	47.67 b	-
'Maria Bonita'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-
'Sweet Dani' x 'Genovese'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-*
'Sweet Dani' x 'Maria Bonita'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-*
'Cinnamon' x 'Maria Bonita'	47.36 cA	47.16 bA	41.93 cB	31.27 cC	41.93 c	75.92
'Genovese' x 'Maria Bonita'	0.00 dA	0.00 cA	0.00 dA	0.00 dA	0.00 d	-*
'Sweet Dani' x 'Cinnamon'	60.13 aA	60.20 aA	60.15 aA	60.13 aA	60.15 a	152.36
Mean	17.71 A	17.17 B	16.33 C	15.35 D	16.64	
CV (%)	3.83	5.34	2.80	5.58	4.50	

Means followed by the same lowercase letters in columns and uppercase letters in rows are not significantly different from each other, according to the Scott-Knott's test ($p \leq 0.05$). CV: coefficient of variation. -*: not possible to calculate because of division by zero.

Sweet Dani also had no 1,8-cineol content. Conversely, 'Genovese' displayed the highest percentage of 1,8-cineol (10.07 %). 'Cinnamon' x 'Maria Bonita' (5.39 %) and 'Sweet Dani' x 'Genovese' (5.92 %) showed the highest contents of 1,8-cineol among the hybrids (Table 3).

The highest percentages of neral were recorded in 'Sweet Dani' (32.20 %) and in the hybrid 'Sweet Dani' x 'Maria Bonita' (11.46 %). Neral was not detected in genotypes 'Genovese', 'Cinnamon', 'Maria Bonita', or 'Cinnamon' x 'Maria Bonita' (Table 3). Similar results were obtained for geranial (Table 3). Neral and geranial had similar results because together they form the citral molecule.

Methyl cinnamate was found in the essential oil from the genotypes 'Genovese', 'Maria Bonita', 'Sweet Dani', or the hybrids 'Sweet Dani' x 'Genovese', 'Genovese' x 'Maria Bonita', and 'Sweet Dani' x 'Maria Bonita'. The hybrid 'Sweet Dani x Cinnamon' showed a stable production over the years evaluated, with 60.15 % methyl cinnamate, which was higher than the level in its 'Cinnamon' parent (47.67 %) (Table 3).

All the evaluated variables showed genetic variances higher than the residual variances; the percentages of broad-sense heritability (h^2) were higher than 90 %; the coefficients of genetic variation (CV_g) were higher than 15 % and were higher than the coefficients of environmental variation (CV_e). A (CV_g/CV_e) ratio higher than one was also observed for the variables (Table 4).

Table 4. Genetic parameters of the combined analysis of variance for the variables dry weight of aerial part (DWA g plant^{-1}), essential oil content (OC %), essential oil yield (OY ml plant^{-1}), 1,8-cineol (CIN %), linalool (LI %), neral (NER %), geranial (GER %), and methyl cinnamate (MC %) of four cultivars and five hybrids of basil (*Ocimum basilicum* L.) grown in four crop years.

Parameters	DWA	OC	OY	CIN	LI	NER	GER	MC
$\hat{\phi}_g$	359.295	0.920	0.580	6.668	648.434	111.397	190.014	644.585
σ^2	57.842	0.116	0.021	0.632	2.416	1.539	0.720	0.539
h^2 % (mean)	98.676	98.956	99.695	99.217	99.969	99.885	99.968	99.993
CV_g (%)	32.813	36.391	48.889	53.004	58.459	152.549	160.570	152.576
CV_e (%)	13.166	12.947	9.372	16.313	3.568	17.933	9.883	4.413
CV_g/CV_e Ratio	2.492	2.811	5.216	3.249	16.384	8.507	16.247	34.573

The studied variables showed low genotypic correlation since no significant difference was detected, based on the Student's t-test between most variables during the four years evaluated (Table 5).

A strong and positive correlation ($r > 0.70$) was observed between dry weight of aerial part and essential oil yield in all years. A similar correlation was also observed between neral and geranial. The lowest value of significant correlation ($p < 0.05$) was detected between 1,8-cineol and neral, in 2010, and the correlation was negative and moderate ($r = -0.672$) (Table 5).

The strong correlation between dry weight of aerial part and essential oil yield might explain the similar performance of genotypes regarding those variables. That correlation predicts an increase in essential oil yield when the dry weight of aerial part increased during the years analyzed, which is of interest for the basil breeding program. Blank et al. (2010) observed a different profile in the variables when they were correlated. The authors reported a negative correlation ($r = -0.204$) between variables in the first experimental year, 2004/2005, and a correlation substantially greater than 1.000 in the last experimental year, 2005/2006.

The positive correlation values suggest that both variables benefit from or are hindered by the same causes of environmental variation. In turn, negative values indicate that the environment favors one variable over the other (Cruz 2005). The high correlation estimates facilitate the hybrid selection process towards meeting market demands, that is, they enable breeders to select or reduce the number of variables to be evaluated without the need for further measurements (Rodrigues et al. 2011). The maintenance of the correlation between variables may indicate the selection for these variables.

The different performances of the genotypes resulted from the parents since genetic variances, when compared to residual variances, exhibited high percentages of h^2 for all variables. This pattern caused a high correlation between the phenotypic and genotypic values and, therefore, the transmission of desirable characteristics to the hybrids.

Table 5. Genotypic correlations of the variables dry weight of aerial part (DWA), essential oil content (OC), essential oil yield (OY), 1,8-cineol (CIN), linalool (LI), neral (NER), geranial (GER), and methyl cinnamate (MC) of four cultivars and five hybrids of basil (*Ocimum basilicum* L.), in the crop years of 2009/2010, 2010/2011, 2011/2012, and 2012/2013.

Variables	OC (%)	OY (ml plant^{-1})	CIN (%)	LI (%)	NER (%)	GER (%)	MC (%)
				2009/2010			
DWA (g plant^{-1})	-0.190	0.709*	-0.236	0.292	0.285	0.269	-0.519
OC (%)		0.552	-0.061	-0.066	-0.476	-0.471	0.614
OY (ml plant^{-1})			-0.094	0.326	-0.260	-0.264	0.021
CIN (%)				0.731*	-0.672*	-0.666	-0.240
LI (%)					-0.509	-0.499	-0.551
NER (%)						1.002**	-0.405
GER (%)							-0.412
				2010/2011			
DWA (g plant^{-1})	0.343	0.884**	0.142	-0.006	-0.258	-0.317	0.404
OC (%)		0.742*	0.150	0.497	-0.096	-0.111	-0.281
OY (ml plant^{-1})			0.135	0.227	-0.244	-0.287	0.183
CIN (%)				0.735*	-0.605	-0.611	-0.213
LI (%)					-0.382	-0.456	-0.551
NER (%)						0.949**	-0.520
GER (%)							-0.450
				2011/2012			
DWA (g plant^{-1})	0.469	0.851**	-0.056	0.089	-0.222	-0.240	0.247
OC (%)		0.845**	-0.083	0.322	-0.456	-0.474	0.215
OY (ml plant^{-1})			-0.142	0.328	-0.343	-0.361	0.129
CIN (%)				0.444	-0.598	-0.594	0.030
LI (%)					-0.518	-0.501	-0.552
NER (%)						1.000**	-0.413
GER (%)							-0.435
				2012/2013			
DWA (g plant^{-1})	-0.248	0.871**	0.003	0.105	0.274	0.284	-0.267
OC (%)		0.256	0.421	0.365	-0.604	-0.605	0.278
OY (ml plant^{-1})			0.298	0.392	-0.094	-0.087	-0.173
CIN (%)				0.602	-0.955**	-0.945**	0.280
LI (%)					-0.469	-0.454	-0.563
NER (%)						1.005**	-0.436
GER (%)							-0.448

*,**: significant at the 5 % and 1 % probability levels, respectively, according to the Student's t-test.

The wide variability between genotypes may also be noted by the high percentages of CV_g since the higher this value, the higher the genetic variability (Silva et al. 2002). Furthermore, the superiority of CV_g over CV_e enabled maintaining the yield values for those variables.

Another parameter that reinforces variability is the (CV_g/CV_e) ratio, which is the fraction of total variance explained by the genotype (Silva et al. 2002, Vasconcelos et al. 2012). All variables exhibited values higher than 1 (Table 4), indicating a weak effect of the environment (Vencovsky and Barriga 1992), although the genotypes showed a significant genotype x environment interaction.

The high values of the genotypic coefficients of determination, combined with the high coefficients of genetic variation and (CV_g/CV_e) ratios, explain the success of the hybridization process, which may have resulted in the development of new cultivars adapted to the state of Sergipe. This process combined compounds present separately in the parents, which is of interest to the essential oils' market.

The hybrids had better performance, especially 'Cinnamon' x 'Maria Bonita', which showed the best performance for dry weight of aerial part (90.72 g plant^{-1}) and essential oil yield (2.37 ml plant^{-1}) and exhibited two main essential

oil compounds, methyl cinnamate (41.93 %) and linalool (34.92 %). The hybrid 'Sweet Dani' x 'Cinnamon' stood out from the other hybrids regarding its essential oil content (3.79 %), and it had methyl cinnamate (60.15 %) as its main compound, with contents higher than those detected in its parent, 'Cinnamon' (47.67 %). In addition, this hybrid exhibited 16.01 % of linalool, a compound absent in the parent 'Sweet Dani'. The hybrid 'Sweet Dani' x 'Maria Bonita' had linalool (58.83 %) as its main compound, but it also contained substantial levels of geranial (15.20 %) and neral (11.46 %), which are the components of citral and are absent in the parent 'Maria Bonita'.

The hybrid 'Cinnamon' x 'Maria Bonita' had the highest dry weight of aerial part (90.72 g plant^{-1}) and essential oil yield (2.37 ml plant^{-1}) and contained two main compounds, methyl cinnamate (41.93 %) and linalool (34.92 %). The hybrid 'Sweet Dani' x 'Cinnamon' contained linalool (16.01 %) and methyl cinnamate (60.15 %) as the main compounds. The main compounds of the hybrid 'Sweet Dani' x 'Maria Bonita' were linalool (58.83 %), geranial (15.20 %), and neral (11.46 %). All variables expressed high percentages of broad-sense heritability (> 90 %), coefficients of genetic variation (> 30 %), and ratios between genetic and environmental variation coefficients (> 2 %). The greatest genotypic correlation occurred between neral and geranial (r ranging from 0.949 to 1.005). Most of the variation found in the studied variables resulted from genetic variation.

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RESUMO: Este trabalho teve o objetivo de avaliar a performance fenotípica e genotípica de híbridos e cultivares de manjericão (*Ocimum basilicum* L.), cultivados em quatro anos agrícolas no município de São Cristóvão, Estado de Sergipe. Foram avaliados os caracteres: massa seca de parte aérea; teor de óleo essencial; rendimento de óleo essencial; linalol; 1,8-cineol; neral; geranial e (E)-cinamato de metila para cinco híbridos de manjericão ('Sweet Dani' x 'Maria Bonita', 'Genovese' x 'Maria Bonita', 'Cinnamon' x 'Maria Bonita', 'Sweet Dani' x 'Cinnamon' and 'Sweet Dani' x 'Genovese') e quatro cultivares ('Maria Bonita', 'Sweet Dani', 'Genovese' e 'Cinnamon'). Os óleos essenciais foram obtidos de folhas secas por hidrodestilação. A composição química dos óleos essenciais foi determinada por CG/EM-DIC. Foi realizado o agrupamento das médias e foram estimados parâmetros genéticos e fenotípicos. Linalol foi o composto majoritário do óleo essencial da maioria dos genótipos. Os híbridos 'Cinnamon' x 'Maria Bonita', 'Sweet Dani' x 'Cinnamon' e 'Sweet Dani' x 'Maria Bonita' apresentaram também outros compostos majoritários, (E)-cinamato de metila (41,93 %); (E)-cinamato de metila (60,15 %); geranial (15,20 %) e neral (11,46 %); respectivamente. As fontes de variação foram significativas no nível de probabilidade de 1% de acordo com os testes F para todas as variáveis, o que confirma as diferenças do desempenho dos genótipos nos diferentes anos. A maior parte da variação encontrada para os caracteres estudados é determinada pela variação genética dos genótipos.

PALAVRAS-CHAVE: *Ocimum basilicum*. Variabilidade genética. Óleo essencial. Constituintes químicos.

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