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PRODUCTIVE PERFORMANCE OF COCOA TREE (*Theobroma cacao* L.) HALF-SIB FAMILIES IN THE MUNICIPALITY OF OURO PRETO DO OESTE-RO, BRAZIL

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ABSTRACT: This study aimed to evaluate the agronomic behavior of 22 cacao half-sib families over 3 years, considering the yield components and resistance to the fruit borer and witches' broom. The characteristics were interpreted using analysis of variance with a split-plot model, with the effects of families on the plot and years on the subplot. Estimates of genetic parameters and the non-parametric Lin–Binns test were used to quantify adaptability and stability. The results indicated a high genetic variability among the evaluated progenies. The progenies AM 1090, AM 1066, AM 1070, AM 1077, and AM 1085 showed better adaptability and stability over the years in terms of yield. AM 1068, AM 1081, AM 1091, AM 1095, and AM 1097 exhibited better performance for witches' broom resistance, whereas AM 1077, AM 1081, AM 1085, AM 1088, and AM 1112 exhibited better performance for fruit borer resistance.

Keywords: Genetic breeding, *Moniliophthora perniciosa*, *Conotrachelus humeropictus*, Cocoa.

DESEMPENHO PRODUTIVO DE FAMÍLIAS DE MEIOS-IRMÃOS DE CACAUEIRO (*Theobroma cacao* L.) NO MUNICÍPIO DE OURO PRETO DO OESTE-RO, BRASIL

RESUMO: O objetivo desde trabalho compreendeu a avaliação do comportamento agronômico de 22 famílias de meios-irmãos de cacaueiro, considerando componentes de produção e resistência a coleobroca-dos-frutos e resistência à vassoura-de-bruxa. As características foram interpretadas utilizando a análise de variância em modelo de parcela subdividida, com os efeitos de famílias na parcela e anos na subparcela. Para quantificar a adaptabilidade e estabilidade foram

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interpretadas as estimativas de parâmetros genéticos e o teste não paramétrico de Lin Binns. Os resultados indicam elevada variabilidade genética entre as progênies avaliadas. As progênies AM 1090, AM 1066, AM 1070, AM 1077 e AM 1085 apresentaram melhor adaptabilidade e estabilidade ao longo dos anos para a produtividade. As progênies AM 1068, AM 1081, AM 1091, AM 1095 e AM 1097 tiveram melhores desempenhos para resistência à vassoura-de-bruxa, enquanto AM 1077, AM 1081, AM 1085, AM 1088 e AM 1112, para a resistência à coleobroca-dos-frutos.

Palavras-chave: Melhoramento genético, *Moniliophthora perniciosa*, *Conotrachelus humeropictus*, Cacau.

DESEMPEÑO PRODUCTIVO DE FAMILIAS DE MEDIO HERMANOS DE CACAUEIRO (*Theobroma cacao* L.) EN EL MUNICIPIO DE OURO PRETO DO OESTE-RO, BRASIL

RESUMEN: El objetivo comprendió la evaluación del comportamiento agronómico de 22 familias de medios hermanos de cacao, considerando componentes de producción y resistencia a la broca del fruta y resistencia a la escoba de bruja. Las características se interpretaron utilizando el análisis de varianza en un modelo de parcela dividida, con los efectos de las familias en la parcela y los años en la subparcela. Para cuantificar la adaptabilidad y la estabilidad, se interpretaron estimaciones de parámetros genéticos y la prueba no paramétrica de Lin Binns. Los resultados indican una alta variabilidad genética entre las progenies evaluadas. Las progenies AM 1090, AM 1066, AM 1070, AM 1077 y AM 1085 mostraron una mejor adaptabilidad y estabilidad a lo largo de los años para la productividad. Las progenies AM 1068, AM 1081, AM 1091, AM 1095 y AM 1097 tuvieron mejores rendimientos para la resistencia a la escoba de bruja, mientras que AM 1077, AM 1081, AM 1085, AM 1088 y AM 1112, para la resistencia a la broca del fruta.

PALABRAS CLAVE: Mejora genética, *Moniliophthora perniciosa*, *Conotrachelus humeropictus*, Cacao.

INTRODUCTION

Currently, cocoa (*Theobroma cacao* L.) is commercially exploited in six Brazilian states (Bahia, Pará, Rondônia, Espírito Santo, Amazonas, and Mato Grosso), totaling 274 thousand tons in 2017 (SILVA NETO et al., 2001; IBGE, 2017; MENDONÇA; PEDROZA FILHO, 2019). Between the 1970s and 1980s, Brazilian cocoa production reached over 470,000 tons per year, from more than 66,000 properties, most of which belonged to family farming (SILVA NETO et al., 2001; IBGE, 2017). However, the second half of the 1980s was marked by a sudden drop in cocoa production in Brazil owing to the emergence and spread of witches' broom disease (*Moniliophthora perniciosa*) in Bahia (EVANS; BARRETO, 1996; PAIM et al., 2006).

Witches’ broom, a main disease of cacao in Brazil resulting in up to 90% losses in production, mainly attacks the meristematic tissues causing characteristic symptoms of hormonal imbalance in the pathogen-host interaction. Infected tissues lose their apical dominance and undergo hypertrophy, resulting in the formation of brooms (EVANS; BARRETO, 1996; RESENDE et al., 2007). In addition to the witches' broom, other pests may affect cocoa production in the Brazilian Amazon, such as the fruit borer, caused by the infestation of *Conotrachelus humeropictus*, which, although less severe, can cause damage up to 50% of production. *Conotrachelus humeropictus* is an insect whose larvae form galleries in cacao fruits, causing damage that depreciates the product and causes losses in production (TREVISAN, 1989).

Among the measures to control the main cocoa pests, the use of resistant and high-yielding varieties is one of the most appropriate, as cultural, chemical, and biological controls have proven to be costly and in some cases, ineffective (PINTO; PIRES, 1998). In addition to pest resistance, other characteristics are considered for plant selection in breeding programs, mainly the components of dry seed production, estimated based on the total number of fruits harvested per plant and the weight of the wet seeds of the healthy fruits of the plant. In Brazil, the yield of cocoa in commercial plantations that are not genetically improved is approximately 300 kg ha^{-1} year^{-1}. However, with advances in breeding programs, clonal varieties with yields exceeding 2,200 kg ha^{-1} year^{-1} have been registered (ALMEIDA, 2017).

Genotype versus environment (G × E) interaction is one of the biggest challenges in cacao breeding, both for plant selection and cultivar recommendation, with breeders looking for stable genotypes with better productive performance (DIAS et al., 2003). The existence of genetic variability in a population is a basic condition for obtaining gains from the selection and structuring of breeding populations in half-sib families. This allows manipulation of the additive fraction of genotypic variance, promoting the attainment of gains with the selection of traits of low heritability. The progeny/families test is based on the selection of plants through the mean of the families and the deviation of the individual value to identify the individuals with the best performance.

For perennial crops with overlapping generations and a long reproductive cycle, as in the case of *T. cacao*, repeated assessments should be considered in each individual over time and manipulation of genotypic variance in plant selection. Genetic breeding programs conducted by the Executive Committee of the Cocoa Cultivation Plan (CEPLAC) in the State of Rondônia have evaluated the productive performance of cacao plants for several years in the region (CARVALHO et al., 2001; ALMEIDA et al., 2009; GUIMARÃES, 2016; ALMEIDA et al., 2016). In this context, as registered with SisGen under the number A9C58F9, the objective of this study was to quantify the agronomic behavior of cocoa half-sib families over 3 years, considering the main components of seed production and field resistance to witches' broom (*M. perniciosa*) and fruit borer (*C. humeropictus*), aiming to promote plant selection and the development of new commercial varieties.

MATERIAL AND METHODS

FIELD EXPERIMENT

The experiment was implanted in 2007 at the CEPLAC Experimental Station (10º42’30”S, 62º13’30”W), located in the municipality of Ouro Preto do Oeste, Rondônia. According to the Köppen classification, the climate in this region is Am. The annual mean temperature is 25.6 ºC, the annual mean relative humidity is 89%, and the total annual precipitation is greater than 2,200 mm (BARBOSA; NEVES, 1983). The soil is classified as eutroferric haplic Cambisol according to the socio-economic and ecological zoning of Rondônia.

The half-sib progeny test was setup as a split-plot design with three replications of eight plants per plot to evaluate the performance of 22 progenies compared to two controls, the hybrids IMC 67 × BE 8 and SCA 6 × ICS 1, identified with the abbreviations C1 and C2, respectively (Table 1).

Table 1. Identification of progenies and controls among commercial hybrids of known behavior, evaluated in the CEPLAC experimental field, in the municipality of Ouro Preto do Oeste, Rondônia, from 2012 to 2014.

Progeny Code	Progeny denomination/accession
1	AM 1066 (2)
2	AM 1067 (3)
3	AM 1068 (1)
4	AM 1069 (22)
5	AM 1070 (6)
6	AM 1071 (24)
7	AM 1072 (21)
8	AM 1073 (14)
9	AM 1077 (20)
10	AM 1079 (5)
11	AM 1081 (10)
12	AM 1085 (7)
13	AM 1088 (9)
14	AM 1090 (11)
15	AM 1091 (12)
16	AM 1092 (17)
17	AM 1093 (13)
18	AM 1095 (16)
19	AM 1097 (15)
20	AM 1101 (19)
21	AM 1112 (18)
22	AM 1114 (27)
23	IMC 67 X BE 8 (C1)
24	SCA 6 X ICS 1 (C2)

Source: Prepared by the authors.

Each plot consisted of eight plants distributed in two rows, spaced 3.0 m × 3.0 m. Two rows of cocoa trees were planted around the area that comprised the trial, serving as a border. Provisional shading was provided with banana trees at a 3.0 m × 3.0 m spacing.

Definitive shading consisted of a mixture of forest species and fruit trees that were already in the area, with variable spacing between plants. Fertilization and other cultural treatments, such as weeding, mowing, pruning, thinning, plant staking, and phytosanitary control, were carried out in accordance with the recommendations of CEPLAC.

AGRONOMIC PERFORMANCE

To evaluate the agronomic performance of the progenies, four characteristics were considered: a) total number of fruits harvested from the plant (TFH) in units (un.); b) weight of the wet seeds of the healthy fruits of the plant (WWSHF), in grams (g); c) total number of fruits with fruit borer on the plant (TFBR) in units (un.); and d) total number of fruits with witches' broom on the plant (TFWB), in units (un.).

In addition to these characteristics, the following were also evaluated: e) potential yield (PYiel), estimated by multiplying the total number of fruits harvested from the plant by the weight of the wet seeds of the healthy fruits of the plant (TFH × WWSHF), expressed in grams (g); f) resistance to witches' broom (Fbroom), estimated as the percentage (%) of fruits with witches' broom (TFWB/TFH); and resistance to fruit borer (Fborer), estimated as the percentage (%) of fruits with fruit borer (TFBR/TFH). To estimate the yield, expressed as the weight of dry seeds, in kg ha^{-1}, a characteristic that is of interest to the farmer, a rate of 38% was used as the mean conversion factor from wet cocoa to dry cocoa (PIRES et al., 2012). Yield components were measured at intervals of 30 to 60 days from 2012 to 2014, corresponding to the period from the 4th to the 6th year of planting.

STATISTICAL ANALYSES

The characteristics evaluated were subjected to analysis of variance in a split-plot model, allocating blocks and families in the plot, and years of production in the subplot, according to the model (DIAS; BARROS, 2009):

$$Y_{ijk} = u + f_i + b_j + (fb)_{ij} + a_k + (fa)_{ik} + \varepsilon_{ijk} \quad (1)$$

where:

Y_{ijk} = value observed in the plot of the i-th family, in the j-th block and k-th year;

u = overall mean, considered as a fixed effect;

f_i = effect of the i-th family, considered as a fixed effect;

b_j = effect of the j-th block, considered as a fixed effect;

$(fb)_{ij}$ = represents the experimental error at the plot level, as a random effect;

a_k = represents the effect of years, considered as a fixed effect;

$(fa)_{ik}$ = effect of the interaction between families and years, considered as random;

ε_{ijk} = experimental error at subplot level, considered as random.

Production means were grouped using the Scott–Knott test (1974) at a 5% probability. All analyses were performed using Genes software. Based on this model, the genetic parameters for heritability (h^2) and repeatability (p) were estimated, and subsequently, the estimates of genotypic and phenotypic variance decompositions for the respective estimates (CRUZ, 2008).

Heritability, defined as the ratio between the genetic and phenotypic variances, is considered low when estimates are lower than 0.30. In contrast, repeatability corresponds to the correlation between measurements taken on the same individual, whose assessments were repeated over time. The value of the repeatability coefficient (p) varies from 0 to 1, and values equal to or less than 0.30 are considered as low repeatability (RESENDE, 2002).

The adaptability analysis was performed with the production averages of the three replications, considering each production year as an environment. The stability and adaptability statistic adopted was Pi proposed by Lin and Binns (1988), defined as

$$P_i = \frac{\sum_{j=1}^{n}(Y_{ij} - M_j)^2}{2n}$$

(2)

where:

P_i = estimation of stability and adaptability of family i;

Y_{ij} = yield of family i in year of production j;

M_j = maximum response observed among all families in production year j;

n = number of years of production.

Order number 1 was assigned to the progeny with the lowest estimate of the respective parameter, and so on, until order number g was assigned to the progeny with the highest estimate of this estimate.

RESULTS AND DISCUSSION

PRODUCTION COMPONENTS ANALYSIS

The results of the analysis of variance indicated that the effects of progenies and years were significant at 1% probability for all traits evaluated, indicating the existence of genetic variability among the progenies. Specifically, the effect of the families × years interaction was significant at 5% probability only for potential productivity, which indicates that families showed changes in their relative performance over time (Table 2).

Regarding the performance of the progenies, the PYiel presented a general average of 1,596.84 g wet seeds plant^{-1}, which is equivalent to a yield of 674 kg dry seeds ha^{-1}, if 1,111 plants are planted per hectare (ALMEIDA et al., 2016). This yield estimate is above the average for commercial crops in Brazil; however, higher yields have been reported in plantations in the states of Bahia (PIRES, 2003) and Rondônia (OKABE et al., 2004, ALMEIDA et al., 2009; GUIMARÃES, 2016; ALMEIDA et al., 2016). Pires (2003) observed an average dry seed weight per hectare of 893 kg under the conditions of the Cocoa Research Center (CEPEC) in Ilhéus-BA. Okabe et al. (2004) evaluated the performance of 48 cacao clones from different genetic origins and found that the average dry seed weight per hectare was 1,195 kg.

Table 2. F-test estimates of analysis of variance (ANOVA) of yield and resistance components in the field of 22 cocoa progenies and two controls evaluated in the CEPLAC experimental field located in the municipality of Ouro Preto do Oeste, Rondônia, from 2012 to 2014.

SV	DF	TFH	PYiel	Fborer	Fbroom
Blocks	2				
Progenies	23	1.74*	1.72*	1.89*	1.73*
Error A	46				
Years	2	6.01**	7.78**	146.02**	58.23**
P x Y Interaction	46	1.38^{NS}	1.61*	1.32^{NS}	1.40^{NS}
Error b	96				
TOTAL	215				
12 months mean		15.0	1,567.9	9.7	3.1
24 months mean		12.7	1,374.0	10.3	4.4
36 months mean		16.6	1,848.6	34.5	13.3
Overall mean		**14.80**	**1,596.84**	**18.17**	**6.95**

**, Significant at 1% probability; *, significant at 5% probability; NS, not significant; TFH, total harvested fruits; PYiel, potential yield; Fborer, Percentage of bored fruits; Fbroom, percentage of fruits with witches' broom.
Source: Prepared by the authors

Almeida et al. (2009), reported 1,890 g wet cocoa plant^{-1}, when evaluating the agronomic behavior of 140 accessions of cocoa from different origins. Guimarães (2016) reported average productivity as 798 kg dry seeds ha^{-1}, when evaluating the genetic diversity in the Active Germplasm Bank of the CEPLAC Experimental Station in Ouro Preto do Oeste-RO. Finally, Almeida et al. (2016), when evaluating the agronomic behavior of cacao clones, also in Ouro Preto do Oeste-

RO, reported that the general mean yield was 816 kg dry seeds ha^{-1}.

Regarding resistance in the field, an increase in pest and disease infestations was observed over the years, with a general average of 18.17% for Fborer and 6.95% for Fbroom. These results indicate higher infestation in relation to that observed by Pires (2003) in Bahia and Almeida et al. (2009) in Rondônia, but lower than that reported by Okabe et al. (2004). Pires (2003) observed that approximately 59% of the fruits presented witches' broom for the 50 best clones evaluated in their work. Almeida et al. (2009) found that, as a general average for all accessions evaluated, 43.74% of fruits had witches' broom and 30.06% of fruits had fruit borers. Okabe et al. (2004) obtained mean values of 5.34% and 7.71% for the percentage of fruits with borers and witches' broom, respectively.

Despite the increase in infestation over the years, of both the witches' broom and borer, no significant difference was observed in the Progenies × Years (P × Y) interaction. This result indicates that resistant progenies showed a tendency to maintain their behavior over time. Although this result is not common in the evaluation of the cacao tree over time (CARVALHO et al., 2001), other studies have already reported the absence of the P × Y interaction for both the incidence of witches' broom and attack by the fruit borer (DIAS; KAGEYAMA, 1998).

The existence of genetic variability among progenies indicates the possibility of obtaining gains with selection. The success of genetic breeding depends on the accuracy of selection, which is based on the estimation of variance components and prediction of genetic values, defined as unknown random variables that are estimated using biometric models suitable for the genetic evaluation of selected candidates (FRANCISCO NETO, 2008). In this model, the genetic progress to be obtained depends on the selection differential and estimates of the genetic components.

Among the most important genetic parameters for the interpretation of selection efficiency, the coefficient of variation, heritability, and repeatability of traits stand out (RESENDE, 2002). The coefficient of variation is the relationship between the mean and mean square of the residue, which depends on both the experimental conditions and the nature of the characteristic. The estimates of the values of the coefficient of experimental variation of the characteristics TFH (45.5%) and PYiel (44.5%) were comparable with the estimates obtained in Bahia (PIRES, 2003), Rondônia (CARVALHO et al., 2001; OKABE et al., 2004), and Ghana (OFORI et al., 2016), ranging from 23% to 58% for TFH and from 25.3% to 78.56% for PYiel. This is different from the estimates associated with the Fborer and Fbroom characteristics, which indicate lower accuracy in the evaluation of these characteristics.

Estimates of h^2 can present variable magnitudes according to the experimental conditions of the environment and studied characteristics. Higher values are found for single-inheritance characteristics, whereas quantitative traits tend to have lower magnitudes (RESENDE, 2002). The trait that presented the highest heritability estimate was TFH, followed by PYiel, Fborer, and Fbroom (Table 3).

The heritability estimate for the TFH trait was 0.43, which means that approximately 43% of the variation in this trait was explained by the genetic variance between the progenies. Similar results were reported by Mustiga et al. (2018), who observed an heritability estimate of 0.42 for TFH in the evaluation of 34 cocoa progenies in Costa Rica.

Table 3. Estimates of the genetic parameters of yield and resistance components in the field of 22 cocoa progenies and two controls evaluated in the CEPLAC experimental field located in the municipality of Ouro Preto do Oeste, Rondônia, from 2012 to 2014.

Genetic parameters	TFH	PYiel	Fborer	Fbroom
Parcel variance component	7.8	8,1715.4	9.7	2.4
Quadratic component of the subplot	3.2	4,9619.6	198.9	30.3
Variance component of the interaction	2.8	44,377.7	5.3	2.5
Average heritability (h^2)	42.7	41.0	32.9	25.3
Repeatability (*p*)	49.0	53.1	37.1	29.1
Parcel variation coefficient	45.5	44.5	73.4	114.8
Subplot variation coefficient	38.9	35.8	47.6	74.9

TFH, total harvested fruits; PYiel, potential yield; Fborer, percentage of bored fruits; Fbroom, percentage of fruits with witches' broom.
Source: Prepared by the authors.

Francisco Neto (2008), Ofori et al. (2016), and Wuriandani et al. (2018) obtained lower estimates for this characteristic than those found in this study. Quantifying the genetic progress with the selection of hybrid cacao trees in the Brazilian Amazon, Francisco Neto (2008) observed a heritability estimate of 0.20 for the TFH trait. Ofori et al. (2016) observed a heritability estimate of 0.14 for TFH when evaluating the performance of 116 cocoa clones introduced in Ghana during different periods. Wuriandani et al. (2018) reported heritability coefficient estimates of less than 1% for TFH when analyzing genetic diversity and the influence of season on the quality of cocoa beans in Indonesia.

For PYiel, the estimated heritability was 0.41. Similar results have been reported by DuVal et al. (2017) and Mustiga et al. (2018). DuVal et al. (2017) evaluated the genetic parameters in four cacao progenies in Bahia and found a heritability coefficient of 0.37 for this trait. Mustiga et al. (2018) reported an estimate of 0.57, whereas Ofori et al. (2016) and Wuriandani et al. (2018) reported heritability coefficients of 0.18 and 0.24, respectively.

Regarding Fborer and Fbroom, which quantify resistance in the field, heritability estimates were 0.33 and

0.25, respectively. These genetic parameters indicate that there is a possibility of selecting progenies with increased resistance, as some of the phenotypic variability is explained by genotypic variation. These results are superior to those found by DuVal et al. (2017) and Mustiga et al. (2018) for field resistance to witches' broom, as they reported heritability coefficients of 0.16 and 0.15, respectively.

In perennial plants, such as cocoa, despite the predominance of the genetic component in the expression of these characteristics, the same genotype may show differences in performance from one year to the next owing to the action of the environment (PETEK et al., 2009). The repeatability coefficient for the TFH (0.49) and PYiel (0.53) traits can be considered medium, indicating a tendency of the progenies to maintain their behavior over time (Table 3). Similar results were obtained by Almeida et al. (2001), with values ranging between 0.46 and 0.80 for the total harvested fruits. However, the repeatability estimates of the Fborer and Fbroom characteristics were considered low (Table 3).

According to Cruz (2008), the non-parametric methodology of Lin and Binns is distinguished by its ease of interpretation, and by enabling the classification of the performance of genotypes in environments (Table 4).

The control SCA 6 × ICS 1 (C2) showed good performance in the tests, with the second highest Pi for TFH (21.6 fruits per plant) and the highest Pi for PYiel (2,448 g wet seed plant^{-1}) (Table 4), which corresponds to an average yield of 1,033 kg dry seeds ha^{-1}. Carvalho et al. (2001) and Fonseca et al. (2008) found similar results for the high performance of hybrid SCA 6 × ICS 1 (C2). Carvalho et al. (2001) reported 49.40 for TFH and 1,590 g for PYiel, corresponding to productivity of 671.27 kg ha^{-1}. Fonseca et al. (2008) reported a yield of 1,702 kg ha^{-1}.

The hybrid IMC 67 × BE 8 (C1) exhibited a lower productive performance, surpassed by the progenies under evaluation, having been ranked 19th for the total number of harvested fruits and 16th for seed production, with a registered mean of 1,359 g wet seeds plant^{-1}, corresponding to a yield of 574 kg dry seeds ha^{-1}. The low yield of this hybrid was also recorded by Carvalho et al. (2001), who reported a yield of 342 kg ha^{-1}. Unlike the result of the present study, Fonseca et al. (2008) found a higher yield for the hybrid IMC 67 × BE 8 (C1), recording approximately 1,836 kg ha^{-1}.

Expressive genetic variability was observed in the productive performance of the progenies that were grouped into five different groups according to the Scott–Knott grouping test of means at 5% probability (Table 4).

The progenies AM 1090 and AM 1066 had lower Pi indexes, were ranked as more stable for seed productivity, and were ordered in the 1st (20.8 fruits per plant) and 3rd position (21.2 fruits per plant) of higher fruit production and in the 3rd and 2nd positions of higher productivity, respectively. The AM 1070, AM 1077, and AM 1085 progenies also stood out for their good ordering according to the Lin and Binns criterion (Table 4), with values ranging between 18.8 and 21.2 for TFH and 1,885 g and 2,368 g for PYiel. These results indicate a mean yield range of 796 kg ha^{-1} and 1,000 kg dry seeds ha^{-1}, respectively.

Carvalho et al. (2001), when evaluating cocoa hybrids with higher yield and seed quality in the edaphoclimatic conditions of the state of Rondônia, reported a range of variation from 21.07 to 49.40 for TFH and from 350 g to 1,590 g for PYiel. Okabe et al. (2004) reported a range of 16.3 to 111 for TFH and from 872.2 g to 5,320.4 g for PYiel. Almeida et al. (2009) reported ranges from 70.6 to 108.1 for TFH and from 250 g to 4,510 g for PYiel. Ofori et al. (2016) evaluated the genetic variation of 116 cocoa clones introduced in Ghana and found values ranging from 19 to 57 for TFH and 183 kg ha^{-1} to 952 kg ha^{-1} for yield (dry seeds). Almeida et al. (2016) highlighted a range of 4.89 to 45.53 for TFH and from 493.8 g to 3,234.8 g for PYiel.

Table 4. Productive performance of 22 cocoa progenies and two controls evaluated in the CEPLAC experimental field, located in the municipality of Ouro Preto do Oeste, Rondônia, from 2012 to 2014.

Progenies	Total fruits harvested (TFH) plant^{-1}					Yield (TFH*WWSHF) plant^{-1}				
	2012	2013	2014	Mean	Pi	2012	2013	2014	Mean	Pi
AM 1066 (2)	15.5Bb	18.3Ba	29.8Aa	21.2	3	1,657Bb	2,132Ba	3,313Aa	2,368	2
AM 1067 (3)	18.5Ab	8.4Bd	14.8Ac	13.9	17	1,508Ab	724Ac	1,541Ac	1,258	19
AM 1068 (1)	11.6Ac	8.1Ad	11.6Ad	10.4	20	1,247Ac	852Ac	1,227Ad	1,109	21
AM 1069 (22)	7.5Ad	7.9Ad	7.3Ae	7.6	23	848Ac	918Ac	713Ae	826	23
AM 1070 (6)	18.8Ab	20.4Aa	19Ab	19.4	6	1,935Aa	2,092Aa	2,105Ac	2,044	5
AM 1071 (24)	9.1Bd	10.5Bc	23Ab	14.2	14	853Bc	986Bc	2,055Ac	1,298	15
AM 1072 (21)	22.4Aa	15.5Bb	13.9Bc	17.3	8	2,446Aa	1,643Ab	1,567Ac	1,885	10
AM 1073 (14)	12.1Ac	12.2Ac	12Ad	12.1	18	1,294Ac	1,177Ac	1,376Ad	1,282	18
AM 1077 (20)	18Ab	20.7Aa	20Ab	19.6	4	1,655Ab	1,988Aa	2,012Ac	1,885	6
AM 1079 (5)	9.9Bd	10.3Bc	20.5Ab	13.6	15	983Bc	1,147Bc	2,380Ab	1,503	14
AM 1081 (10)	21.1Aa	14.8Bb	11.9Bd	15.9	16	1,677Ab	1,376Ac	1,197Ad	1,417	17
AM 1085 (7)	21.5Aa	13.2Bc	21.7Ab	18.8	5	2,414Aa	1,400Bc	2,369Ab	2,061	4
AM 1088 (9)	21.3Aa	14.7Bb	14.8Bc	16.9	7	2,058Aa	1,510Ab	1,631Ac	1,733	11
AM 1090 (11)	19.6Bb	16.5Bb	26.2Aa	20.8	1	2,062Ba	1,621Bb	2,785Ab	2,156	3
AM 1091 (12)	3.9Ae	7Ad	6.4Ae	5.8	24	495Ac	976Ac	886Ae	786	24
AM 1092 (17)	8.5Ad	7.3Ad	13.5Ac	9.8	21	1,011Ac	877Ac	1,670Ac	1,186	20
AM 1093 (13)	8.8Bd	12Bc	22.5Ab	14.4	11	999Bc	1,555Bb	2,714Ab	1,756	8
AM 1095 (16)	19.1Ab	9.6Bd	16.2Ac	15	12	2,077Aa	989Bc	1,748Ac	1,605	13
AM 1097 (15)	13.9Ac	16.7Ab	14.5Ac	15	13	1,721Ab	1,919Aa	1,877Ac	1,839	7
AM 1101 (19)	18.3Ab	11.6Ac	16.2Ac	15.4	9	1,933Aa	1,310Ac	1,722Ac	1,655	12
AM 1112 (18)	18.9Ab	12.3Ac	15.4Ac	15.5	10	1,887Aa	1,404Ac	1,839Ac	1,710	9
AM 1114 (27)	12.9Ac	8Ad	8.8Ae	9.9	22	1,488Ab	1,024Ac	953Ae	1,155	22
IMC 67 x BE 8 (C1)	13.2Ac	8.8Ad	11.7Ad	11.2	19	1,575Ab	1,160Ac	1,341Ad	1,359	16
SCA 6 x ICS 1 (C2)	16.6Bb	20.6Ba	27.5Aa	21.6	2	1,807Bb	2,195Ba	3,343Aa	2,448	1
Mean	15	12.7	16.6	14.8		1,567.9	1,374	1,848.6	1,596.8	
Maximum	22.4	20.7	29.8	21.6		2,446.1	2,194.9	3,342.9	2,448.4	
Minimum	3.9	7	6.4	5.8		494.6	724.3	712.9	785.5	

Note: Capital letters represent differences between years, whereas lowercase letters represent differences between progenies. **TFH**, total fruits harvested; **WWSHF**, weight of wet seeds of healthy fruits of the plant.
Source: Prepared by the authors.

FIELD RESISTANCE COMPONENTS ANALYSIS

The results for the resistance to fruit borers, calculated by means of the average percentage of fruits plant^{-1} year^{-1}, infested by *C. humeropictus*, presented a significant difference (*P* < 0.05), according to the Scott–Knott test, highlighting four groups (Table 5). The values of this characteristic ranged from 11% to 36% of bored fruits per plant. The progenies with the least propensity to infestation were AM 1081, AM 1088, AM 1112, AM 1077, AM 1085, and AM 1097, with means between 11% and 15% of bored fruits per plant and good ordering according to the Lin and Binns criterion. The lowest repeatability estimates for these traits indicate the impossibility of selecting progenies with stable behavior over time. Significant differences (*P* > 0.05) were also observed in the Scott–Knott test for the incidence of witches' broom, with the formation of four distinct groups (Table 5).

The values varied from 1.9% to 16.8% of infested fruits per plant, with the best performance presented by the progenies AM 1068, AM 1091, AM 1081, AM 1095, AM 1097, AM 1066, AM 1067, AM 1069, AM 1070, AM 1073, AM 1077, AM 1079, AM 1085, AM 1088, AM 1090, AM 1092, AM 1093, AM 1101, AM 1112, and AM 1114, with values ranging between 1.9% and 9.9% of fruits infested per plant, considering a limit lower than 10% of infestation as ideal for breeding programs (OKABE et al., 2004).

The results of field resistance to *C. humeropictus* were lower than those reported by Okabe et al. (2004), but higher than those reported by Almeida et al. (2009) and Almeida et al. (2016). Okabe et al. (2004) reported an incidence range of 1.18% to 14.97% of the harvested fruits for *C. humeropictus*, and in the 10 best clones, incidence ranged from 1.18% to 5.18%. Almeida et al. (2009) highlighted a fruit borer infestation range of 2.9% to 27.6% of the total number of fruits harvested per plant, with the 10 best performances ranging from 2.9% to 5.2%. Almeida et al. (2016) observed a range of 21.57% to 48.95% of fruits with borer fruits per plant.

Table 5. Occurrence in the field of the cacao borer (*Conotrachelus humeropictus*) and witches' broom (*Moniliophthora perniciosa*) in 22 cacao progenies and two controls evaluated in the CEPLAC experimental field, located in the municipality of Ouro Preto do Oeste, Rondônia, in the period from 2012 to 2014.

Progenies	Fruit with fruit borer % (TFBR)					Fruit with witches' broom % (TFWB)				
	2012	2013	2014	Mean	Pi	2012	2013	2014	Mean	Pi
AM 1066 (2)	12Bb	16Ba	38Ab	22	21	3.7Ba	3Bc	17.1Ab	7.9	19
AM 1067 (3)	15Bb	10Bb	32Ac	19	18	1.7Ba	1.5Bc	15Ab	6.1	10
AM 1068 (1)	5Bc	4Bb	34Ac	15	8	4.2Aa	0.3Ac	1.2Ad	1.9	1
AM 1069 (22)	14Bb	4Bb	28Ad	15	12	0.9Ba	0.6Bc	17.4Ab	6.3	11
AM 1070 (6)	10Bb	12Ba	52Aa	24	20	4.1Aa	6.3Ac	12.3Ac	7.6	14
AM 1071 (24)	17Bb	10Bb	41Ab	23	23	5.8Ca	15.3Ba	29.4Aa	16.8	24
AM 1072 (21)	7Bc	14Ba	37Ab	19	14	10.2Aa	8.3Ab	14.8Ab	11.1	21
AM 1073 (14)	13Bb	5Bb	35Ac	18	17	1.5Ba	5.6Bc	14Ab	7	15
AM 1077 (20)	4Bc	9Bb	27Ad	14	4	3.4Aa	2.8Ac	8.8Ac	5	7
AM 1079 (5)	7Bc	15Ba	35Ac	19	13	1.8Ba	4Bc	16.5Ab	7.4	16
AM 1081 (10)	3Bc	6Bb	26Ad	12	1	1.7Ba	0.6Bc	8.9Ac	3.7	4
AM 1085 (7)	2Bc	9Bb	32Ac	14	5	2.3Ba	4.5Bc	13.4Ab	6.7	12
AM 1088 (9)	1Bc	5Bb	31Ac	12	2	1.5Ba	3.9Bc	11.7Ac	5.7	8
AM 1090 (11)	6Bc	15Ba	33Ac	18	11	3.9Ba	3.3Bc	17.6Ab	8.3	20
AM 1091 (12)	12Bb	6Bb	36Ac	18	16	0Aa	3.9Ac	6.1Ad	3.4	3
AM 1092 (17)	14Bb	16Ba	42Ab	24	22	3.8Ba	3.3Bc	20.9Ab	9.3	22
AM 1093 (13)	42Aa	17Ba	49Aa	36	24	1Ca	9.2Bb	19.6Ab	9.9	23
AM 1095 (16)	3Cc	15Ba	31Ac	16	9	1.9Aa	2.7Ac	8.1Ac	4.2	5
AM 1097 (15)	1Bc	11Bb	33Ac	15	6	3Aa	5.6Ac	6.5Ad	5	6
AM 1101 (19)	5Cc	22Ba	40Ab	23	15	2.2Ba	4.9Bc	11.9Ac	6.3	9
AM 1112 (18)	6Bc	4Bb	24Ad	11	3	2.5Ba	2.3Bc	18.4Ab	7.7	18
AM 1114 (27)	6Bc	7Bb	28Ad	14	7	6.6Aa	9.2Ab	11.6Ac	9.1	17
IMC 67 x BE 8 (C1)	15Ab	11Ab	20Ad	15	10	3.2Ba	2Bc	15.1Ab	6.8	13
SCA 6 x ICS 1 (C2)	12Bb	5Bb	45Aa	21	19	3.4Aa	3.6Ac	3.3Ad	3.4	2
Mean	9.7	10.3	34.5	18.2		3.1	4.4	13.3	6.9	
Maximum	41.9	22.1	51.5	36		10.2	15.3	29.4	16.8	
Minimum	1.1	3.9	19.8	11.5		0	0.3	1.2	1.9	

Note: Capital letters represent differences between years, whereas lowercase letters represent differences between progenies. TFBR, total fruit with fruit borer; TFWB, total fruit with witches' broom.
Source: Prepared by the authors.

These results also highlight the susceptibility of the hybrids IMC 67 × BE 8 and SCA 6 × ICS 1 to fruit beetles, with an average of 15% and

21% of fruits with borers, respectively, although this does not mean the total loss of the seeds. These performances are superior to those reported by Carvalho et al. (2001) and Almeida et al. (2009), and relatively close to those of Okabe et al. (2004). Carvalho et al. (2001) highlighted the range of witches' broom infestation from 45.68% to 69.71% of total fruits harvested plant^{-1} year^{-1}, including the hybrids IMC 67 × BE 8 (55.63%) and SCA 6 × ICS 1 (45.68%).

Almeida et al. (2009) highlighted the range of infestation by witches' broom from 4.1% to 40.7% of the total number of fruits harvested per plant, with the best performances being those with ranges from 4.1% to 9.9%. Okabe et al. (2004) found that the range varied from 3.21% to 27.06%, therefore closer to the performance found in this study.

CONCLUSION

Half-sib progenies have high genetic variability associated with selection accuracy, which promotes plant selection. The progenies AM 1090, AM 1066, AM 1070, AM 1077, and AM 1085 stood out in terms of productivity, whereas the progenies AM 1077, AM 1081, AM 1085, AM 1088, and AM 1112 showed greater resistance to *C. humeropictus* infestation. The progenies AM 1068, AM 1081, AM 1091, AM 1095, and AM 1097, in contrast, showed better performance in terms of infection by *M. perniciosa*.

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