Hybrid cocoa tree adaptability and yield temporal stability in Rondônia State, Brazil

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ABSTRACT

Hybrid cocoa tree (*Theobroma cacao L.*) adaptability and yield temporal stability were studied to screen agronomically superior varieties for yield, bean quality and resistance to witches' broom under the ecological conditions of Ouro Preto do Oeste County, Rondônia State, Brazil. Assessments were based on yield component measurements evaluated at maturity in a randomized complete block experiment. Additionally, the possibility of early hybrid selection, at the initial fructification phase, was investigated. For this, the results obtained from both periods was compared. At maturity, the SCA 6 x ICS 1, PA 150 x SIC 328 and IMC 67 x BE 8 hybrids were superior in the simultaneous analysis of total number of healthy fruits (TNHF), total weight of fresh beans (TWFB) and mean weight of fresh beans per fruit (MWFBF). Using Eberhart and Russell's methodology, PA 150 x SIC 328 had general adaptability and highly predictable performance for TNHF. The SCA 6 x ICS 1 hybrid also had general adaptability, in spite of indicated low predictability. The IMC 67 x BE 8 cross was adapted to unfavorable environments and had high predictability for TNHF. The SCA 6 x ICS 1 and PA 150 x SIC 328 hybrids behaved similarly for TWFB, showing adaptability to favorable environments and high predictability. IMC 67 x BE 8 showed general adaptability and high predictability for this trait. The three hybrids showed general adaptability and high predictability for MWFBF. On the base of mean performance (or P_i values of Lin and Binn' methodology), hybrid selection was also successful using measurements taken at the initial fructification phase. On the other hand, the Eberhart and Russel's adaptability and stability parameters depended on the period evaluated.

KEY WORDS: Genetic breeding, *Theobroma cacao*, yield component.

INTRODUCTION

Atanda and Jacob (1975) stated that cacao (*Theobroma cacao* L.) tree cultivar assessments should focus on the industry and farmer requirements. High product quality and high yield are the main industrial and farmer concern, respectively.

There is a generalized idea that quality is associated with light color and bean size (Pound, 1933; Soria, 1961). Bell and Rogers (1957) reported that the proportion of anthocyanin in the nuts influences the cacao degree of astringency and flavor. However, the 'Catongo' mutant, which has no anthocyanin pigments, does not produce the true chocolate aroma after fermentation and roasting (Maravalhas, 1972). According to the author, this pigment is necessary for the aroma production.

The bean size, expressed by its fresh or dry weight, is a very important trait because it is directly related with yield (Baez, 1984; Vello, 1971). Its relationship with quality is based on the fact that small beans generally have low fat content and high husk proportion (Glendinning, 1963). Therefore, the chocolate industry has established minimum desirable limits for dry bean weight mean of not less than 1g (Wood, 1979) for a high quality product.

The main aim of cacao plant breeding is to increase the dry cacao bean yield while maintaining an adequate bean quality. Since yield is a difficult trait to evaluate, selection can be practiced on more easily measured correlated traits. Several traits, when taken isolated or in combination, have been mentioned as important and considered sufficient to discriminate cacao tree genotypes for yield. Pereira et al. (1987) and Dias et al. (1998) used the number of healthy fruits per plant and the weight of fresh beans per plant and per fruit, together and successfully, to select promising hybrids in Linhares, ES. The increase in the first two traits provided the increase in yield and the addition of the third trait is associated with improvement in the bean size.

This study was carried out to assess the adaptability and temporal stability of hybrid cocoa trees in an experiment at the Ouro Preto Experimental Station in Ouro Preto do Oeste, Rondônia. The assessment and later hybrid selection were carried out to indicate cacao varieties agronomically superior for yield, bean quality and disease resistance, especially to witches' broom (*Crinipellis perniciosa*), for the ecological conditions of the region. The possibility of early hybrid selection, at the initial fructification phase, was investigated to reduce selection time and cost.

MATERIAL AND METHODS

Field experiment and assessment

An experiment with 20 cocoa hybrids obtained from crosses between clones was carried out by the Comissão Executiva do Plano da Lavoura Cacaueira (CEPLAC) at the Ouro Preto Experimental Station in the county of Ouro Preto do Oeste, Rondônia State, Brazil.

All hybrids were obtained from crosses among the Upper x Lower Amazon genetic types, except for SCA 6 x ICS 1 (Upper Amazon x Trinitario). These crosses aimed to obtain trees combining the robustness of the Upper Amazon type with the yield and bean quality of the Lower Amazon and Trinitario types.

A randomized complete block design with seven replications was used. Each plot consisted of 12 plants distributed in three rows and four columns with a 3.0 x 3.0 m plant spacing. Two rows of cocoa trees were planted around the experiment area as a border. Temporary shading was provided by 3.0 x 3.0 m spaced banana trees and by cassava plants, using four cassava plants per cocoa tree. Permanent shading was also provided by planting 24.0 x 24.0 m spaced *Erythrina glauca*, with one additional plant on the diagonal.

Fertilization and other crop management practices such as weeding, hoeing, pruning, shoot removal, plant tutoring and phytosanitary control were carried out to maintain the plants under optimum growth and development conditions. Plants which died because of rodent, pest or root disease damage were replaced in the first four years of the experiment to maintain the originally planned tree stand.

The traits evaluated were: a) total number of healthy fruits (TNHF); b) total weight of fresh beans (TWFB), in kg; c) mean weight of fresh beans per fruit (MWFBF), in g. The first yield component was measured from the fourth to the thirteenth planting year and the two latter were assessed from the fourth to the eleventh planting year. Fruit without witches' broom or other disease symptoms, wild animal damage or germinated seeds were considered to be healthy. The fruits were harvested monthly, but the accumulated yield of each year was considered in the analyses.

Analysis of variance

A joint analysis of variance for all the assessed years was carried out for each yield component, using a split plot in time treatment design described by the model:

$$y_{ijk} = \mu + g_i + b_k + \gamma_{ik} + a_j + \varphi_{kj} + ga_{ij} + \varepsilon_{ijk}$$

where y_{ijk} = observation of the ith hybrid (i=1,...,h), in the jth year (j=1,...,n), in the kth block (k=1,...,r); μ = general mean; g_i = effect of ith hybrid under the permanent environment influence, $\sum_{i=1}^{h} g_i = 0$; b_k = effect of kth block, $\sum_{k=1}^{r} b_k = 0$; γ_{ik} = experimental error (error a) associated with ith hybrid in the kth block, $NID(0,\sigma_\gamma^2)$; a_j = effect of jth year, $\sum_{j=1}^{n} a_j = 0$; φ_{kj} = experimental error (error b) associated with kth block in jth year, $NID(0,\sigma_\varphi^2)$; ga_{ij} = effect of interaction between ith hybrid and jth year, $\sum_{i=1}^{h} ga_{ij} = 0$ for every j and $\sum_{j=1}^{n} ga_{ij} = 0$ for every i; ε_{ijk} = experimental error (error c) associated with ith hybrid, in the jth year and kth block, $NID(0,\sigma_\varepsilon^2)$.

Two distinct assessment periods were considered for these analyses. The first, from 4th and 7th years after planting, refers to the pre-climax period of the hybrid cocoa experiment and the second, from 8th and 13th years after planting refers to maturity. The climax and post climax periods are included in the latter period. The climax is the phase at which the trees express their greatest yield potential. It begins between eight to ten years after planting (Dias and Kageyama, 1998). After this period, the trees can maintain or gradually decline the yield level (post-climax period).

Hybrid selection

The hybrid selection was based on yield component measurements taken at maturity and aimed at releasing cocoa varieties for the ecological conditions of the region where this experiment was carried out. Agronomically superior trees were selected for yield, bean quality and disease resistance, mainly witches' broom. The possibility of discriminating these hybrids at the initial fructification stage was investigated from 4th and 7th years after planting, to reduce selection time and cost and to increase selection gain per year. For this, the results obtained from both periods was compared.

To carry out the selection in pre-climax and climax periods the adaptability and temporal stability of the hybrids were evaluated using the Lin and Binns (1988) and Eberhart and Russell (1966) methodologies. According to Lin and Binns' methodology the best hybrid was selected based on the lowest P_i value (adaptability and temporal stability parameter of the ith hybrid) for the assessed yield components. According to Eberhart and Russell (1966) the best hybrid had high yield, regression coefficient equal to 1 and the smallest possible regression deviations. The determination coefficient was used as a indicator of a possible unstable genotype selection. In the regression analysis, the weighted mean error (error (b) and error (c)) with h(r-1)(n-1) degrees of freedom was used.

The computer program GENES (Cruz, 1997) was used to perform all the analyses of this experiment.

RESULTS AND DISCUSSION

Selection at maturity

Table 1 shows the joint analysis of variance for the total number of healthy fruits (TNHF), total weight of fresh beans (TWFB) and mean weight of fresh beans per fruit (MWFBF) assessed at maturity in the cacao tree hybrid experiment. Significant differences among the hybrids at the 1% level of probability were found for all the assessed traits, indicating the possibility of selecting superior varieties for the Ouro Preto do Oeste region.

Although the ecoclimatic conditions of the Ouro Preto do Oeste region are considered good for cacao tree cropping the hybrids yield, in terms of healthy fruit number and fresh bean weight, was not satisfactory in the period. Healthy fruit yield was on average 117.28 units per plot. Almeida (1991) obtained 472,68 healthy fruits for a corresponding area when assessing cacao tree hybrids at the Experimental Station at Medicilandia, PA. The low yield in Ouro Preto do Oeste was due to the high incidence of the witches' broom disease caused by an inadequate removal of inoculum sources. Furthermore, the disease is endemic in this region.

Significant interaction among hybrids x years, at a level of less than 5% of probability, was found for all the assessed traits. In spite of not having studied the hybrid x year interaction nature, the change in the relative position of the hybrids shown during the successive measuring is an indication that they were complex, at least in part. The presence of this type of interaction justifies the temporal adaptability and stability analysis of the hybrids submitted to selection. Successive measurements of the same cacao genotype, taken during various cropping years to assess the yield capacity, has been normal practice in cacao breeding. Large annual oscillations in cultivar yield have been observed (Pereira et al., 1987; Mariano et al., 1988; Dias et al., 1998). However, in only a few studies, such as that of Dias et al. (1998) has adaptability and stability been studied.

Data on yield adaptability and temporal stability are important for the cacao tree farmer interested in a steady income from the crop by exploiting a stable cultivar along the years (Dias et al., 1998). Therefore, a cultivar which has a lower mean, but which has greater stability during successive measuring, may be preferred to a cultivar which has a slightly higher mean but has larger yield oscillations. This latter cultivar would bring high income to the farmer in a given year and poorer performance in other. The P_i value calculated by Lin and Binns' (1988) methodology reflects not only the mean performance of each hybrid in the successive assessments but also considers the distance of each annual performance compared with a maximum response and is satisfactory in discriminating genotypes of greater income stability.

Hybrid classification by the Lin and Binns' methodology was similar in this study to that obtained based on the means of several years assessment (β_{0i} of Eberhart and Russell) (Table 2). The classification for the five best and eight worst performances for MWFBF, for example, was not altered when the P_i and β_{0i} values were compared. Pearson's correlation between these two parameters for TNHF**,** TWFB**,** MWFBF were -0.96, -0.96 and –0.98, respectively.

Table 1. Joint analyses of variance for the yield components[1/] assessed during the pre-climax period and maturity in an experiment of cacao hybrids in randomized complete block design field experiments.

Sources	d.f.[4/]	Mean squares					
		Pre-climax			Maturity		
		TNHF	TWFB	MWFBF	TNHF	TWFB	MWFBF
Blocks (B)	6	95272.779	867.385	100.365	98226.910	167.991	1431.581
Hybrids (H)	19	159876.815 [6/]	962.598 [6/]	4901.991 [6/]	28329.692 [6/]	80.636 [6/]	1291.865 [6/]
Error (a)	114	12550.427	116.889	172.957	6224.172	21.183	177.113
Years (A)	3 (5)	235171.050 [6/]	2916.804 [6/]	1367.539 [6/]	682095.832 [6/]	171.898 [5/]	923.192 [5/]
Error (b)	18 (30)	15460.023	183.737	198.113	22191.859	46.926	210.191
H x A	57 (95)	9479.873 [6/]	95.622 [6/]	108.390 [ns]	4551.749 [6/]	17.915 [6/]	231.198 [5/]
Error (c)	342 (570)	2145.361	20.169	86.402	1414.909	5.020	167.837
Means		231.42	21.878	96.400	117.277	6.650	91.542
C.V. (%)[2/]		48.40	49.41	13.64	67.27	69.20	14.53
C.V. (%)[3/]		20.01	20.52	9.64	32.07	33.69	14.15

[1/] TNHF - total number of healthy fruits; TWFB - total weight of fresh beans; MWFBF - mean weight of fresh beans per fruit; [2/] Refers to the experimental plot; [3/] Subplot; [4/] The numbers in parenthesis correspond to the TNHF trait degrees of freedom in the ANOVA, assessed at maturity; n.s., [5/],[6/] indicates non-significance and significance at the 5% and 1% levels of probability, respectively, by the F test.

A contrasting result, however, was obtained for the performance of the SCA 6 x ICS 1 hybrid that had the second greatest β_{0i} value for TNHF but was placed only sixth, according to Lin and Binns' methodology. The relationship between the best performance based on the mean and greater stability was also found by Dias et al. (1998) when analyzing cacao cultivar yield in Linhares, ES.

The hybrids derived from the PA 150 clone, and especially the SCA 6 clone, showed high stability in the univariate analysis for TNHF. The SCA 6 x BE 10 (hybrid 20), PA 150 x MA 11 (hybrid 17) and SCA 6 x BE 9 (hybrid 19) hybrids were outstanding by their P_i value.

The PA 150 clone was also important for TWFB. The IMC 67 x BE 8 (hybrid 4), SCA 6 x ICS 1 (hybrid 2), PA 150 x SIAL 325 (hybrid 16) and PA 150 x SIC 328 (hybrid 15) hybrids performed best for this trait. In spite of having a low stand, even when the seedlings were replaced in the first four years of the experiment, the SCA 6 x ICS 1 hybrid had the second greatest stability. The high performance of this hybrid is due at least in part to the inclusion of the ICS 1 parent. This clone was also able to increase the stability or mean of this yield component in hybrid combinations, as observed by Pereira et al. (1987), Dias and Kageyama (1995) and Dias et al. (1998).

The IMC 67 x CA 4 (hybrid 3) and POUND 7 x MA 15 (hybrid 10) hybrids performed best for MWFBF. The inclusion of IMC 67 and POUND 7 clones as parents was important for these and other hybrids to condition high stability or mean for this trait. In contrast, the inclusion of POUND 12, PA 150 or SCA 6 clones as parents in the hybrid combinations decreased the trait value. The increase in the MWFBF mean reflects the capacity of the clone to improve cacao bean size (Ruinard, 1961; Pereira et al., 1987). Small beans in the progenies from the SCA 6 or POUND 12 clones were also observed by Pereira et al. (1987) and Mariano et al. (1988).

Simultaneous analysis of TNHF, TWFB and PMSU based on P_i values, showed that the SCA 6 x ICS 1, PA 150 x SIC 328 and IMC 67 x BE 8 hybrids performed best as they had high yield stability and reasonable MWFBF stability values, meeting the farmer and industry demands. These same hybrids were also important using the mean comparison criteria. Consequently, the change mentioned in the relative position of SCA 6 x ICS 1, by taking into consideration P_i and β_{0i} for TNHF was not relevant to the best hybrid selection. The SCA 6 x BE 10 (hybrid 20) hybrid, which performed well for healthy fruit yield, was not selected because it had the second greatest P_i value for MWFBF. Generally, the crosses which expressed the lowest P_i value for TNHF and TWFB were not the same for MWFBF. Therefore, the hybrids which had intermediary P_i values for the three traits were selected in this experiment.

Table 2 shows the β_{0i} values and the other adaptability and stability parameters of the yield components obtained using Eberhart and Russell's methodology. PA 150 x SIC 328 had general adaptability $(\beta_{1i} = 1)$ and highly predictable performance $(\sigma^2_{di} = 0)$ for TNHF. The SCA 6 x ICS

Table 2. Temporal adaptability and stability parameters[1/] of the yield components[2/] estimated according to Eberhart and Russel (1966) and Lin and Binns (1988) methodologies. Assessment involved 20 cacao hybrids at maturity in an experiment at the Ouro Preto Experimental Station in Ouro Preto do Oeste, Rondônia State, Brazil.

Hybrids[3/]	TNHF					TWFB					MWFBF				
	Eberhart and Russell				Lin and Binns	Eberhart and Russell				Lin and Binns	Eberhart and Russell				Lin and Binns
	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i
1	114.02	0.89 ns	-329.30 ns	99.57	3771.82	6.95	0.83 ns	-0.97 ns	97.14	11.58	94.32	1.92 ns	-3.02 ns	63.20	109.46
2	149.30	0.93 ns	731.76 *	83.05	2289.13	10.17	3.97 **	-1.00 ns	99.96	4.78	92.94	0.31 ns	-12.24 ns	7.59	134.44
3	94.59	0.93 ns	-298.58 ns	99.02	5432.54	5.67	1.47 ns	-0.50 ns	88.63	18.57	103.35	0.57 ns	99.72 **	2.57	18.28
4	116.45	0.64 **	-291.06 ns	97.68	4453.50	8.79	1.52 ns	-0.63 ns	91.72	4.56	97.91	0.28 ns	-23.56 ns	52.15	63.76
5	99.38	0.86 ns	-308.63 ns	99.08	5193.50	5.89	1.21 ns	-0.67 ns	88.68	17.45	96.46	2.94 ns	6.18 ns	73.77	89.83
6	75.52	0.43 **	-337.26 ns	98.84	9047.44	5.52	0.72 ns	-0.87 ns	86.89	19.54	97.79	0.70 ns	-24.16 ns	97.73	63.90
7	114.90	1.18 *	-126.57 ns	97.45	3377.25	5.82	-0.19 **	-0.94 ns	48.88	18.57	94.03	-0.53 ns	-22.42 ns	60.35	111.00
8	81.09	0.91 ns	-136.02 ns	95.93	6974.67	3.74	-0.54 **	-0.35 ns	45.62	33.68	93.26	0.18 ns	76.43 *	0.32	175.87
9	105.97	0.95 ns	-238.98 ns	98.04	4449.83	6.14	0.00 *	-0.64 ns	0.03	16.53	95.72	-2.06 *	6.02 ns	58.12	120.11
10	104.45	0.99 ns	-101.13 ns	96.06	4391.21	5.95	-0.45 **	0.19 ns	31.36	18.41	100.35	-0.84 ns	18.75 ns	14.08	36.02
11	142.69	1.08 ns	-211.93 ns	98.10	1758.59	7.59	0.07 *	-0.67 ns	3.22	9.20	83.33	0.34 ns	-1.81 ns	5.06	327.38
12	94.33	1.12 ns	-283.65 ns	99.14	5148.94	3.53	0.53 ns	-0.76 ns	67.48	34.09	79.60	2.79 ns	-19.82 ns	94.54	436.11
13	100.92	0.94 ns	-202.30 ns	97.33	4818.49	4.86	-0.07 *	-0.83 ns	5.41	24.57	83.97	1.76 ns	-19.02 ns	85.49	297.34
14	133.35	0.87 ns	482.20 ns	84.76	2848.90	8.01	-1.14 **	3.54 *	34.62	10.83	87.01	1.70 ns	-9.60 ns	66.19	251.17
15	134.71	1.06 ns	143.66 ns	93.30	2565.86	8.26	2.70 **	0.24 ns	91.43	7.30	95.27	0.82 ns	-22.24 ns	78.66	95.41
16	142.88	1.05 ns	243.14 ns	91.91	1999.09	8.42	1.98 *	-0.18 ns	89.74	6.00	85.44	3.14 ns	57.03 *	54.63	277.30
17	149.16	1.37 **	65.83 ns	96.52	1141.79	7.89	2.23 **	2.87 *	70.31	8.78	89.26	0.21 ns	-6.75 ns	2.47	196.25
18	85.40	0.57 **	-50.75 ns	87.09	7583.85	5.54	2.28 **	-0.48 ns	94.75	20.06	90.65	0.69 ns	-17.22 ns	40.07	170.21
19	140.42	1.44 **	-277.93 ns	99.43	1661.01	6.67	1.42 ns	-0.99 ns	99.37	12.83	88.45	1.90 ns	29.80 ns	39.78	198.48
20	165.92	1.70 **	271.88 ns	96.58	475.34	7.52	1.41 ns	0.29 ns	73.73	8.96	79.65	3.13 ns	-23.33 ns	99.03	428.70

[1/] β_{0i} : mean of the ith hybrid, considering all the assessment years; $\hat{\beta}_{1i}$: linear regression coefficient, which measures the response of the ith hybrid to annual environmental variations; $\hat{\sigma}^2_{di}$: variation of deviations from regression; P_i : adaptability and temporal stability parameter of the ith hybrid; R^2 : determination coefficient; [2/] TNHF - total number of healthy fruits; TWFB - total weight of fresh beans; MWFBF - mean weight of fresh beans per fruit; [3/] 1 - IMC 67 x SIC 813, 2 - SCA 6 x ICS 1, 3 - IMC 67 x CA 4, 4 - IMC 67 x BE 8, 5 - IMC 67 x BE 9, 6 - IMC 67 x SIAL 169, 7 - POUND 7 x BE 10, 8 - POUND 7 x MA 12, 9 - POUND 7 x SIC 864, 10 - POUND 7 x MA 15, 11 - POUND 12 x SIC 329, 12 - POUND 12 x MA 14, 13 - POUND 12 x SIAL 505, 14 - POUND 12 x SIC 831, 15 - PA 150 x SIC 328, 16 - PA 150 x SIAL 325, 17 - PA 150 x MA 11, 18 - PA 150 x SIC 864, 19 - SCA 6 x BE 9 and 20 - SCA 6 x BE 10; [4/] n.s., *,**: non-significance and significance at the 5% and 1% levels of probability, respectively, by the t test; [5/] n.s., *,**: non-significance and significance at the 5% and 1% levels of probability, respectively, by the F test.

1 hybrid also had general adaptability, in spite of indicated low predictability ($\sigma^2_{di} \neq 0$). This hybrid should not be considered as totally undesirable as its R^2 value was 83.06%. The IMC 67 x BE 8 cross was adapted to unfavorable environments (β_{1i} < 1) and had high predictability for TNHF, indicating that healthy fruit yield in this hybrid does not respond to improvement in environmental conditions.

The SCA 6 x ICS 1 and PA 150 x SIC 328 hybrids behaved similarly for TWFB, showing adaptability to favorable environments (β_{1i} >1) and high predictability. Therefore, the fresh bean yield of these hybrids will positively respond to better cropping conditions. IMC 67 x BE 8 showed general adaptability and high predictability for this trait. Furthermore, the three hybrids showed general adaptability and high predictability for MWFBF. Consequently in the simultaneous analysis of TNHF, TWFB and MWFBF, none of these hybrids could be considered ideal based on Eberhart and Russell's methodology, because they do not have general adaptability for some of the traits assessed.

Pre-climax selection

Significant differences at the 1% probability level were found among the hybrids for all traits in the assessments made in the pre-climax period of the experiment (Table 1). The coefficients of variation (C.V.%) were less than that at maturity, disagreeing with those obtained by Vello et al. (1972). These authors found that the C.V.% for bean yield decreased progressively as the cacao tree age increased.

Although the plants tended to express their maximum yield potential at maturity, the greatest mean yields were obtained at the beginning of fructification. The reduced hybrid performance from 8th and 13th years after planting was due to the greater incidence of witches' broom in this period. For example, there was a reduction of 49.3% and 69.6% in the TNHF and TWFB traits, respectively.

Significant hybrid x year interaction at the 1% probability level was found for all the yield components, except MWFBF. Changes observed in the relative hybrid ranking, even for MWFBF, showed the need to consider more than one year of assessment to select the best hybrids.

An adaptability and stability study using the Lin and Binns (1988) methodology was also carried out for the pre-climax period (Table 3). Similarly to the maturity analysis, the hybrid classification based on P_i values was equivalent to that using the means of the several assessment years (β_{0i} of Eberhart and Russell). Pearson's correlation between these two parameters for TNHF, TWFB and MWFBF were of similar magnitude ($r = -0{,}97$). Only four hybrids changed their relative positions considering TNHF and MWFBF. The POUND 7 x SIC 864 (hybrid 9) hybrid stood out among the relevant changes for best hybrid selection because it had the fifth greatest means but only the ninth lowest P_i for TWFB.

The Scavina (SCA) hybrids performed well in the univariate analysis for healthy fruit yield stability. Hybrids from PA 150 performed better at maturity. Crosses with Scavina also had greater TWFB stability comparatively to the PA 150 derived hybrids. However, at maturity SCA 6 x BE 10 (hybrid 20) went from the second to the sixth position while PA 150 x SIAL 325 (hybrid 16) went from the fourteenth to the third position. The hybrids from the IMC 67 and POUND 7 clones were the most stable for MWFBF, contrasting with the participation of the POUND 12, SCA 6 and PA 150 clones in the hybrid combination. The simultaneous analysis of the TNHF, TWFB and MWFBF traits based on the P_i values, highlighted the performance of the PA 150 x SIC 328, SCA 6 x ICS 1 and IMC 67 x BE 8 hybrids as had already happened at maturity. The POUND 7 x SIC

Table 3. Temporal adaptability and stability parameters[1/] of the yield components[2/] estimated according to Eberhart and Russel (1966) and Lin and Binns (1988) methodologies. Assessment involved 20 cacao hybrids at pre-climax in an experiment at the Ouro Preto Experimental Station in Ouro Preto do Oeste, Rondônia State, Brazil.

Hybrids[3/]	TNHF					TWFB					MWFBF				
	Eberhart and Russell				Lin and Binns	Eberhart and Russell				Lin and Binns	Eberhart and Russell				Lin and Binns
	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i	β_{0i}	$\hat{\beta}_{1i}$ [4/]	$\hat{\sigma}^2_{di}$ [5/]	R^2	P_i
1	209.21	1.07 ^{ns}	678.69 ^{ns}	73.04	22554.98	21.03	1.09 ^{ns}	5.99 ^{ns}	79.01	151.82	101.45	-11.59 ^{ns}	-10.79 ^{ns}	94.92	201.01
2	365.46	2.08 *	9607.20 **	52.20	2119.46	35.00	2.11 **	80.93 **	62.18	1.92	94.97	-9.82 ^{ns}	-9.03 ^{ns}	91.30	347.45
3	144.71	0.81 ^{ns}	57.64 ^{ns}	78.60	35671.50	17.08	0.78 ^{ns}	5.11 ^{ns}	67.81	204.57	118.86	5.12 **	5.92 ^{ns}	59.17	1.52
4	219.46	0.91 ^{ns}	-350.25 ^{ns}	97.64	19295.33	23.83	1.07 ^{ns}	-1.14 ^{ns}	92.53	104.89	108.32	5.72 ^{ns}	6.52 ^{ns}	26.46	95.35
5	182.25	0.71 ^{ns}	-187.85 ^{ns}	85.64	26563.69	20.15	0.76 ^{ns}	-1.78 ^{ns}	88.89	152.73	111.13	-11.67 ^{ns}	-10.87 ^{ns}	19.13	50.97
6	163.92	1.09 ^{ns}	1107.56 *	66.68	32949.50	16.86	0.97 ^{ns}	10.44 *	67.38	229.80	102.41	-9.88 ^{ns}	-9.08 ^{ns}	42.87	167.10
7	260.71	1.09 ^{ns}	1042.09 *	67.65	13053.71	26.25	1.19 ^{ns}	25.19 **	60.28	80.86	99.13	49.16 ^{ns}	49.95 **	26.32	256.13
8	104.07	0.77 ^{ns}	-344.30 **	96.31	47623.08	11.28	0.71 ^{ns}	-2.60 ^{ns}	91.66	340.28	109.12	8.78 ^{ns}	9.58 ^{ns}	4.81	74.47
9	232.53	0.65 ^{ns}	2071.77 ^{ns}	30.21	19046.89	24.90	0.60 ^{ns}	18.40 **	34.11	115.96	107.16	3.22 ^{ns}	4.02 ^{ns}	6.35	94.83
10	136.67	1.08 ^{ns}	-387.37 ^{ns}	99.51	38239.59	16.21	1.15 ^{ns}	-3.68 ^{ns}	99.14	220.72	114.62	-10.47 ^{ns}	-9.67 ^{ns}	92.15	41.22
11	288.60	0.75 ^{ns}	-19.99 ^{ns}	79.00	8464.30	23.28	0.73 ^{ns}	-1.78 ^{ns}	88.16	109.04	81.46	-12.32 ^{ns}	-11.52 ^{ns}	96.69	769.13
12	153.21	0.66 ^{ns}	-398.82 ^{ns}	99.75	33928.53	11.78	0.50 *	-4.04 ^{ns}	99.89	332.29	74.14	-7.35 ^{ns}	-6.55 ^{ns}	90.47	1096.42
13	210.39	0.78 ^{ns}	-185.08 ^{ns}	87.83	21449.09	18.14	0.80 ^{ns}	-2.28 ^{ns}	91.91	195.88	85.82	-10.70 ^{ns}	-9.90 ^{ns}	94.70	621.89
14	256.67	1.16 ^{ns}	-388.84 ^{ns}	99.62	12724.93	21.80	0.88 ^{ns}	-3.56 ^{ns}	98.05	131.43	85.40	-6.98 ^{ns}	-6.18 ^{ns}	0.35	612.06
15	293.53	0.90 ^{ns}	1124.52 *	57.74	9259.18	29.04	1.14 ^{ns}	16.38 **	66.71	59.41	99.02	-4.10 ^{ns}	3.30 ^{ns}	88.77	264.66
16	212.42	0.88 ^{ns}	1402.90 *	52.14	20594.08	20.15	0.90 ^{ns}	17.10 **	54.62	155.07	93.39	-3.44 ^{ns}	-2.64 ^{ns}	55.87	379.08
17	261.42	1.07 ^{ns}	2176.85 **	52.87	14396.39	24.13	0.93 ^{ns}	15.71 **	57.77	115.91	91.06	-0.51 ^{ns}	0.28 ^{ns}	36.39	435.88
18	230.78	1.13 ^{ns}	1626.20 **	61.51	19088.14	22.35	1.06 ^{ns}	16.03 **	63.88	138.19	97.13	6.00 ^{ns}	6.80 ^{ns}	38.38	282.68
19	300.89	1.43 ^{ns}	3241.92 **	58.57	6090.18	23.92	1.34 ^{ns}	22.90 **	67.61	81.79	78.48	12.99 ^{ns}	-12.20 ^{ns}	99.74	902.22
20	401.50	0.89 ^{ns}	3694.86 **	33.02	122.34	30.30	1.20 ^{ns}	25.50 **	60.41	24.37	74.85	-11.02 *	-10.22 ^{ns}	97.43	1072.38

[1/] β_{0i} : mean of the ith hybrid, considering all the assessment years; $\hat{\beta}_{1i}$: linear regression coefficient, which measures the response of the ith hybrid to annual environmental variations; $\hat{\sigma}^2_{di}$: variation of deviations from regression; P_i : adaptability and temporal stability parameter of the ith hybrid; R^2 : determination coefficient; [1/] TNHF - total number of healthy fruits; TWFB - total weight of fresh beans; MWFBF - mean weight of fresh beans per fruit; [2/] 1 - IMC 67 x SIC 813, 2 - SCA 6 x ICS 1, 3 - IMC 67 x CA 4, 4 - IMC 67 x BE 8, 5 - IMC 67 x BE 9, 6 - IMC 67 x SIAL 169, 7 - POUND 7 x BE 10, 8 - POUND 7 x MA 12, 9 - POUND 7 x SIC 864, 10 - POUND 7 x MA 15, 11 - POUND 12 x SIC 329, 12 - POUND 12 x MA 14, 13 - POUND 12 x SIAL 505, 14 - POUND 12 x SIC 831, 15 - PA 150 x SIC 328, 16 - PA 150 x SIAL 325, 17 - PA 150 x MA 11, 18 - PA 150 x SIC 864, 19 - SCA 6 x BE 9 and 20 - SCA 6 x BE 10; [3/] n.s., *,**: non-significance and significance at the 5% and 1% levels of probability, respectively, by the t test; [4/] n.s., *,**: non-significance and significance at the 5% and 1% levels of probability, respectively, by the F test.

864 (hybrid 9) hybrid became less important because of its yield oscillation in TWFB, as previously mentioned.

Table 3 shows the Eberhart and Russell' (1966) adaptability and stability parameters for the yield components. IMC 67 x BE 8 and PA 150 x SIC 328 had general adaptability ($\beta_{1i} = 1$) for TNHF and TWFB. They had high ($\sigma^2_{di} = 0$) and low ($\sigma^2_{di} \neq 0$) predictability, respectively. SCA 6 x ICS 1 was considered to have specific adaptability to favorable environments ($\beta_{1i} > 1$), but low predictability. These three hybrids have general adaptability and high predictability for the MWFBF trait. Thus the IMC 67 x BE 8 hybrid can be considered ideal because of high yield, general adaptability and high predictability for the assessed traits. This, however, was not true at maturity.

The possibility of selecting cacao tree genotypes using measurements taken in the pre-climax period was also investigated by Soria and Esquivel (1967), Atanda (1972), Bartley (1970) and Dias et al. (1996). Conflicting results have been reported in the assessment of different yield components. Studies in Costa Rica (Soria and Esquivel, 1967), Nigeria and Trinidade (Atanda, 1972) showed that the use of measurements taken at the initial fructification phase suffices to discriminate cacao genotypes for yield. These results were based on the correlation coefficients among the accumulated number of fruit per plant after 1, 2, 3 and 4 successive years of assessment and the accumulated number taking all the assessment years. On the other hand, Bartley (1970) studied the nature of the frequency distribution of fresh bean weight per plant and reported that selection should begin eight years after planting. Dias et al. (1996) reached the same conclusion after assessing cacao cultivars in Linhares, ES. In this experiment, hybrids with a high performance at the beginning of fructification for certain traits, as evaluated by their P_i value, had their performance reduced later because of the development of diseases (witches' broom) or the physiological behavior of the hybrid itself. These observations indicate that selection for yield in cacao should only begin eight years after planting. However, simultaneous analysis of TNHF, TWFB and MWFBF suggested that the same hybrids could be selected in either period, and consequently, the hybrid selection was also successful using measurements taken at the initial fructification phase. On the other hand, the Eberhart and Russell' (1966) adaptability and stability parameters depended of period evaluated. It intensifies the former hypothesis.

RESUMO

Adaptabilidade e estabilidade temporal de rendimento de híbridos de cacaueiro (*Theobroma cacao* L.) no Estado de Rondônia, Brasil

Estudo de adaptabilidade e estabilidade temporal de rendimento de híbridos de cacaueiro foi realizado visando indicar variedades agronomicamente superiores no que concerne a produtividade, a qualidade das sementes e a resistência à vassoura-de-bruxa, para as condições ecológicas do município de Ouro Preto do Oeste, RO, Brasil. As avaliações foram feitas com base em medidas de componentes de rendimento tomadas no período de maturidade de um ensaio com delineamento em blocos completos casualizados. Além disso, a possibilidade de seleção precoce de híbridos , na fase inicial de frutificação, foi investigada. Para isto, os resultados obtidos nos dois períodos foram comparados. Na maturidade, os híbridos SCA 6 x ICS 1, PA 150 x SIC 328 e IMC 67 x BE 8 foram superiores na análise simultânea de número de frutos sadios (TNHF), peso total de sementes úmidas(TWFB) e peso médio de sementes úmidas por fruto (MWFBF). Com base na metodologia de Eberhart e Russell, PA 150 x SIC 328 tiveram adaptabilidade geral e alta previsibilidade para TNHF. O híbrido SCA 6 x ICS 1 teve também alta adaptabilidade, apesar da baixa previsibilidade. IMC 67 x BE 8 foi adaptado à ambientes desfavoráveis e teve alta previsibilidade para TNHF. Os híbridos SCA 6 x ICS 1 e PA 150 x SIC 328 tiveram comportamento similares para TWFB, mostrando adaptabildade a ambientes favoráveis e alta previsibilidade. IMC 67 x BE 8 mostrou adaptabilidade geral e alta previsibilidade para esse caráter. Os três híbridos mostraram adaptabilidade geral e alta previsibilidade para MWFBF. Com base na performance média (ou valores de P_i da metodologia de Lin e Binns), verificou-se também ser possível a realização da seleção na fase inicial de frutificação.

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Received: March 14, 2002;

Accepted: December 11, 2002.