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Estimates of genetic parameters in Arabic coffee derived from the Timor hybrid

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ABSTRACT - *Genetic parameters of Arabic coffee progenies derived from the cross 'Villa Sarchi' x 'Timor hybrid' were estimated in order to evaluate their potential for improvement. The experiment was installed in a random block design with ten treatments, eight replicates and eight plants per plot. The parameters cherry yield, plant height, canopy diameter, seed types and sizes were estimated. Results demonstrated significant differences between treatments for all traits. Greatest yield gains were achieved when the selection was performed based on plot means and in years of high yields. The variation index b was the best indicator of genetic variability. The progenies IAC 3786. IAC 3788, IAC 4094, IAC 4095, IAC 3425, and IAC 3429 were outstanding regarding the evaluated agronomic traits, representing progenies of high agronomic potential. All progenies presented leaf rust resistance.*

Key words: *Coffea arabica*, quantitative genetics, genetic parameters, genetic variability, yield.

INTRODUCTION

The species *Coffea arabica* Linnaeu (Arabic coffee) and *C. canephour* Pierre ex A. Froehner (Robusta coffee) are the most important of the genus *Coffea*; Arabic accounts for around 70% of the coffee cultivated and traded in the world.

Brazil is the largest coffee producer and exporter, where the crop is of great economic importance, since it comes up for 20% of the agricultural Gross Domestic Product, as well as social importance, with around 8 million jobs in this sector. Furthermore, the country stands out in the development of cultivars, since a great part of the Arabic coffee grown in all the world are originated, mainly, from the Coffee Improvement Program of the Instituto Agronômico de Campinas (IAC/APTA).

It is estimated that the global coffee consumption will exceed 105 million bags per year and reach 145 millions in the next ten years (Herszkowicz N., personal communication). This requires the development of new cultivars with high production potencial, adapted to dense systems, resistant to diseases (mainly to coffee leaf rust, caused by the fungus *Hemileia vastatrix* Berk et Br.), resistant to pests, as well as superior regarding other agronomic, technological and quality traits.

Arabic coffee is a perennial, autogamous and allotetraploid species with 2n = 4x = 44 chromosomes. The fruit is a drupe with two compartments and a single seed in each one. When the development of the fruit is normal it forms two seeds of the flat type, with a convex and a flat side, after which it is named

Coffee improvement is a slow process, which requires four to six harvests to practice selection in each generation, in average over 20 years until the final recommendation of

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a cultivar for commercial planting. Besides, coffee has peculiar biological aspects such as: a long reproduction cycle; pronounced annual yield oscillation, resulting in a biennial yield cycle; overlapping generations and trait expression over the course of several years (Sera 2001).

The detection of the variability in a population alone does not quantify the variation within this population; other parameters must be estimated. The study of genetic parameters is of vital importance for the progress of plant improvement since it helps distinguish genetic from environmental effects, for the subsequent selection of superior genotypes. One of the main genetic parameters is the heritability coefficient, which indicates how much of the variability is due to a genotype or an environment (Falconer 1987); the genetic variation coefficient, which, according to Valois et al. (1980), shows the amplitude of the genetic variation of a trait; the variation index, which indicates whether the situation is or is not favorable for selection (Vencovsky 1987). Therefore, the basic knowledge on the genetic variation of a species and the estimates of genetic parameters allows the choice of the most suitable selection strategy and, consequently, a time reduction in cultivar releases.

The present study aimed to estimate the magnitude of genetic parameters in Arabic coffee progenies, derived from the cross of cultivar Villa Sarchi with the Timor hybrid CIFC 832/2, in order to understand their genetic structure and potential for improvement in the different agronomic traits.

MATERIAL AND METHODS

A progenies group of Arabic coffee in F_2 generation was introduced from the Centro de Investigação das Ferrugens do Cafeeiro (CIFC), in Oeiras - Portugal, by the Instituto Agronômico (IAC/APTA). After two selection cycles, the eight best progenies, designated IAC 1669, which are focus of the present study, were evaluated in Mococa, state of São Paulo.

The experiment consisted of eight progenies derived from the cross 'Villa Sarchi' x Timor hybrid CIFC 832/2, in the F_4 generation, highly resistant to leaf rust, (treatments 1 to 8) as well as two rust-susceptible cultivars used as controls, Catuaí Vermelho IAC 81 and Catuaí Vermelho IAC 24 (treatments 9 and 10). The genealogy of the progenies evaluated in this study is displayed below:

Treatment 1: IAC 3786 = [(Villa Sarchi x Timor hybrid 832/2) x Catuaí V.];
Treatment 2: IAC 3787 = [(Villa Sarchi x Timor hybrid 832/2) x Catuaí V.];
Treatment 3: IAC 3788 = Villa Sarchi x Timor hybrid 832/2;
Treatment 4: IAC 4094 = Villa Sarchi x Timor hybrid 832/2;
Treatment 5: IAC 4095 = Villa Sarchi x Timor hybrid 832/2;
Treatment 6: IAC 3426 = Villa Sarchi x Timor hybrid 832/2;
Treatment 7: IAC 3425 = Villa Sarchi x Timor hybrid 832/2;
Treatment 8: IAC 3429 = Villa Sarchi x Timor hybrid 832/2;
Treatment 9: Catuaí Vermelho IAC 81;
Treatment 10: Catuaí Vermelho IAC 24.

The treatments 1 to 4 were selected in Garça (SP) and 5 to 8 in Votuporanga (SP).

The experiment was established in the Pólo Regional do Nordeste Paulista (APTA Regional), in Mococa, state of São Paulo, using a randomized block design with ten treatments, eight replicates and eight plants per plot, in a spacing of 3.5 x 2.0 meters (lat 21° 28' S, long 47° 01' W and alt 665 m asl), with an annual mean temperature of 22.5 ºC and annual rainfall of 1,500 mm. The soil type is a dark red eutrophic Podzólic of medium-clayey texture.

The following agronomic traits were evaluated in every single plant of the experiment:

Cherry yield: in g plant^{-1}, the weight of the cherry fruits harvested from each plant in eight years.

Plant height: in cm, the distance from the soil surface to the tip of the orthotropic branch. This trait was determined in the fourth year.

Canopy diameter: in cm, the distance between the most extended lateral branches of the canopy. This trait was determined in the fourth year.

Seed types: a sample of 100 grams of processed coffee was separated in the classes flat, peaberry (when a single seed of rounded shape is formed in the fruit) and elephant beans (when more than one ovule develops in a compartment of the ovary, the resulting seeds are grown together). Then each seed type was weighed, in grams. This trait was determined in the third year.

Seed size: a machine with a series of 15 sieves was used, with meshes of 12 to 26/64 inches, arranged in deceasing order. When placed in the machine, the seeds of the flat type only were distributed in the sieves. The ones that were retained in the drawer with a mesh 15 bottom are the seeds with a width of over 15/64 inches, i.e., they are classified as mesh 16. The seeds of each mesh were weighed and the following was calculation performed: the mesh number was multiplied by its respective seed mass; the products were added and the sum divided by the total seed mass of all sieves; the quotient represented the value of the seed size. This trait was determined in the third year.

The analyses of variance for all traits were obtained with plot means, according to the randomized block design with observation within plots, considering treatment and year effects as random (Cruz 2001). The joint analysis was realized using the randomized block design, in split-plots in time, since sucessive measures were carried out on a same plot, in a certain time intervals.

The estimates of heritability based on plot means (h^2_m), of the coefficients of genetic (CV_g) and environmental variation (CV_e) and of the variation index (b) were obtained by formulas proposed by Vencovsky and Barriga (1992):

$$h^2_m = \frac{\sigma^2_g}{\frac{\sigma^2_d}{nr} + \frac{\sigma^2_e}{r} + \sigma^2_g} \qquad CV_e\,\% = \frac{\sqrt{\sigma^2_e}}{m} * 100$$

$$CV_g\,\% = \frac{\sqrt{\sigma^2_g}}{m} * 100 \qquad b = \frac{CV_g}{CV_e}$$

A formula proposed by Cruz (2001) was used to calculate the heritability within plots h^2_d

$$h^2_d = \frac{\sigma^2_{gd}}{\sigma^2_d} \qquad \sigma^2_{gd} = \frac{\theta_d}{\theta_e}\sigma$$

where σ^2_{gd} is the variance within the plot; and the fractions of variance among (θ_e) and within (θ_d) are, respectively fifty-fifty percent for full-sib families.

The statistical analyses and the estimates of all genetic parameters were obtained by the software Genes (Cruz 2001).

RESULTS AND DISCUSSION

Table 2 shows the mean square values of the individual and joint analyses for cherry yield. Significant differences between treatments were detected in all evaluated years, except the sixth, indicating the existence of genetic variability, which is a basic requirement for any improvement program. In the second, third, fifth, seventh, and eighth years the differences were significant at 1 and 5% probability in the first and fourth years. At 5% there were also significant differences in the joint analysis for treatments and for the treatments x years interaction, expressing the change in the ranking of the treatment yields over the course of the years.

Table 3 shows the cherry mean yields in g plant^{-1}, as well as the estimates of the components of the genetic

Table 1. Individual and joint analysis of variance and expectation of the mean squares [E (MS)] for the agronomic traits of the Arabic coffee treatments, according to the random block design

Sources of variation	df	MS	E (MS)
		Individual analysis	
Block	r-1	MS_1	$\sigma^2_d + n\sigma^2_e + ng\sigma^2_b$
Genotypes	g-1	MS_2	$\sigma^2_e + g\sigma^2_b$
Among plots	(r-1) (g-1)	MS_3	$\sigma^2_e + g\sigma^2_b + gr\sigma^2_a$
Within plots	(n-1)gr	MS_4	σ^2_d
		Joint analysis	
Block	(r-1)	MS_1	
Genotypes (G)	g-1	MS_2	$\sigma^2_e + g\sigma^2_b$
Error a	(r-1) (g-1)	MS_3	$\sigma^2_e + g\sigma^2_b + gr\sigma^2_a$
Years (Y)	y-1	MS_4	$\sigma^2_e + rl\sigma^2_{ga} + ar\phi_g$
GxY	(g-1) (y-1)	MS_5	$\sigma^2_e + rl\sigma^2_{ga}$
Error b	g (r-1) (y-1)	MS_6	σ^2_e

[1] σ^2_g = genetic variance in genotype means; σ^2_d = variance among plants within genotypes; σ^2_e = variance of the environmental residue among plots; σ^2_{ga} = genetic variance of the genotypes x years interaction; σ^2_a = genetic variance in genotypes; θ_g = genetic variance between years; r = nr. of replicates; g = nr. of genotypes; y = nr. of years; n = nr. of plants per plot and l = g/g-1.

Table 2. Values of the mean squares of the individual and joint analyses of cherry yield of Arabic coffee evaluated in the Pólo Regional do Nordeste Paulista (APTA Regional), Mococa (SP)

S.V.	df	Individual analyses							
		1st year	2nd year	3rd year	4th year	5th year	6th year	7th year	8th year
Block	7	10662544.0205	706395.6027	41447123.6301	10970236.2516	46503808.5786	44957168.3205	29064713.6455	23854351.3266
Genotype	9	4413073.5458*	1162844.9785**	76084022.5904**	10958587.1884*	273941112.8028**	46720372.6944	165156516.4903**	377201148.4793**
Among plots	63	2059245.1490	266731.8170	13292426.3484	4757907.1876	21642207.2929	23603085.3151	31089053.4367	11000348.3524
Within plots	560	560001.1535	117586.9179	8817251.477	1669916.3560	16694065.4308	2882936.6750	17214067.7478	5636279.1560

Joint analysis

Block	7	3059590.2312
Gen. (G)	9	25732411.2924*
Error a	63	2446153.9237
Years (Y)	7	699466976.7670
G x Y	63	7326555.2094*
Error b	490	1744603.213

*, ** significant at 5 and 1% probability, respectively, by the F test

and environmental variances and genetic parameters in every year and the eight year mean. Under normal climate conditions, coffee yields usually increase from the first until the fourth/fifth year. Thereafter, the biennial yield cycles begin, characterized by the alternating high and low yields, owing to the weakening of the plants in the high yield years (Fazuoli et al. 2000). In this experiment an earlier beginning of the biennial yield cycles performance was observed from the second year on due to occurrence of two climatic adversities in the first year: a cold winter with temperatures of around 1 ºC over several days, together with dry periods. This fact can be verified with the mean yield of 1,541 g plant^{-1} in the first year, 296 g plant^{-1} in the second, 7,165 g plant^{-1} in the third and so on. The highest yields and the lowest coefficients of experimental variation were observed in the third, fifth and seventh years, with mean yields of over 6,800 g plant^{-1} and coefficients of less than 20%. In the other years the yields were lower, below 2,800 g plant^{-1}, and the coefficients of variation were higher, over 28%. The mean yield of the treatments in the eight years was 3,768 g plant^{-1} with an experimental variation coefficient of 35.05%.

In all years the variances due to the genotype effect, among (σ^2_g) as well as within (σ^2_d), were constantly superior to the corresponding environmental variances (σ^2_e), indicating high genetic variability. In the years of high yields the genetic variances were higher than in low-yield years and in the mean yield of the eight years, as for instance the σ^2_g of 36778.5687 of the first year, versus 981118.6913 of the third year. The estimates of heritabilities at the level of plot means (h^2_m) were superior to the heritabilities within plots (h^2_d) in all years under study, demonstrating that selection based on plot means must be more effective than within plots. The h^2_m values varied from 53.34 to 92.10 and h^2_d from 5.80 to 23.61. However, the best progenies could be selected in the fifth year and then the best plants within each progeny, since the values of the two heritabilities were the highest during the eight years of production. The heritabilities in the years of high yields - third (82.53), fifth (92.10) and seventh (81.18) - were higher than in the low-yield years, with exception of the second (77.06), be it in the plot means or within plots. Probably, the phenotypic expression of the genotype is stronger in high yield years.

The coefficients of genotypic variation (CV_g), that express the quantity of existing genetic variation in

Table 3. Estimates of the genetic and environmental variances and genetic parameters for coffee cherry yield of Arabic coffee genotypes evaluated in the Pólo Regional do Nordeste Paulista (APTA Regional), Mococa (SP)

Year	Yield Mean	σ^2_g	σ^2_d	σ^2_e	σ^2_{ga}	h^2_m	h^2_d	CV_g	CV_e	b
	g plant^{-1}							—— % ——		
1st	1,541	36778.5687	560001.1536	187405.4994	-	53.34	6.60	12.44	28.09	0.44
2nd	296	14001.7681	117586.9179	18643.1124	-	77.06	11.91	39.96	46.11	0.87
3rd	7,165	981118.6913	8817251.4771	559396.8589	-	82.53	11.13	13.82	10.44	1.32
4th	1,517	96885.6250	1669916.3560	385998.8539	-	56.58	5.80	20.52	40.96	0.50
5th	7,628	3942170.3986	16694065.4308	618517.7328	-	92.10	23.61	26.03	10.31	2.53
6th	2,363	-	-	-	-	-	-	-	-	-
7th	6,879	2094804.1102	17214067.7438	1734373.2116	-	81.18	12.17	21.04	19.14	1.10
8th	2,755	417496.8770	5636279.1560	670508.6495	-	70.84	7.41	23.45	29.72	0.79
JA	3,768	276629.7715	-	1832297.0519	697743.9995	68.80	-	13.96	35.05	0.40

[1] σ^2_g = genetic variance among genotypes; σ^2_d = variance among plants within genotypes; σ^2_e = environmental variance; σ^2_{ga} = variance of the interaction genotypes x years; h^2_m = coefficient of heritability with plot means; h^2_d = coefficient of heritability within plots; CV_g = genetic variation coefficient; CV_e = environmental variation coefficient; b = variation index. JA = joint analysis

percentage of the overall mean, varied from 12.44 to 39.96% in the study years and was 13.96% in the joint analysis (Table 3). This shows that the selection of the best progenies enables an expressive increase in the genetic value of the population. Bonomo et al. (2004) found similar values, varying from 10 to 32%. the highest CV_g value was estimated in the second year, 39.96%, versus 13.82% in the third year (high yield). Considering that this parameter is related to the mean, which was low in the second year, the high estimated value was probably influenced by the mean. The high genetic variability of the fifth year demonstrated by a CV_g of 26.03% is noteworthy in spite of being the year of the highest yield.

The variation index b is the parameter that helps detect genetic variability in a population. This index is obtained by the relation between the coefficients of genetic and experimental variation, but unaffected by the trait mean. According to Vencovsky (1987) the b index has the advantage of showing the real magnitude of the increase of a trait in a study group of plants. When this relation is equal to or higher than 1.0 the condition is highly favorable for selection. The highest values were estimated in the years of high yields – the third (1.32), fifth (2.53) and seventh (1.10) - while in the other years the values were lower than 1.0. For the second year, the value of index b was 0.87, indicating that selection can not be performed in this year, in spite of the high estimated CV_g value. In the present study the indication of genetic variability in the population was therefore adequately represented by index b.

According to the data presented in Table 3 the high yield years offered more favorable conditions for selection, in view of the high values of variances and genetic parameters, the lower experimental errors, as well as the high yield potential of the treatments.

The values of the mean squares and estimates of genetic parameters regarding the agronomic traits of the Arabic coffee progenies and control cultivars are shown in Table 4. There were significant differences among the genotypes at 1% probability for all evaluated traits, indicating the existence of genetic variability in the study population. The genetic variances for plant height (PH), canopy diameter (CAD), seed types and sizes (SS) were higher than the environmental variances, which indicates a high genetic variability, contributing to the selection response (Vencovsky 1987). As in the case of cherry yield, the heritabilities at the level of plot means

Table 4. Values of the mean squares of the analyses of variance and estimates of the genetic parameters[1] regarding the agronomic traits[2] of the treatments of Arabic coffee evaluated in the Pólo Regional do Nordeste Paulista (APTA Regional), Mococa (SP)

Agronomic	Mean squares				Genetic parameters							
traits	Blocks	Treatment	Among plots	Within plots	σ^2_d	σ^2_g	σ^2_e	h^2_m	h^2_d	CV_g	CV_e	b
										%		
Plant height	642.7107	1017.8583**	296.7444	203.4223	11.2674	203.4223	11.6653	70.85	5.56	2.39	2.35	0.98
Canopy diamete	937.3301	5743.7474**	927.2875	423.9882	75.2572	423.9882	62.9124	83.86	17.75	4.63	5.07	1.10
Flat beans	241.4568	679.1999**	49.4186	37.9390	9.8403	37.9390	1.4350	92.72	25.94	1.46	3.82	2.62
Peaberry beans	98.0578	420.4692**	31.5949	25.5670	6.0761	25.5670	0.75352	92.49	23.77	7.12	20.2	12.84
Elephant beans	87.3992	627.1744**	22.8569	11.3030	9.4425	11.3030	1.4442	96.36	83.54	21.18	54.15	2.56
Seed size	1.4537	7.1659**	0.6336	0.3276	0.1021	0.3276	0.0382	91.16	31.16	1.17	1.91	1.64

** significant at 1% probability, by the F test

[1] σ^2_g = genetic variance in genotypes; σ^2_d = variance among plants within genotypes; σ^2_e = environmental variance; h^2_m = coefficient of heritability based on plot means; h^2_d = coefficient of heritability within plots; CV_g = genetic variation coefficient; CV_e = environmental genetic variation coefficient; b = variation index

(h^2_d) exceeded the heritabilities within plots (h^2_d), except for those of grains of the elephant bean type. For CAD, seed types and sizes one could select the best progenies first and then the best plants within each progeny, since the heritabilities within plots were high. Regarding CV_g, the values were only high for grains of the peaberry and elephant bean types, 20.21 and 54.15 respectively. On the other hand, the CV_e were low, except for elephant beans, expressing a good experimental precision. This contributes to the high estimates of the variation indices (b), indicating a successful selection. For plant height (PH) this index was close to 1.0.

In respect of the agronomic traits under study, the progenies 1 (IAC 3786), 3 (IAC 3788), 4 (IAC 4094), 5 (IAC 4095) and 8 (IAC 3429) were most outstanding with high yields, rust resistance and desirable grain types and sizes; and 7 (IAC 3425) for rust resistance, larger seed sizes and a more appropriate plant architecture for dense systems. In the future, these progenies could represent new cultivars or be used as plant genetic sources in crosses.

CONCLUSIONS

1. The progenies presented genetic variability for all agronomic traits, indicating a genetic potential that can be exploited effectively.

2. For coffee yield, the selection based on plot means resulted in a higher genetic gain.

3. In the years of high yields the conditions were more favorable for selection, since the genetic parameters estimated in these years were superior to those obtained in low-yield years.

4. The variation index b was a better indicator of genetic variability in a given population than the genotypic variation coefficient.

5. The progenies 1 (IAC 3786), 3 (IAC 3788), 4 (IAC 4094), 5 (IAC 4095), 7 (IAC 3425) and 8 (IAC 3429) stood out in relation to the agronomic traits studied. These progenies could be used as genetic sources or eventually be released as cultivar.

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Estimativas de parâmetros genéticos em cafeeiros tipo arábica derivados do híbrido de timor

RESUMO - *Objetivou-se estimar parâmetros genéticos em progênies de café arábica derivadas do cruzamento 'Villa Sarchi' x 'Híbrido de Timor', visando conhecer seu potencial para o melhoramento. O experimento seguiu o delineamento de blocos ao acaso, com dez tratamentos, oito repetições e oito plantas por parcela. Avaliaram-se a produção de café cereja, altura das plantas, diâmetro da copa, tipos de grãos e peneira média. Os resultados revelaram diferenças significativas entre os tratamentos em todas as características. Para a produção houve maior ganho quando se realizou a seleção com médias de parcelas, além dos anos de altas produções serem mais propícios à seleção. O índice de variação b foi a melhor indicação da variabilidade genética. Os progênies IAC 3786, IAC 3788, IAC 4094, IAC 4095, IAC 3425 e IAC 3429 destacaram-se quanto às características agronômicas avaliadas, constituindo-se em materiais genéticos de alto potencial agronômico. Todas as progênies apresentaram resistência à ferrugem-da-folha.*

Palavras-chave: *Coffea arabica*, genética quantitativa, parâmetros genéticos, variabilidade genética, produção.

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