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Estimates of genetic parameters and expected genetic gains with selection in robust coffee

Júlio César Mistro[1*], Luiz Carlos Fazuoli[1], Paulo de Souza Gonçalves[2] and Oliveiro Guerreiro Filho[1]

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ABSTRACT - *The present paper aimed to study the genetic variation of 15 half-sib progenies of robust coffea (*Coffea canephora *Pierre). The trial was conducted at the Instituto Agronômico de Campinas (IAC/APTA) in a randomized complete block design with seven replications and one tree-plot. Annual and joint analyses of variance were obtained to estimate the genetic parameters for yield, in order to quantify the genetic gain from selection in eight production years. The genotypic variation coefficients indicated expressive genetic variability for improvement of the yield. On account of the high variation in annual production, it is recommended that selection should be based on the general mean of the years. In low yield years, larger heritability values, coefficients of genetic variation, index of genotypic determination, and genetic gains were estimated.*

Key words: quantitative genetics, heritability, genetic improvement, genetic variability, yield.

INTRODUCTION

Among the 80 species of *Coffea* genus described to date, only two are of economic importance: *Coffea arabica* L. (Arabic coffee) and *Coffea canephora* Pierre (Robust coffea). Arabic coffee represents 70% of the national and global trade and robust coffee 30%. The largest world producers of robust coffee, in millions of sacs, are Vietnam (12.44), Brazil (11.50), Indonesia (5.84), Ivory Coast (3.30), and India (3.00). In Brazil, the State of Espírito Santo is the largest national producer (Anuário Estatístico do Café 2002/2003).

Coffea canephora is a diploid (2n = 22 chromosomes) and allogamous species, in which insects and wind are mainly responsible for pollination. Plants of this species are highly heterozygotes, presenting gametophytic incompatibility, caused by a S allelic serial in a single locus (Conagin and Mendes 1961).

This species is used for “blends” with arabic coffee in order to decrease the price of the final product. It is a rustic species, tolerant to diseases, insects and nematodes. Due to the good adaptation to low, hot, and humid regions, the *C. canephora* is of great interest for the State of São Paulo, because it would make planting possible in areas considered marginal for the Arabic coffee (Silva and Costa 1995).

Perennial plant species like the coffee plant present peculiar biological aspects: long vegetative and reproductive cycles in the same year and an accentuated annual yield oscillation after four or five years. The plant is weakened by a high annual yield and is prone to produce little in the following year, in agreement with Sera (1980) and Fazuoli et al. (2000), who worked with the Icatu variety of *Coffea arabica*. Furthermore, the environmental factors, as drought and cold, influence this oscillation. Such aspects demand rigid and precise selection methods for coffee improvement programs.

[1] Centro de Café “Alcides Carvalho”, Instituto Agronômico (IAC/APTA), C.P. 28, 13.001-970, Campinas, SP, Brasil. *E-mail: mistrojc@iac.sp.gov.br
[2] Centro de Café “Alcides Carvalho”, Programa Seringueira, IAC/APTA.

The introduction and research into original *C. canephora* populations from International Germplasm Centers, as that of Costa Rica, is of great importance in order to evaluate and to identify the most promising progenies, which may serve as basis for the development of new cultivars.

Information on the genetic variability of traits under improvement is extremely important and essential for the prediction of the progress. The quantification of the variability and estimates of genetic parameters are highly important, since they reveal more about the genetic structure of a population, aiding to make appropriate decisions on the selection methods to be chosen. Estimates of genetic parameters of *C. canephora* are hardly mentioned at all in literature, except by Fonseca (1999), who studied clones. In France, Leroy et al. (1994, 1997) studied reciprocal recurrent selection between the two groups of the species, and Cilas et al. (2000) studied a clone population.

The objective of this paper was to evaluate, based on eight yield years, genetic parameters that aid in the selection of superior progenies of the species *C. canephora*, cultivar Robust.

MATERIAL AND METHODS

From a population of 30 half-sib progenies of *Coffea canephora* of Asian origin, carried out at the Instituto Interamericano de Ciencias Agrarias (IICA) in Costa Rica, 15 Robust coffee progenies were evaluated.

In the Instituto Agronômico de Campinas (IAC/APTA) (lat 22 º 54 ’ S, long 47 º 05 ’ W and altitude 674 asl) the seeds were sown into polyethylene bags under nursery conditions. In the same year, these seedlings were transplanted to the field when they had developed three pair of leaves, in 3.5 m spacing between rows and 2.0 m between plants in a row. The local climate is tropical, with predominantly humid summers and dry winters with low temperatures and smaller pluvial precipitations. The annual medium temperature is 22 ºC and the annual precipitation 1.380 mm. In general, the contrast between evapotranspiration and monthly rain curves creates a favorable balance for growth and production between October and April, while water deficiency and low thermal levels are characteristic May through September.

The field trial was established according to a randomized block design with 15 progenies, in seven replications and one tree-plot. Eight years of cherry-coffee yield were evaluated, by means of the total weight (in kg) of fruits per plant.

In the variance analyses, each progeny represented a treatment, each plot a replication and each year an environment. All effects used in the variance analyses were considered to be random. The estimates of the variance components were obtained according to Vencovsky and Barriga (1992). The joint analysis was realized using the randomized block design, in split-plots in time (Steel and Torrie 1980), since successive measures were carried out on a same plot, in a certain time intervals (Table 1).

Broad-sense heritabilities for the joint analysis, which consider the progenies x years interaction, were estimated in agreement with Vencovsky and Barriga (1992):

Table 1. Expected mean square [E(MS)] of joint analyses to estimate components of variance[1]

Sources	df	MS	E(MS)
Replications	r - 1	MS_6	$\sigma^2_{eb} + \sigma^2_{ea} + py\sigma^2_r$
Progenies (P)	p - 1	MS_5	$\sigma^2_{eb} + y\sigma^2_{ea} + r\sigma^2_{py} + ry\sigma^2_p$
Error a	(r - 1) (p - 1)	MS_4	$\sigma^2_{eb} + y\sigma^2_{ea}$
Years (Y)	y - 1	MS_3	$\sigma^2_{eb} + r\sigma^2_{py} + rp\sigma^2_y$
P x Y	(y - 1) (p - 1)	MS_2	$\sigma^2_{eb} + r\sigma^2_{py}$
Error b	p (r - 1) (y - 1)	MS_1	σ^2_{eb}

σ^2_{ea} = variance due to environmental error among plots; σ^2_{eb} = variance due to environmental error among subplots; σ^2_p = variance due to differences among progenies; σ^2_y = variance due to differences among years progenies; σ^2_{py} = variance due to interactions of progenies and year; p = number of progenies; r = number of replications; y = number of years.

$$h^2 = \frac{\hat{\sigma}^2_p}{MS_5 / ry}$$

The genetic variation coefficient ($CV_g\%$) was estimated using the equation (Vencovsky and Barriga 1992):

$$CV_g\% = \left(\frac{\sqrt{\hat{\sigma}^2_p}}{\bar{X}}\right)$$

Similarly, the phenotypic variation and experimental variation coefficient were estimated, where $\bar{X}$ represents the general mean corresponding to the annual yield.

In order to detect the genetic variability of the coffee yield in the population, index b was used (Cruz and Regazzi 1997), as follows:

$$b = \frac{CV_g}{CV_e}$$

Index *b* represents the ratio between the coefficient of genetic variation and the coefficient of experimental variation. It is therefore not influenced by the mean of the character.

The expected selection gain (G_s) was estimated according to Vencovsky (1987):

$$G_s = i\left(\frac{\hat{\sigma}^2_p}{\sqrt{\hat{\sigma}^2_F}}\right)$$

where $\hat{\sigma}^2_F$ = ***MS_5/ry; i*** is the coefficient associated to the progenies percentage selected among the 15 progenies, which corresponds to the selection differential. For each annual yield, different selection intensities were used. As the number of progenies was inferior to 50, ***i*** was calculated using Becker’s table (Becker 1984).

The genetic gain from selection in percentage was estimated using the expressions presented by Vencovsky (1987)

$$G_S\% = \left(\frac{G_S}{\bar{X}}\right)100$$

RESULTS AND DISCUSSION

The mean annual yield of cherry-coffee per plant (kg plant^{-1}) of the progenies of Robust coffee, as well as the variation coefficients, between years and progenies, are shown in Table 2. Yields were highest in the second (3.38), fourth (6.84), fifth (3.42), and seventh year (9.49), while in the first (0.47), third (1.31) and sixth year (1.29) the production was low. Characteristically, an ascendant production until the fourth or fifth year would be expected in Arabic species (Fazuoli et al. 2000), but this trend was interrupted in the third year. In this year production dropped drastically, owing to frosts registered in the second year, where the absolute minimum temperatures plunged to 0 ºC (data supplied by the Center of Research and Development of Ecophysiology and Biophysics - IAC/APTA) and detracted from the production of the third year by causing burns of several floral yolks.

From the fifth year on, the beginning of the biennial cycle was observed, in which years of high and low yields alter, as described by Sera (1980) for Arabic coffee. Examples to this were the fifth and seventh year with high yields, while production slumped considerably in the following years, in consequence of the physiologic wear of the plants. Variation coefficients of the half-sib progenies were relatively high. However, values of these magnitudes are common in Arabic and Robust coffee trials.

Mean squares values of the variance analyses concerning the annual coffee yields are presented in Table 3. Except for the seventh yield year, highly significant differences ($P < 0.01$) were observed among the progenies, indicating variability in yield, which is an important condition for coffee improvement programs.

By the mean squares of joint variance analyses (Table 4), a significant ($P < 0.01$) effect was observed for the progenies x years interaction since the progenies production presented a varying performance along the years, as shown clearly by progenies 2, 3, 7, and 11 (Table 2), which presented the largest variation coefficients among years.

Estimates of the genotypic were smaller than the environmental variances in each year and in the joint analysis (Table 5). Estimates of the heritability coefficients (h^2) were low, due to a larger contribution of the environmental variance in the phenotypic expression. Annual heritability estimates were larger than in years with low yields.

The genetic variation coefficients ($CV_g\%$), which express the amount of genetic variation in percentage of the general mean, are of great importance for genetic improvement programs. They show the range of genetic variation of a character, in view of its improvement potential (Valois et al. 1980). The range of genetic variation coefficients - from

Table 2. Annual mean of cherry-coffee production per plant (kg plant^{-1}), and of the variation coefficient (CV%) of the 15 half-sib progenies of robusta coffee

Progenies	Years									
	1st	2nd	3rd	4th	5th	6th	7th	8th	Mean	CV
	kg plant^{-1}									%
1	0.85	4.27	0.85	11.93	6.37	0.31	13.05	4.60	5.28	93.75
2	0.15	1.91	1.30	6.21	3.74	0.40	11.11	2.33	3.39	108.55
3	0.47	3.84	1.39	6.89	2.70	0.28	12.71	2.22	3.81	109.45
4	0.26	4.17	2.10	6.72	3.73	0.56	8.07	2.37	3.50	79.43
5	0.71	3.84	2.02	5.94	4.51	3.81	6.22	4.11	3.90	47.18
6	0.61	4.16	0.70	5.95	1.73	2.40	4.75	3.15	2.93	65.87
7	0.46	1.71	0.86	4.34	3.37	0.11	10.12	1.25	2.77	119.14
8	0.23	2.41	0.61	5.55	2.51	0.75	6.46	3.23	2.72	84.56
9	0.34	2.90	0.99	5.55	3.10	0.99	9.88	1.75	3.19	99.37
10	0.64	5.49	0.89	8.53	3.91	2.30	12.42	3.71	4.74	84.81
11	0.00	1.49	0.67	6.21	1.03	0.20	4.81	1.50	1.99	114.07
12	0.50	4.30	1.13	11.09	3.29	2.82	12.14	4.76	5.00	86.80
13	0.74	4.01	1.71	6.89	2.86	1.59	10.45	4.75	4.12	78.64
14	0.36	4.13	2.15	6.64	6.14	1.10	9.16	2.16	3.98	77.64
15	0.67	2.03	2.25	4.10	2.27	1.71	10.91	2.60	3.32	96.69
Mean	0.47	3.38	1.31	6.84	3.42	1.29	9.49	2.97	3.64	-
CV (%)	51.43	35.55	45.04	57.28	42.37	52.75	61.17	68.47	70.02	-

Table 3. Annual mean square values of the analysis of the variance for cherry coffee production of 15 half-sib progenies of robusta coffee

Sources of variation	Years								
	df	1st	2nd	3rd	4th	5th	6th	7th	8th
Replications	6	0.109	1.896	0.457	11.208	3.097	0.601	68.038	6.103
Progenies	14	0.411**	10.098**	2.434**	34.635**	14.717**	9.949**	55.545	9.705**
Error	84	0.091	2.518	0.443	15.939	5.531	0.873	33.673	4.310

** = $P < 0.01$.

Table 4. Mean square values of the joint analyses of variance of cherry coffee production, coefficients of experimental variation among progenies (CV_p) and among years (CV_y) of 15 half-sib progenies of robusta coffee

Sources of variation	df	Mean square
Replications	6	14.530
Progenies (P)	14	47.318**
Error a	84	12.900
Years (Y)	7	986.024**
P x Y	98	12.671**
Error b	630	7.237
CV_P %		24.80
CV_y %		72.92

** = $P < 0.01$ probability.

Table 5. Estimates of annual and joint analyses of genotypic, environmental, phenotypic, components of variance and broad-sense heritability coefficient (h^2) for cherry coffee production of 15 half-sib progenies of robusta coffee

Annual production	$\hat{\sigma}^2_p$	$\hat{\sigma}^2_{ea}$	$\hat{\sigma}^2_F$	$\hat{\sigma}^2_{py}$	h^2
1st Year	0.046	0.091	0.137	-	0.33
2nd Year	1.083	2.518	3.601	-	0.30
3rd Year	0.284	0.444	0.728	-	0.39
4th Year	2.671	15.939	18.610	-	0.14
5th Year	1.312	5.531	6.843	-	0.19
6th Year	1.297	0.873	2.170	-	0.60
7th Year	3.211	33.067	36.278	-	0.09
8th Year	0.771	4.310	5.081	-	0.15
Joint	0.615	1.433	2.824	0.776	0.22

$\hat{\sigma}^2_p$ = genotypic variance due to differences among progenies; $\hat{\sigma}^2_{ea}$ = environmental variance among plots; $\hat{\sigma}^2_F$ = phenotypic variance based in individual plants; $\hat{\sigma}^2_{py}$ = variance due to interactions of progenies and year.

Table 6. Estimates of the coefficients of genotypic (VC_g%), experimental (VC_e%) and phenotypic (VC_F%) variations and the index "b" of the 15 half-sib progenies of robusta coffee

Annual production	VC_g	VC_e	VC_F	"b"
	%			
1st	45.54	64.22	78.73	0.71
2nd	30.79	39.57	47.32	0.78
3rd	40.70	50.85	65.13	0.80
4th	23.89	57.28	61.89	0.42
5th	33.50	68.77	76.49	0.49
6th	88.28	62.71	98.86	1.41
7th	18.62	60.59	63.47	0.31
8th	29.56	68.52	74.39	0.43
Joint	21.55	71.50	46.17	0.30

18.62 to 88.28% - indicate that there is enough genetic variance available for yield improvement, in spite of the larger CV_e% estimates. The phenotypic variation coefficients (CV_p%) ranged from 46.17 to 98.86% (Table 6).

Index *b* is a parameter that helps detect the genetic variability in a population. According to Vencovsky (1987), this index has the advantage of revealing the real magnitude of the increment of a character in a study group of individuals. When the value is equal to or larger than 1.0, in maize trials, conditions are highly favorable for selection. Values in the present progeny trial were inferior to 1.0, due to the larger value of the environmental in relation to the genetic variation coefficient, with exception of the sixth year (*b* = 1.41). The first, second, third, and sixth year presented the highest indices indicating them as selection-favorable years.

The progresses from selection varied considerably among the different production years (Table 7). There was a superior progress in the first, third and sixth year, regardless of the numbers of selected progenies. In these years, a larger number of progenies could be selected, attaining remarkable genetic gain.

In the first, third, and sixth years the genetic parameter values were higher, for instance, the heritabilities, genetic variation coefficients, and the index b. In function of the high variation in the annual production, it is recommended that the selection should be based on the general mean of the years.

Table 7. Expected gains from different selection levels and in percentage of the means among progenies selection for eight years of production in 15 progenies of robusta coffee

Selection level(1)		Annual expected gain (%G_s) in percent of the mean								
n	i	1st	2nd	3rd	4th	5th	6th	7th	8th	Joint
2	1.495	39.53	25.24	38.00	13.53	21.92	102.04	8.40	17.21	15.03
3	1.313	34.72	22.17	33.36	11.88	19.25	89.62	7.38	15.12	13.20
4	1.163	30.75	19.64	29.55	10.52	17.05	79.38	6.53	13.39	11.70
5	1.034	27.34	17.46	26.27	9.36	15.16	70.57	5.80	11.91	10.40
6	0.918	24.27	15.50	23.32	8.31	13.46	62.65	5.15	10.57	9.23
7	0.811	21.44	13.69	20.60	7.34	11.89	55.35	4.56	9.34	8.15

(1) n = number of selected progenies. i = selection differential in standard measure (after Becker 1984).

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Estimativas de parâmetros genéticos e ganhos esperados com a seleção em café robusta

RESUMO - *O presente trabalho objetivou estudar a variação genética de 15 progênies de meios-irmãos de café robusta (*Coffea canephora *Pierre). O experimento foi instalado no Instituto Agronômico de Campinas (IAC/APTA), em delineamento de blocos ao acaso com sete repetições e uma planta por parcela. A partir das análises anual e conjunta de variância estimaram-se parâmetros genéticos para a produção, a fim de quantificar o ganho genético com a seleção em oito anos de produção. Os valores dos coeficientes de variação genética indicaram expressiva variabilidade genética para melhoramento da produção. Em função da alta variação na produção anual, recomenda-se que a seleção seja baseada na média geral dos anos. Em anos de baixas produções estimaram-se maiores valores de herdabilidades, coeficientes de variação genética, índice de determinação genotípico e ganho genético.*

Palavras-chave: genética quantitativa, herdabilidade, melhoramento genético, variabilidade genética, produção.

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