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Selection for frost resistance in *Coffea arabica* progenies carrying *C. liberica* var. *dewevrei* genes

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ABSTRACT - *This research was carried out to estimate the variability and genetic parameters for the development of cultivars more frost resistant in* Coffea arabica *progenies, carrying* C. liberica *var.* dewevrei *genes. There is genetic variability for frost resistance in progenies with* C. liberica *var.* dewevrei *genes. The rust resistance, vegetative vigor and yield potential should be considered when developing cultivars adapted to frost occurrence areas. Cultivars with yield precocity such as IAPAR 59, that allows a faster recovery yield after a severe frost, minimizing the damage from the phenomenon. The use of index selection is efficient to select simultaneously progenies with greater frost adaptation, vegetative vigor, rust resistance and yield.*

Key words: coffee crop, breeding, frost resistance, genetic parameters, index selection.

INTRODUCTION

Frost is one of major problems in coffee crop, especially in the states of Paraná, São Paulo and south Minas Gerais, where a severe frost occurs every 5 to 6 years (Caramori and Manetti Filho 1993).

There is some controversy about the possibility of obtaining coffee cultivars more resistant to frost, especially because of *Coffea* spp. came originally from tropical climate regions and because it is difficult to separate the genetic and environmental effects when assessing frost resistance.

The existence of genetic variability for frost resistance among *Coffea* species and among *C. arabica* accessions has been reported in previous studies. The Fundação Instituto Agronômico do Paraná (1978) reported that the *C. liberica* var. *dewevrei* and *C. racemosa* species are 30% less susceptible compared with the best *C. arabica* genotypes for frost resistance. Among the *C. arabica* cultivars, Mundo Novo is 30% less susceptible to radiation frost than Catuaí (Caramori and Sera 1979) and Catuaí is 30% less susceptible to wind frost than Mundo Novo (Sera 2001). Androcioli Filho et al. (1986) indicated that *C. arabica* cv. Villalobos is 15% less susceptible to radiation frost than Catuaí and that genotypes with later maturation are

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more susceptible to frost.

Söderholm and Gaskins (1981) reported differences in frost resistance among *C. arabica* accessions and indicated *C. racemosa* as the *Coffea* species most resistant to frost. Triller et al. (2001) detected genetic variability among *C. arabica* species and accessions confirming *C. racemosa* and *C. liberica* var. *dewevrei* as more resistant than *C. arabica* and *C. canephora*.

Bauer et al. (1990), testing the susceptibility of central African *C. arabica* cultivars to frost, classified the normal canopy size cultivars K7, SL28 and K33 as relatively resistant, 'Mundo Novo' as intermediate and 'Agaro' and 'Geisha' as more susceptible. The 'Caturra', 'Catuaí Vermelho' and 'Catuaí Amarelo' were more susceptible than 'Geisha'.

Sentelhas et al. (1995) reported that 'Catuaí Vermelho', 'Mundo Novo', 'Icatu Vermelho' and 'Icatu Amarelo' are not different for lethal temperature, that is, -4 ^{0}C. The *C. racemosa* and *C. liberica* var. *dewevrei* species were shown to be more resistant, with a lethal temperature of -6 ^{0}C and -5 ^{0}C, respectively, while the *C. brevipes* species was the most susceptible, with lethal temperature of -2 ^{0}C.

Frost resistance in coffee trees is greatly influenced by other traits. To express all the resistance potential of a cultivar, precise knowledge of the association between frost resistance and other agronomic traits is fundamental. Correlation studies among various agronomic characteristics and the 1994 frost damage in *C. arabica* lines indicated that coffee plants without rust, better nourished and with more vegetative vigor were less damaged to the frost of -1 ^{0}C (shelter temperature) turning severe damage into moderate damage. Thus, a cultivar that have both, yield and vegetative vigor will be less damaged to most of the severe frosts, minimizing to the moderate damage that is perfectly tolerable economically.

The objective of this research was to detect the existence of variability, estimate parameters, study correlations and predict the genetic gain with selection to develop cultivars more resistant to frost using *C. arabica* progenies carrying *C. liberica var. dewevrei* genes.

MATERIAL AND METHODS

The present study was carried out in a typical distrofic purple latosoil in the Londrina Production and Experimentation Center of the Agronomic Institute of Paraná (IAPAR), with mean annual temperature of 20.8 ^{o}C, lat 23^o 22' S, long 51^o 10' W, and alt 585 m asl. The trial was set up in May 1997 with randomized complete block design, three replications, 14 treatments and 10 plant plots^{-1}, spaced at 2.5 x 0.5 m.

Plant material

The experiment consisted of 14 treatments of 12 F_3 progenies from a natural cross between 'Catuaí' and 'Piatã' (*C. arabica* x (*C. liberica* var. *dewevrei* x *C. arabica*)) and the controls 'Catuaí Vermelho IAC 81' (treatment 2) and 'IAPAR 59' (treatment 1).

Traits evaluated

Frost damage (F00) was assessed after the severe frost in July 2000 (minimum temperature in the meteorological shelter = -1.3 ^{o}C). A scale of scores was used: 1 = 0% damage, 2 = 25% damage, 3 = 50% damage, 4 = 75% damage and 5 = 100% damage, elaborated by Manetti Filho and Caramori (1986) when assessing young plants tested in a cold chamber, adapted for adult plants.

The vegetative vigor of each plant was estimated before yield in 2000 (V00) and 2002, the first yield after the plants were pruned back after the 2000 frost. Two traits were considered in the analyses, vegetative vigor in 2000 (V00) and the 2000 and 2002 mean vigor (Vm). Each plant was assessed by a scale that ranged from 1 to 5, where 1 = yellow plant with abundant branch drying and 5 = dark green plant with abundant ramifications and heavy bean load.

Rust resistance (R) was assessed by a scale of scores ranging from 1 to 5, where 1 = absence of pustules, pustules without spores, 2 = few leaves with pustules and with few spores, 3 = few pustules per leaf with high spore production but little distributed, 4 = mean quantity of pustules per leaf, distributed on the plant with high spore production and 5 = high quantity of pustules with high spore production and high leaf drop. No disease or pest control treatments were performed during the experiment.

Bean size (BS) was assessed by attributing scores from 1 to 5 using commercial cultivar bean size known as standard, where 1 = (tiny) similar to 'Mokka', 2 = (small) similar to 'Icatu Precoce IAC 3282', 3 = (medium size) similar to 'Catuai Vermelho IAC 81', 4 = (large) similar to 'Acaiá IAC 474-7' and 5 = (giant) similar to 'Maragogipe'.

Plants were classified according to fruit maturity (M) as: very late, late, medium, early and very early receiving the scores of 1, 2, 3, 4 and 5, respectively, using as standard cultivars, Catuaí Vermelho IAC-81 (late) and IAPAR-59 (Medium).

The yield potential (Y) of each plant was estimated in liters of cherry fruits, by visual assessment, taking into consideration the fruit size, number of fruit rosette^{-1} and number of rosette with fruits. The yield in liters of cherry fruits plant^{-1} was transformed to yield ha^{-1} with different numbers of plants ha^{-1} according to the plant size. Four different plant size and respective spacing with plants ha^{-1} were used: smaller than the IAPAR 59 cultivar = 2.0 x 0.4 m, similar to 'IAPAR 59' = 2.0 x 0.5 m, similar to 'Catuai' = 2.5 x 0.6 m and similar to 'Mundo Novo' = 3.0 x 0.7 m. This assessment was carried out in 2000 and 2002 considering two traits; the yield potential assessed in 2000 (Y00) and the average yield potential estimated in 2000 and 2002 (Ym).

Statistical analyses

Analyses of non additivity and the F test for heterogeneity of variances were performed according to Ramalho et al. (2000) for the data of all the traits assessed. All the estimates were carried out using the Genes software (Cruz 2001).

Analyses of variance were performed at the level of treatment means in the trial. The Duncan test at 5% probability was performed to compare the means of all the traits. The existence of genetic variability was assessed by analyses of variance performed between and within of the progenies carrying *C. liberica var. dewevrei* genes. Based on the mean square (MS) of analyses of variance, among and within the progenies of all the traits, it were estimated the genetic variance among the progenies $\left[\sigma^2_{gp} = \frac{MS_p - MS_{r(ap)}}{b \times n}\right]$, the genetic variance within the progenies $\left[\sigma^2_{gi} = \theta_i / \theta_p \times \sigma^2_{gp}\right]$

It was adopted that $\theta_i = 1/2$ *and* $\theta_p = 1/2$, because, the progenies are in the F_3 generation, but as one of the parents is an interespecific hybrid, they are holding such as F_2 progenies, the phenotypic variance within the progenies $\left[\sigma^2_{pw} = MS_{wp}\right]$ and the residual variance $\left[\sigma^2_e = \frac{MS_{r(ap)} - MS_{wp}}{n}\right]$, where; MS_p = mean square of progenies, $MS_{r(ap)}$ = mean square of residue among plots, b = number of blocks, n = numbers of plants $plots^{-1}$ and MS_{wp} = mean square within the progenies. The estimates of genetics variances are considered maximum, because it is not possible to separate the dominance effects, and the interactions genetics x year, genetics x place and genetics x place x year. Then, the coefficient of genotypic determination maximum at the mean progenies level $\left[b^2_m = \frac{\sigma^2_{gp}}{MS_p / b \times n}\right]$ and coefficient of genotypic determination maximum at the level of individuals within of progenies $\left[b^2_i = \sigma^2_{gi} / \sigma^2_{pw}\right]$ were estimated.

The expected genetic gain (*GS*) from direct selection towards less frost damage was estimated from an established low selection pressure, 50% among the progenies and 30% within the progenies by the expression: $GS = b^2 \times DS$ (where; b^2 = coefficient of genotypic determination maximum; DS = selection differential).

The indirect selection gain caused on the other traits of agronomic interest by direct selection towards less frost damage was also estimated by the coefficient of genetic regression by the expression: $GS_{j(i)} = \left(COV_{g(x_i;x_j)} / \sigma^2_{gi}\right) \times GS_i$ (where; $GS_{j(i)}$ = indirect selection gain for j trait by selection in the i trait; $\left(COV_{g(x_i;x_j)} / \sigma^2_{gi}\right)$ = genetic coeficient regression among i and j traits and GS_i = genetic direct gain in the i trait).

The index selection of Smith and Hazel (Cruz and Regazzi 1997) was used to select progenies with high aggregate genotypic value, including frost damage, high yield associated to vegetative vigor which is considered an indicator of future high yield and rust resistance. This index is a linear combination of the various important traits that have weight values in the index chosen to maximize the correlation between the index (I) and the agregate genotypic (H) value (Cruz and Regazzi (1997), where the index (*I*) and the agregate genotypic (*H*) are expressed respectively by

$$I = b_1x_1 + b_2x_2 + \ldots + b_nx_n = \sum_{i=1}^{n} b_ix_i = bx'$$

$$H = a_1g_1 + a_2g_2 + \ldots + a_ng_n = \sum_{i=1}^{n} a_ig_i = ag'$$

where n = number of traits in the index; x' = vector (1 x n) of means; g' = vector (1 x n) of genetic values; b = vector (n x 1) of phenotypic coefficients of the indexes; a = vector (n x 1) of economic weights established.

The weights of coefficients were established according to the economic importance of the traits, the proportionality of the traits, the existing genetic variability and the estimates of genetic correlation among the characteristics. The proportionality of scale among the characteristics was respected (Cruz and Regazzi 1997) so that all remained in the same unit, that is, traits with scale from 1 to 5 were multiplied by 10, to be in the same unit as the yield potential, whose values are in dozen. The existing genetic variability (CV_g%) in each traits was considered (Cruz and Regazzi 1997) and greater weights were established for those with lower genetic variation coefficient (CV_g %) because selection on these traits is less efficient. The direction and magnitude of the values of the genetic correlation coefficients were considered because frost damage, that is the main trait of this study, is influenced by other traits (Petek et al. 2002). The weights established were 700, 30, 30, 10, 30 and 25, respectively for the traits less frost damage (F00), greatest vegetative vigor in the frost year (V00), greatest resistance to rust (R), greatest yield potential in the frost year (Y00), greatest mean vegetative vigor in 2000 and 2002 (year of the first production after being pruned in 2000) (Vm) and greatest potential of mean yield in 2000 and 2002 (Ym). From the weights established, the phenotypic coefficients of the indexes were estimated by

$b = P^{-1}Ga$

where b = vector (n x 1) of phenotypic coefficients of the indexes; P^{-1} = inverse matrix (n x n) of phenotypic covariances among the traits; G = matrix (n x n) of genetic covariances among the traits; a = vector (n x 1) of economic weights established.

The indexes established and used to predict the genetic progress in selection among and within progenies were respectively;

$$I_a \quad 668.34 \; F00 \quad 534.71 \; V00 \quad 344.06 \; R \quad 20.28 \; Y00 \quad 599{,}08 \; Vm \quad 24.96 \; Ym$$

$$I_w \quad 113.49 \; F00 \quad 17.95 \; V00 \quad 21.69 \; R \quad 1{,}75 \; Y00 \quad 7.14 \; Vm \quad 3.38 \; Ym$$

The genetic gains for each trait, when selection is made on the index, is expressed by; $\Delta_{gi(I)} = \beta_{giI} \times DS$, where, $\hat{a}_{gjI}$ is the estimator of the regression coefficient of the genetic values of the trait j in function of the I index and DS is the selection differential among the individuals selected and the original mean in relation to the index.

RESULTS AND DISCUSSION

Genetic variability

Analysis of variance at the level of treatment means (Table 1) presented significant differences for all the traits assessed at 1% probability by the F test. The coefficients of experimental variation for the traits assessed ranged from 3.32 to 27.29% showing good experimental accuracy. The traits rust resistance (R), yield potential in the frost year (Y00) and mean yield potential of 2000 and 2002 (Ym) presented experimental variation coefficients greater than 20% but are values considered normal due the annual oscillation in production and correlation between rust intensity and yield.

Analyses of variance between and within the 12 progenies derived from the 'Catuaí' and "Piatã" cross (Table 2), showed that there were significant differences between the means at 1% probability by the F test for all the traits assessed. This indicates the existence of variability among these progenies and consequently the possibility of success with selection. The possibility of obtaining gain with selection between these progenies is also shown in the high values of the estimates of maximum coefficients of genotypic determination at the level of means of the traits correlated with frost damage (Petek et al. 2002) that ranged from 0.649 for rust resistance (R) to 0.819 for mean vegetative vigor in 2000 and 2002 (Vm) (Table 2).

The estimates of the maximum coefficients of genotypic determination, within progenies, ranged from 0.082 for vegetative vigor in the frost year (V00) to 0.213 for bean size (BS) (Table 2). In spite of low maximum genetic determinism, this estimate is fundamentally important to know the variability at individual level within progenies and select efficiently plants that present general merit for the development of cultivars more resistant to frost. These low values obtained are due to an environmental effect among the individuals, within the plot, that cannot be isolated.

The mean of the 12 progenies derived from the "Piatã" x 'Catuaí' (Table 1) obtained for frost damage was 4.32, that is, equivalent to more than 75% damage. This high mean is due to the fact that the frost of 2000 is considered severe (minimum temperature in the shelter = -1.3 ^{0}C) and because of this, any minimum difference becomes very important. Duncan test at 5% of probability indicated progenies less damaged by frost than controls. Progenies 13, 5, 14, 7 and 12 presented mean damage lower than control 'IAPAR 59' (mean = 4,76). Numbers 13, 5 and 14 differed significantly from the control 'Catuaí Vermelho IAC 81' (mean = 4.52) (Table 3). Of these, progenies 13, 14 and 12 were also the best in yield and bean size.

On the scale of bean maturity the progenies can be classified as late, since the 'Catuaí' parent is late maturity and "Piatã" is very late maturity. However there is the possibility of selection for earlier maturity as some progenies presented maturity period similar to the 'IAPAR 59' cultivar, that is, medium maturity. Obtaining early materials is important as an escape from frost on the unripe fruit of the year (Table 3).

For the yield potential assessed in 2000 and the mean 2000 and 2002 yield potential, eleven progenies presented values similar to the Catuaí Vermelho IAC 81 cultivar, because they did not differ significantly by the Duncan test (Table 3). The IAPAR 59 cultivar presented yield potential superior to all the treatments because this cultivar has yield precocity and it was clear that progenies derived from the "Piatã" x 'Catuai' cross didn't possess this characteristic, so 'Catuaí' should be used as a better comparative standard for this case (Table 3).

When yield between the Catuaí and IAPAR 59 cultivars is compared, either in the frost year (2000) or in the mean yield of the frost year and the first yield after severe frost, 'IAPAR 59' has, respectively, yields approximately 25% and 45% greater than 'Catuaí'. This indicated yield precocity in the IAPAR 59 cultivar, or quicker recovery of economic yield that makes it an important adaptive trait of this cultivar to minimize frost damage.

Expected genetic gains with selection

The estimated genetic gain with direct selection of 50% of the progenies, for greater frost resistance, was 3.35% and with selection of 30% of the less damaged plants within the selected progenies was 2.33%, therefore, the total estimated selection gain was 5.68%. With this gain, the mean estimated for frost damage to the next generation was 4.07 (94.21%) against 4.32 (100%) of the original mean. Therefore, even with low selection intensity, satisfactory genetic progress towards frost resistance may be obtained. The use of fairly low selection intensity was because yield had been assessed in a first high yield and the mean of

Table 1. Summary of the analyses of variance for all the traits assessed

Sources of Variation	df	Mean Squares[1]							
		F00	V00	R	M	BS	Y00	V m	Ym
Blocks	2	0.170	0.164	0.105	0.759	0.009	215.920	0.104	7.794
Treatments	13	0.243**	0.075**	1.612**	0.434**	0.181**	430.355**	0.087**	206.177**
Error	26	0.055	0.024	0.261	0.122	0.038	75.578	0.014	40.656
Mean		4.36	3.19	1.87	2.54	3.03	38.45	3.48	26.77
CVe(%)		5.42	4.90	27.29	13.75	6.46	22.61	3.32	23.81

*, ** Signifcant at 5% and 1% of probability by the F test

[1]F00 = frost damage; V00 = vegetative vigor in 2000; Vm = 2000 and 2002 mean vigor; R = rust resistance; BS = bean size; M = fruit maturity; Y00 = yield potential assessed in 2000; Ym = average yield potential estimated in 2000 and 2002 (Ym)

Table 2. Summary of the analyses of variance and genetic parameters among and within of the progenies derived from "Piatã" x 'Catuaí' for all the traits assessed

Sources of variation	df	Mean Squares[1]							
		F00	V00	R	M	BS	Y00	Vm	Ym
Progênies	11	2.278**	0.808**	7.789**	3.542**	1.407**	2582.997**	0.827**	1490.131**
Residue[2]	22	0.580	0.259	2.731	1.055	0.255	788.614	0.149	463.387
Within Prog.	324	0.318	0.224	1.213	0.544	0.180	502.578	0.160	248.027
Mean		4.32	3.20	1.79	2.46	2.99	35.17	3.50	24.92
CVe %		5.58	5.02	29.22	13.22	5.33	25.25	3.48	27.32
Genetic Parameters[1]									
Parameters[2]		**F00**	**V00**	**R**	**M**	**BS**	**Y00**	**Vm**	**Ym**
σ^2_{gp}		0.057	0.018	0.169	0.083	0.038	59.813	0.023	34.225
σ^2_{gi}		0.057	0.018	0.169	0.083	0.038	59.813	0.023	34.225
σ^2_{pw}		0.318	0.224	1.213	0.544	0.180	502.578	0.160	248.027
σ^2_{e}		0.026	0.003	0.152	0.051	0.007	28.604	0.00	21.536
b^2_m		0.745	0.679	0.649	0.702	0.818	0.695	0.819	0.689
b^2_i		0.178	0.082	0.139	0.152	0.213	0.119	0.141	0.138

*, ** Signifcant at 5% and 1% of probability by the F test

[1]Coded as in Table 1

[2] = Experimental error among plots; σ^2_{gp} = genetic variance among the progenies; σ^2_{gi} = the genetic variance within the progenies; σ^2_{pw} = the phenotypic variance within the progenies; σ^2_e = residual variance; b^2_m = coefficient of genotypic determination maximum at the mean progenies level; b^2_i = coefficient of genotypic determination maximum at the level of individuals within of progenies

this with the first yield after being pruned back. The literature indicates that at least six first assessment yields are needed to select the best materials for 15 to 20 yields (Carvalho 1952, 1988). According to Fazuoli et al. (2000) it is possible with three consecutive years of harvest to have high efficiency of 77.8 to 87.7% in selection of the best "Icatu" coffee progenies using 25% selection intensity. However, the IAPAR Coffee Breeding Program is inserted in a set of methodologies to decrease the time spent to obtain improved cultivars and one of these methodologies is the practice of early low intensity selection, so as not to run the risk of losing valuable materials based on one or two harvests and using traits related to yield. This methodology requires more area to carry out experiments, but reduces the time in generation advance that is one of the key points in reducing the time in developing improved coffee cultivars (Sera 2001).

There are correlations between frost damage and

Table 3. Means for all the traits assessed

T[1]	F00		V00		R		M		BS		Y00		Vm		Ym	
13	3.76	a[3]	3.17	b-d	1.73	ab	2.67	a-d	3.13	b-d	42.00	b-d	3.53	b-d	31.47	b
5	4.00	ab	3.40	ab	1.20	a	2.12	d	2.61	f	28.03	cd	3.83	a	19.02	bc
14	4.06	ab	3.33	a-c	1.67	ab	2.47	b-d	3.00	c-e	36.29	b-d	3.68	ab	30.48	b
7	4.26	bc	3.39	ab	1.44	a	2.48	b-d	3.00	c-e	39.19	b-d	3.63	ab	26.89	bc
12	4.26	bc	3.03	cd	2.00	ab	2.42	b-d	3.40	ab	43.81	b-d	3.40	c-f	32.09	b
8	4.33	b-d	3.00	d	2.47	b	3.00	ab	3.18	bc	41.76	b-d	3.30	ef	28.89	bc
4	4.35	b-d	3.11	b-d	1.69	ab	2.26	cd	3.00	c-e	27.34	cd	3.50	b-e	20.68	bc
6	4.36	b-d	3.50	a	1.30	a	2.37	b-d	2.93	c-f	47.85	bc	3.63	a-c	31.29	b
9	4.41	b-d	3.13	b-d	1.45	a	2.16	d	2.74	ef	38.19	b-d	3.46	b-e	28.46	bc
10	4.46	b-d	3.23	a-d	1.33	a	2.09	d	2.79	d-f	38.74	b-d	3.48	b-e	28.04	bc
T-Cí	**4.53**	**c-e**	**3.03**	**cd**	**3.70**	**c**	**2.87**	**a-c**	**2.97**	**c-f**	**55.56**	b	**3.23**	**F**	**32.33**	b
3	4.65	c-e	3.10	b-d	2.62	b	2.28	cd	3.19	a-c	24.99	d	3.34	d-f	15.51	c
T-I59	**4.76**	**de**	**3.13**	**b-d**	**1.03**	**a**	**3.17**	**a**	**3.53**	**a**	**73.50**	a	**3.41**	**c-f**	**58.83**	a
11	4.80	e	3.07	cd	2.57	b	3.19	a	3.00	c-e	48.39	bc	3.28	Ef	29.59	bc

Traits[2] (column group heading over F00–Ym)

[1] Treatments
[2] Coded as in Table 1
[3] Means followed by the same letter on the vertical do not differ significantly by the Duncan test at 5% probability

Table 4. Correlated response in several traits in selection for frost resistance and response to simultaneous selection of the traits, used in the classic stratified selection index, at among 50% and within 30% selection intensity of F_3 progenies derived from the "Piatã" x 'Catuai' cross

	Among Progenies		Within Progenies				
Correlated Response							
Traits[3]	**GS Ind.**	**GS Ind.** (%)	**GS Ind.**	**GS Ind.** (%)	**GS Ind. Total** (%)	**OM[1]**	**IM[2]**
V00	0.024	0.74	0.017	0.52	1.26	3.203	3.244
R	-0.137	-7.65	-0.095	-5.33	-12.98	1.789	1.557
Y00	-1.115	-2.93	-0.778	-2.04	-4.97	38.049	36.156
Vm	0.064	1.82	0.044	1.27	3.09	3.504	3.612
Ym	0.164	0.72	0.135	0.50	1.22	26.867	27.166
Classic Stratified Selection Index							
	Among Progênies		**Within Progênies**				
Traits[3]	**GS Ind.**	**GS Ind.** (%)	**GS Ind.**	**GS Ind.** (%)	**GS Ind. Total** (%)	**OM[1]**	**IM[2]**
F00	-0.091	-2.12	-0.102	-2.36	-4.48	4.316	4.12
V00	0.015	0.46	0.018	0.56	1.02	3.203	3.24
R	-0.056	-3.13	-0.120	-6.71	-9.84	1.789	1.61
Y00	0.761	2.00	-0.599	-1.57	0.43	38.049	38.21
Vm	0.038	1.08	0.044	1.27	2.35	3.504	3.59
Ym	1.662	6.19	0.526	1.19	7.38	26.867	29.05

[1] Original mean
[2] Improved mean
[3] Ccoded as in Table 1

others traits (Petek et al. 2002), than the gains indirect from selection were estimated for all traits of interest for the frost-adapted cultivars (Table 4).

Gains from indirect selection, estimated for vegetative vigor in the frost year (V00) and the 2000 and 2002 mean vegetative vigor were, respectively, 1.26 and 3.09% (Table 4) therefore reasonable indirect gain. This gain indicates indirect increase in yield, as the vegetative vigor indicates future yield potential. An indirect gain of 12.98% was estimated for rust resistance (Table 4) as was expected due to the correlation between this trait and frost damage (Petek et al. 2002). On the other hand there was a 4.97% loss for yield potential in the frost year (Y00) and a gain of only 1.22% for the 2000 and 2001 mean yield potential (Ym) (Table 4). Therefore, there will be a tendency to select lower yielding progenies and plants, as indicated by the correlation. Selection should be made therefore among the most productive, those that are more frost resistant with greater vegetative vigor and rust resistance.

Selection indexes can be used for this, where a breeding program is an important tool for simultaneous selection of various traits of agronomic interest, increasing the efficiency of obtaining superior materials, especially as in this case that direct selection for greater frost resistance will imply loss in yield. Selection by the classic stratified index indicated progenies 13, 12, 5, 9, 10 and 8 and the three best plants within each plot of these progenies, therefore giving origin to 54 progenies in the next generation. This selection will give an estimated 4.48% gain for frost resistance (Table 4), therefore less than when selection was practiced directly for frost damage. This small decrease in the gain for greater frost resistance was in detriment to greater gain for yield, that was 0.43% for yield potential in 2000 (Y00) against a 4.97% loss (Table 4) by direct selection and of 7.38% for mean yield in 2000 and 2002 against 1.22% (Table 4) by direct selection.

Selection by the index gave an estimated 9.84% gain for rust resistance (Table 4) and was less than the estimated indirect gain by direct selection for less frost damage. This loss was caused by greater gain for yield that tends to reduce the vegetative vigor and this has a correlation with rust resistance (Petek et al. 2002), which is not a problem, as most progenies have a good level of rust resistance.

The gains for vegetative vigor in 2000 and the 2000 and 2002 mean vegetative vigor, by the index, were respectively, 0.24% and 0.74% less than in direct selection for less frost damage. This small fall in the gains is caused by the increase in gain for yield, that correlates significantly and negative with vegetative vigor. Therefore, selection will be a little less efficient for vegetative vigor but will be selecting plants with balance between the vegetative and reproductive parts, without problems because vegetative vigor in these materials is already high.

The use of the selection index gave reasonable gains for all the characteristics, decreasing the gain of some to increase the gain in others, and consequently, select plants with superiority for all the characteristics considered important in selection.

CONCLUSIONS

- ·Progenies carrying genes of *C. liberica* var. *dewevrei*, possess potential for development of cultivar more frost resistant
- ·The traits rust resistance, vegetative vigor and yield potential should be considered in the selection index for more frost-adapted cultivar in progenies carrying genes of *C. liberica* var. *dewevrei*
- ·Yield precocity, as presented by 'IAPAR-59', that allows a faster recovery of the productivity after a severe frost is adaptive trait for minimize frost damage
- ·The selection index using frost damage and other correlated traits was efficient to improve for more frost resistant cultivar with productivity.

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Seleção para resistência à geada em progênies de *Coffea arabica* portadoras de genes de *C. liberica* var. *dewevrei*

RESUMO - *Estimou-se a variabilidade e parâmetros genéticos, para o desenvolvimento de cultivares mais resistentes à geada em progênies de* C. arabica, *portadoras de genes de* C. liberica *var.* dewevrei. *Existe variabilidade genética para resistência à geada em progênies com genes de* C. liberica *var.* dewevrei. *As características resistência à ferrugem, vigor vegetativo e potencial de produtividade devem ser consideradas no desenvolvimento de cultivares mais adaptadas à geada. Cultivares com maior precocidade produtiva como 'IAPAR 59', recuperam a produtividade mais rápido após uma geada severa, minimizando o dano do fenômeno. O uso de índice de seleção é eficiente para selecionar simultaneamente progênies com maior resistência à geada, vigor vegetativo, resistência à ferrugem e maior produtividade.*

Palavras-chave: cultivo de café, melhoramento, resistência à geada, parâmetros genéticos, índice de seleção.

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