academicJournals

Vol. 10(46), pp. 4252-4257, 12 November, 2015
DOI: 10.5897/AJAR2015.9838
Article Number: 5D3726656161
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Genetic gain prediction in coffee progenies derived from the cross between 'Híbrido de Timor' and 'Catuaí' cultivars

Ramiro Machado Rezende[1], Juliana Costa de Rezende[2]*, Gladyston Rodrigues Carvalho[2], Cesar Elias Botelho[2], Sonia Maria de Lima Salgado[2] and Andre Dominghetti Ferreira[3]

[1]Vale do Rio Verde University, Agronomic Course, Av. Castelo Branco, 82, Chácara das Rosas, CEP 37410-000 Três Corações, MG, Brazil.
[2]Agricultural Research Corporation of Minas Gerais, Epamig Unidade Regional do Sul de Minas, Campus da Ufla, s/n°, P. O. Box 176, CEP 37200-000 Lavras, MG Brazil.
[3]Brazilian Agricultural Research Corporation Embrapa Gado de Corte, Av. Rádio Maia, 830, CEP 79106-550 Campo Grande, MS. Brazil.

Received 22 April, 2015; Accepted 6 October, 2015

The objective of this study was to estimate genetic parameters and predict the genetic gains of coffee plant progenies using characters that are targeted in coffee breeding. The experiment was conducted in an area naturally infested with *Meloidogyne exigua* on Ouro Verde Farm, which is located in the municipality of Campos Altos in the state of Minas Gerais- Brazil. Twenty-three progenies that were potentially resistant to root-knot nematodes were used in the study, and seven commercial cultivars were used as controls. The evaluated progenies are in the fourth generation of a cross between 'Híbrido de Timor' and 'Catuaí', and they were provided by the coffee plant-breeding program conducted in Minas Gerais. The following characters were evaluated in the 2010 to 2011 and 2011 to 2012 crops: Productivity per processed coffee bags per hectare; percentage of grains at the berry stage; percentage of floating grains; grains size; and plant vigor. Furthermore, the number of *M. exigua* eggs per root gram was evaluated in the latter crop. The following genetic parameters were evaluated: Coefficient of environmental variation; phenotypic variance; genotypic variance; broad sense heritability; coefficient of genetic variation; and variation index. Gains by direct and indirect selection and the selection index, based on the sum of ranks of Mulamba and Mock, were used to estimate the genetic gain prediction. The progenies exhibited large genetic variability for the assessed traits. The index based on the sum of ranks presented higher simultaneous gains in relation to direct and indirect selection. The progenies (H493-1-2-2, H514-7-4-5, H518-2-10-1, and 514-5-2-4) were the most promising in the area infested by *M. exigua* and were identified for generational advancement based on the two procedures of analytical gain prediction.

Key words: *Coffea arabica*, selection index, breeding.

INTRODUCTION

The contributions of genetic breeding techniques for coffee cultivation are unquestionable for farmers and especially for the Brazilian economy. Although the selected cultivars had already reached high yield levels, studies showed that new technologies are still largely demanded by Brazilian farmers and consumers. Those people long for new cultivars, which offer a differentiated product in relation to the drink quality and also an effective reduction in crop losses by rational use of agriculture inputs through resistance to the main pathogens infecting the coffee, especially plant parasitic phytonematodes, which has been responsible for serious damage to coffee crops.

Moreover, the utilization of new cultivars also effective reduction in crop losses, and cultivars that are resistant to major pathogens can be established. Regarding the coffee plant, are one of the main parasites, and they account for severe damage in coffee (Castro et al., 2008; Barbosa et al., 2010). Advances in research are made difficult by the perennial condition of this crop and the period of time required for evaluating the behavior of plants derived from sources of the *Coffea* spp. germplasm in an infested area. In fact, under Brazilian conditions, few research has been conducted under field conditions for genetic selection of plants resistant to nematodes; on the other hand, various studies, among which are Ito et al. (2008) and Boisseau et al. (2009) have been carried out under greenhouse conditions. Nevertheless, evaluation of genetic materials of the coffee plant under the conditions of an infested area in the field allow better knowledge of plant behavior and, according to Alpizar et al. (2007), verify the stability of plant reaction.

Thus, the use of more accurate selection procedures becomes essential. Estimates of genetic parameters are extremely important in breeding programs because they allow genetic effects to be distinguished from environmental effects. This aids the selection of the best breeding strategy by supplying the basis for a posterior selection of higher genotypes, with consequent reductions in the time needed to launch new cultivars (Cruz and Carneiro, 2006).

One of the most important contributions of quantitative genetics in plant breeding is the possibility of gains being obtained in the following generation. Thus, direct and indirect selection arises as the first alternative to providing compensated genetic gains (Bhering et al., 2012; Nick et al., 2013). The selection of higher progenies based on one or a few characters may not be suitable for the breeder. Therefore, the simultaneous selection of many desirable characters aims to increase the probability of program success (Gonçalves et al., 2007; Mendes et al., 2009).

The selection indices are multivariate techniques that allow the combination of various data sources in the experimental unit. This allows the selection of superior materials based on complex of variables that meet attributes of interest to the breeder, which results in best simultaneous gains (Cruz and Carneiro, 2006). The index based on the sum of “ranks” (Mulamba and Mock, 1978) has been shown in the literature by providing better simultaneous gains in various situations (Costa et al., 2004; Santos et al., 2007).Thus, the objective of this study was to predict genetic gains of progenies from the cross between ‘Híbrido de Timor’ and ‘Catuaí’ cultivars based on characters targeted by coffee plant breeding programs in an area that is naturally infested with *Meloidogyne exigua*.

MATERIALS AND METHODS

The experiment was conducted in an area infested with *M. exigua* immediately following the uprooting of an old coffee crop (December, 2000), with no soil mobilization, on the Ouro Verde Farm, which is located in the Campos Altos municipality in the Alto Parnaíba region of Minas Gerais State. The materials used in the experiment included 23 progenies that were potentially resistant to root-knot nematodes and seven cultivars that were used as controls (Table 1).

The assessed progenies were from the fourth generation of a cross between the ‘Híbrido de Timor’ and ‘Catuaí’ cultivars, and they were provided by the coffee plant-breeding program conducted in Minas Gerais, which is managed by Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG) with the participation of Universidade Federal de Viçosa (UFV) and Universidade Federal de Lavras (UFLA).

A random block design with four replicates was used (totaling 120 plots), and each plot contained eight plants. The spacing used in the experiment was 4.0 x 0.8 m between rows and plants, respectively, which corresponded to a total area of 3072 m^2. The experiment was designed and conducted following the technical recommendations for coffee crops in the region. Evaluations of the 2010 to 2011 and 2011 to 2012 harvests were made, including the following characters: productivity per 60 kg bags•ha^{-1}; percentage of grains at the berry stage; percentage of floating grains; grain retained in high sieve (screen 17 or above); plant vigor; and the number of *M. exigua* eggs per root gram.

Yield was assessed in 60 kg bags of hulled coffee per hectare (bags•ha^{-1}). The harvest was carried out in individual plots that were measured in liters of “field coffee” (coffee fruits of mixed maturity) per plot. Subsequently, the volume of coffee harvested was converted to bags•ha^{-1}, considering the mean yield of a 60 kg bag of hulled coffee for each 480 L of “field coffee”, and this yield corresponded to the regional average. The percentage of fruit at the cherry stage was determined by counting a 300 ml sample of fruit per plot. The methodology proposed by Antunes Filho and Carvalho (1954) was used to determine the percentage of floating fruits. Based on this method, 100 cherry fruits were placed in water, and the fruits remaining at the surface were considered floating fruits.

Grains size was graded (17 sieve or above) after coffee processing. A 300 g sample was passed through a set of sieve perforations (from 17/64 to 19/64 inch diameter holes). The material retained in each sieve was weighed, determining the percentage of

*Corresponding author. E-mail: julianacr@epamig.ufla.br.

Table 1. Relation and genealogy of F_4 generation progenies assessed in Campos Altos – Brazil.

S/N	Progenies	Origin
1	514-5-4-C25	CA IAC 86 x HT UFV 440-10
2	436-1-4-C26	CV IAC 99 x HT UFV 442-42
3	518-7-6-C71	CV IAC 141 x HT UFV 442-34
4	514-7-14-C73	CA IAC 86 x HT UFV 440-10
5	514-5-2-C101	CA IAC 86 x HT UFV 440-10
6	516-8-2-C109	CA IAC 86 x HT UFV 446-08
7	504-5-6-C117	CV IAC 81 x HT UFV 438-01
8	514-5-4-C121	CA IAC 86 x HT UFV 440-10
9	514-7-4-C130	CA IAC 86 x HT UFV 440-10
10	493-1-2-C134	CV IAC 44 x HT UFV 446-08
11	505-9-2-C171	CV IAC 81 x HT UFV 438-52
12	518-2-6-C182	CV IAC 141 x HT UFV 442-34
13	514-7-16-C208	CA IAC 86 x HT UFV 440-10
14	514-7-16-C211	CA IAC 86 x HT UFV 440-10
15	493-1-2-C218	CV IAC 44 x HT UFV 446-08
16	438-7-2-C233	CA IAC 86 x HT UFV 451-41
17	514-7-16-C359	CA IAC 86 x HT UFV 440-10
18	514-7-8-C364	CA IAC 86 x HT UFV 440-10
19	518-2-10-C408	CV IAC 141 x HT UFV 442-34
20	514-5-2-C494	CA IAC 86 x HT UFV 440-10
21	518-2-4-C593	CV IAC 141 x HT UFV 442-34
22	516-8-2-C568	CA IAC 86 x HT UFV 446-08
23	518-2-6-C685	CV IAC 141 x HT UFV 442-34
24	Catuaí Vermelho IAC 99*	-
25	Catuaí Amarelo IAC 62*	-
26	Topázio MG 1190*	-
27	Rubi MG 1192*	-
28	Acaia Cerrado MG 1474*	-
29	Icatu Precoce IAC 3282*	-
30	Icatu Amarelo IAC 2942*	-

CA: Catuaí Amarelo; CV: Catuaí Vermelho; HT: Híbrido de Timor.*Commercial cultivars used as control.

beans graded as screen 17 and above (Brasil, 2003). Plant vigor was evaluated by rank, according to an arbitrary 1 to 10 point scale. As suggest by Carvalho et al. (1979), 1 corresponded to the worst plant with reduced plant vigor and a sharp weakening symptom, and 10 was assigned to plants with excellent vigor, which had more leaves and sharp plant growth of productive branches.

The number of *M. exigua* eggs per root gram was evaluated by collecting the roots at 20 to 40 cm depth on both sides of the plant, perpendicular to the planting line, at an approximated amount of 50 g for all plants in the plot. After being mixed, 100 g of the roots were taken to make a sample composed of specimens from each experimental plot.

This evaluation was conducted during two seasons: the rainy season (January, 2011) and the dry season (July, 2011). Nematodes were extracted in the laboratory following the methodology of Hussey and Barker (1973). After extraction, quantification was performed in an inverted biological microscope using a counting blade to determine the number of eggs per root gram. The mean values from two assessments were considered for the analysis of variance among all traits, and a 1% significance level was adopted for the F test. The Box-Cox methodology (Box and Cox, 1964) was used to transform the data from the number of eggs per root gram with the aid of the statistical software R (R Development Core Team, 2011). The following parameters were estimated from the analyses of variance: coefficient of environmental variance (CV_e), phenotypic variance (σ^2_f), genotypic variance (σ^2_g), broad sense heritability (h^2_a), genetic variance coefficient (CV_g), and variation index (θ).

Regarding the prediction of genetic gains, direct and indirect selection gains were estimated (Cruz and Carneiro, 2006) for all of the assessed characters, and a selection of approximately 20% of the genotypes (that is, the six best progenies) were considered.

In addition to this strategy, the selection process was also conducted based on the index proposed by Mulamba and Mock (1978), in which are added the "ranks" of each genetic material for each of the characters in order to improvement favorable, resulting in selection index. This resulted in the following selection index: $I = r_1 + r_2 + ...+ r_n$, where I is the index value for a given individual or family; r_n is the rank of an individual in relation to the n^{th} trait; and n is the number of traits considered in the index. Moreover, the variables are specified for different weights, so $I = p_1r_1 + p_2r_2 +... + p_nr_n$, where p_n is the economic weight given to the n^{th} trait (Cruz and Carneiro, 2006; Santos et al., 2007).

The following economic weights were adopted in this study: CV_g;

Table 2. Summary of analysis of variance and estimates of genetic parameters for grain yield per bags.ha^{-1} (PROD), percentage of cherry grains (CG), percentage of floating grains (PFG), plant vigor (PV), bean size (S17), and number of eggs/root gram (NERG) of 23 progenies and seven cultivars evaluated in Campos Altos-Brazil.

FV	GL	Mean Square					
		PROD	CG	PFG	PV	S17	NERG$^{(1)}$
Treatment	29	126.66**	336.17**	97.74**	2.09**	428.55**	89.13**
Block	3	65.99	47.64	2.38	0.83	316.18	326.80
Residue	87	50.32	42.24	2.91	0.18	25.29	18.26
Mean	-	41.79	50.80	9.53	6.90	33.80	13.49
CVe (%)	-	16.98	12.79	17.93	6.25	14.88	31.67
σ^2_f	-	31.67	84.04	24.44	0.52	107.14	22.28
σ^2_g	-	19.09	73.48	23.71	0.48	100.81	17.72
h^2_a	-	60.27	87.44	97.02	91.09	94.10	79.51
CVg(%)	-	10.46	16.87	51.12	10.00	29.71	31.19
θ	-	0.62	1.32	2.85	1.60	2.00	0.98

$^{(1)}$Data transformed into (y $^{0.22}$ -1) /0.22.** Significant at 1% of probability by the F test. CVe: coefficient of environmental variation; σ^2_f: phenotypic variance; σ^2_g: genotypic variance; h^2_a: broad sense heritability; CVg: coefficient of genetic variation; θ: variation index (CVg/CVe).

h^2_a; θ; weight 1 for all characters (W1); and values provided by the relative importance (RIP) of magnitudes 100, 40, 40, 60, 60, and 80 for productivity (PROD), percentage of grains at the cherry stage (BS), percentage of floating grains (PFG), plant vigor (PV), screen 17 sieve or above (S17), and number of eggs per root gram (NERG), respectively. Regarding productivity, BS and S17 selection was performed towards addition, and selection for PFG and NERG was done in the opposite direction. All statistical-genetic analyses were performed using the Genes software (Cruz, 2006).

RESULTS AND DISCUSSION

Significant differences were observed for all of the assessed characters, which indicated that progenies exhibited differentiated behavior under the trial conditions (Table 2). Values of CV_e ranged from 6.25% (PV) to 31.67% (NERG), revealing good experimental precision. High CV_e values for the variables related to the nematode population in the roots were also found in other cultures by Moura et al. (2008) and Silva et al. (2011), and they may be explained by the complex methods used to evaluate this pathogen, especially under field conditions.

Broad-sense heritability (h^2_a) reflects the importance of inheritance and the environment in character expression. The values found for heritability were 60.27, 87.44, 97.02, 91.09, 94.10, and 79.51% for PROD, CG, PFG, PV, S17, and NERG, respectively (Table 2). High heritability values were found for all characters when compared to other trials that evaluated *Coffea arabica* progenies (Botelho et al., 2007; Petek et al., 2006). Interestingly, the heritability of the studied trait should be high to achieve successful selection (Miranda et al., 1988). The higher the expression level of genetic variability in relation to the environment, the higher the gains estimated for the next generation.

Thus, such results provide evidence that supports the existence of genetic variability among progenies, with possible selection gains. This indicates the possibility of obtaining high genetic gains with genetics improvement to the characteristics studied, which are of high interest commercial, and that parents with higher PROD, CG, PFG, PV, S17 and NERG can be used in directed crosses genotypes aimed these characteristics.

CV_g expresses the magnitude of genetic variation in relation to the mean of the trait. Estimates of CV_g shown in Table 2 reveal that the analyzed traits generally presented variations ranging from 10.00% (PV) to 51.12% (PFG). Bonomo et al. (2004) and Mistro et al. (2007), when studying progenies derived from the germplasms of 'Híbrido de Timor', in F_3 and F_4 generations, respectively, also found high genetic variability. Moreover, this variability supports the conclusion that the selection of the best progenies will increase expression and the genetic value of the population.

The proportion of CVg to CVe is referred to as the variation index (θ). According to Vencovsky (1987), when this index is near or higher than 1.0, it indicates a situation where selection is favorable. The values found in this study (Table 2) show a satisfactory situation for selection of all characters, with the exception of productivity, which showed a value of 0.62. Values less than 1.0 for productivity were also reported by Bonomo et al. (2004), and can be explained by the fact that productivity is a quantitative inheritance character and also by the coffee biannuality.

Therefore, the genetic variation in productivity depends on allelic variation in a large number of loci, and expression of those loci is highly affected by environmental factors (Guo et al., 2004; Huang et al., 2011). However, productivity is an important variable, and any gain in this character should be taken into account.

Estimates of the direct and indirect gain of selection are

Table 3. Estimates of percentage gains by indirect and direct selection for productivity per bags.ha^{-1} (PROD), percentage of cherry grains (CG), percentage of floating grains (PFG), plant vigor (PV), bean size (S17), and number of eggs/root gram (NERG) from 23 progenies in F_4 generation and seven cultivars evaluated in Campos Altos-Brazil.

Selection on	Expected gain in (%)					
	PROD	**CG**	**PFG***	**PV**	**S17**	**NERG***
PROD	11.69	8.85	-22.32	6.09	20.36	-13.97
CG	6.38	18.56	-19.78	7.86	5.21	-12.63
PFG*	3.19	-4.08	-48.21	0.16	24.76	-2.81
PV	7.62	16.67	-24.02	12.12	-10.53	-18.69
S17	7.44	13.90	0.59	3.60	39.84	-17.61
NERG*	5.35	2.03	-13.62	6.21	0.07	-35.81

*Variables selected towards decrease (it is desired negative values for those characters).

Table 4. Estimates of percentage gains by simultaneous selection, using the index based on the sum of ranks, based upon five economic weight criteria(1), for grain productivity per bags.ha^{-1} (PROD), percentage of cherry (CG), percentage of floating grains (PFG), plant vigor (PV), bean size (S17), and number of eggs/root gram (NERG) from 23 progenies in F_4 generation and seven cultivars assessed in Campos Altos-Brazil.

Trait	Expected gain in (%)				
	CVg	**h^2_a**	**CVg/CVe**	**W1**	**WRI**
PROD	9.27	9.05	9.27	9.05	10.73
CG	11.21	15.08	11.21	15.08	10.65
PFG(2)	-42.27	-30.81	-42.27	-30.81	-29.96
PV	5.80	5.66	5.80	5.66	6.90
S17	24.96	27.61	24.96	27.61	22.30
NERG(2)	-19.34	-20.06	-19.34	-20.06	-22.59

(1)CVg: coefficient of genetic variation; h^2_a: broad sense heritability; CVg/CVe: variation index; W1: weight 1 for all characters; WRI: values provided by the relative importance (100, 40, 40, 60, 60 and 80).(2) Variables selected towards decrease.

presented in Table 3. From this selection, gains were obtained from the main character (upon which selection was performed) with the possible occurrence of favorable and unfavorable responses in the characters of secondary importance (Costa et al., 2004).

Considering that the target was to obtain an increase in the PROD, CG, PV, and S17 characters and a decrease in PFG and NERG, the best result was achieved when selection was performed on the PROD trait, which provided positive gains of 11.69, 8.85, 6.09, and 20.36% for PROD, CG, PV, and S17, and negative values of 22.32 and 13.97% for PFG and NERG, respectively. Thus, based on direct selection on yield, progenies H493-1-2-2, H518-2-10-1, 514-7-4-5, 436-1-4-2, 518-2-6-1, and 514-5-2-4 were selected as the promising ones for the generational advancement. The index based on the sum of ranks (Mulamba and Mock, 1978) was also used to target increasing reliability of the results obtained in this experiment.

The results indicate that it is possible to obtain desirable gains for all assessed characters, considering all the provided economic weights (Table 4). This suggests that it is possible to promote the effective increase of favorable alleles via the stocking of the assessed characters in the population. Among the economic weight options used to obtain selected gains, the results indicated that weight, based on the relative importance (WRI), presented the best results with predicted gains of 10.73, 10.65, 6.90, and 22.30% for PROD, CG, PV, and S17, respectively. This was in addition to the negative gains for PFG (-29.96%) and NERG (-22.59) (Table 4), which were the favorable characters for the selection of higher genotypes, where the number of plants with floating fruits and susceptibility to *M. exigua* tended to be lower.

Although yield gain was smaller than indirect and direct selection, the index of Mulamba and Mock (1978) provided greater magnitudes of predicted gain for all of the other characters, which corroborates the results of Costa et al. (2004) and Santos et al. (2007). Progenies selected by the Mulamba and Mock (1978) procedure, based on WRI, were as follows: H493-1-2-2, H514-7-4-4, H518-2-10-1, H514-7-16-3, H493-1-2-8, and H514-5-2-4. The results show that four of these (H493-1-2-2, 514-7-4-5, 518-2-10-1, and 514-5-2-2) were also selected by the criteria for direct and indirect selection, which confirms the potential of these progenies for generational advancement.

Conclusions

The progenies presented large amounts of genetic variability for the assessed characters, and the index based on the sum of the ranks presented comparable gains relative to direct and indirect selection. The H493-1-2-2, H514-7-4-5, H518-2-10-1, and 514-5-2-4 progenies were the most promising in the area infested by *M. exigua* and pointed to generational advancement based on the two analytical gain prediction procedures.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGMENTS

The authors thank Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Consórcio Brasileiro de Pesquisas Cafeeiras and INCT- Café for supporting the Project. We also thanks CNPq for granting the fellowship (RMR and JCR).

REFERENCES

Alpizar E, Etienne H, Bertrand B (2007). Intermediate resistance to *Meloidogyne exigua* root-knot nematode in *Coffea arabica*. Crop Protect. 26:903-910. doi:10.1016/j.cropro.2006.08.018

Antunes Filho H, Carvalho A (1954). Coffee breeding. VII - Empty fruit locules in the Mundo Novo coffee. Bragantia 13:165-179. http://dx.doi.org/10.1590/S0006-87051954000100014

Barbosa DHSG, Souza RM, Vieira HD (2010). Field assessment of coffee (*Coffea arabica* L.) cultivars in *Meloidogyne exigua*-infested or –free fields in Rio de Janeiro State, Brazil. Crop Protect. 29:175-177. doi:10.1016/j.cropro.2009.10.011

Bhering LL, Laviola BG, CC Salgado, Sanchez CFB, Rosado TB, Ahmed AA (2012). Genetic gains in physic nut using selection indexes. Brazilian Agric. Res. 47:402-408. http://dx.doi.org/10.1590/S0100-204X2012000300012.

Boisseau M, Aribi J, Sousa FR de, Carneiro RMDG, Anthony F (2009). *Resistance to* Meloidogyne paranaensis *in wild* Coffea arabica*.* Trop. Plant Pathol. 34:38-41. http://dx.doi.org/10.1590/S1982-56762009000100006

Bonomo P, Cruz CD, Viana JMS, Pereira AA, Oliveira VR de, Carneiro PCS (2004). Evaluation of coffee progenies from crosses of Catuaí Vermelho and Catuaí Amarelo with "Hibrido de Timor" descents. Bragantia 63:207-219. http://dx.doi.org/10.1590/S0006-87052004000200006

Botelho CE, Mendes ANG, Carvalho SP, Carvalho GR, Gonçalves FMA, Carvalho AM. (2007). Evaluation of coffee progenies from crosses between the Icatu and Catimor cultivars (*Coffea arabica* L.). Coffee Sci. 2:10-19.

Box GEP, Cox DR (1964). An analysis of transformations. J R Stat. Soc. Series B 26:211-252.

Brazil. Ministry of Agriculture, Livestock and Food Supply (2003). Normative Instruction No. 8 of 11 June 2003. Available from:<http://www.abic.com.br/publique/media/NMQ_LEGISLAcaO_IN8.pdf>. Accessed: June 15.

Castro JMC, Campos VP, Pozza EA, Naves RL, Andrade Junior VC, Dutra MR, Coimbra JL, Maximiniano C, Silva JRC (2008). Levantamento de fitonematóides em cafezais do Sul de Minas Gerais. Nematol Bras. 32:56-64.

Carvalho A, Mônaco LC, Fazuoli LC (1979). Coffee breeding. XL — Progenies and hybrids of the catuaí cultivar. Bragantia 38:202-216. http://dx.doi.org/10.1590/S0006-87051979000100022

Costa MM, Mauro AOD, Unêda-Trevisoli SH, Arriel NHC, Bárbaro IM, Muniz FRS *(2004).* Genetic gain by different selection criteria in soybean segregant populations. Pesq. Agropec. Bras. 39:1095-1102. http://dx.doi.org/10.1590/S0100-204X2004001100007

Cruz CD (2006). Programa genes: biometria. Viçosa, MG: UFV. 382p.

Cruz CD, Carneiro PCS (2006). Modelos biométricos aplicados ao melhoramento genético. 2. ed. Viçosa, MG: UFV, v. 2, 586p.

Gonçalves GM, Viana AP, Bezerra Neto FV, Pereira MG, Pereira TNS (2007). Selection and heritability in the prediction of genetic gain in yellow passion fruit. Pesq. Agropec. Bras. 42:193-198. http://dx.doi.org/10.1590/S0100-204X2007000200007

Guo M, Rupe MA, Zinselmeier C, Habben J, Bowen BA, Smith OS (2004). Allelic Variation of Gene Expression in Maize Hybrids. Plant Cell 16:1707-1716. http://dx.doi.org/10.1105/tpc.022087

Huang X, Paulo MJ, Boer M, Effgen S, Keizer P, Koornneef M, van Eeuwijk FA (2011). Analysis of natural allelic variation in Arabidopsis using a multiparent recombinant inbred line population. PNAS 108:4488-4493. doi: 10.1073/pnas.1100465108.

Hussey RS, Barker KR (1973). A comparison of methods of collecting inocula of *Meloidogyne* spp. including a new technique. Plant Dis. 57:1025-1028.

Ito DS, Sera GH, Sera T, Santiago DC, Kanayama FS and Grossi L Del (2008). Progenies of coffee with resistance to nematodes *Meloidogyne paranaensis* and *Meloidogyne incognita* race 2. Coffee Sci. 3:156-163.

Mendes FF, Ramalho MAP, Abreu A de FB (2009). Selection index for choosing segregating populations in common bean. Pesq. Agropec. Bras. 44:1312-1318. http://dx.doi.org/10.1590/S0100-204X2009001000015

Miranda JEC, Costa CP, Cruz CD (1988). Correlações genotípica, fenotípica e de ambiente entre caracteres de fruto e planta de pimentão (*Capsicum annunn* L.). Rev. Bras. Genét. 11:457-468.

Mistro JC, Fazuoli LC, Gallo PB, Oliveira ACB, Toma-Braghin M, Silvarolla MB (2007). Estimates of genetic parameters in arabic coffee derived from the Timor hybrid. Crop Breed. Appl. Biotechnol. 7:141-147. DOI: 10.12702/1984-7033.v07n02a05

Moura MF, Vencovsky R, Silva JFV, Morais LK, Moura NF, Pinheiro JB (2008) Genetic parameters for soybean resistance to Race 1 cyst nematode. Bragantia 67:119-125. http://dx.doi.org/10.1590/S0006-87052008000100014

Mulamba NN, Mock JJ (1978). Improvement of yield potential of the Eto Blanco maize (*Zea mays* L.) population by breeding for plant traits. Egypt J. Genet. Cytol. 7:40-51.

Nick C, Laurindo BS, Almeida V de S, Freitas RD de, Aguilera JG, Silva ECF da, Cruz CD, Silva D JH da. (2013). Simultaneous selection for fruit quality and resistance to late blight in tomato progenies. Pesq. agropec. Bras. 48:59-65. http://dx.doi.org/10.1590/S0100-204X2013000100008

Petek MR, Sera T, Sera GH, Fonseca ICB, Ito DS (2006). Selection of progenies of *Coffea arabica* with simultaneous resistance to bacterial blight and leaf rust. Bragantia 65:65-73. http://dx.doi.org/10.1590/S0006-87052006000100009

R Development Core Team (2011). R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing, 2011. Available from: <http://www.R-project>. Accessed: Jun 15.

Santos FS, Amaral Júnior AT, Freitas Júnior SP, Rangel RM, Pereira MG (2007). Genetic gain prediction by selection index in a UNB-2U popcorn population under recurrent selection. Bragantia 66:389-396. http://dx.doi.org/10.1590/S0006-87052007000300004

Silva GO, Pinheiro JB, Vieira JV, Carvalho ADF (2011). Selection for carrot genotypes resistance to root-knot nematodes in field and greenhouse*.* Hortic. Bras. 29:335-341. http://dx.doi.org/10.1590/S0102-05362011000300013

Vencovsky R (1987). Herança quantitativa. In: Melhoramento e produção de milho. Eds. Paterniani E, Viegas GP. Campinas: Fundação Cargill, 1. pp. 137-214.