

ARTICLE

Two cycles of recurrent selection in red bean breeding

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Abstract – This study was carried out for the purpose of estimating genetic progress after two cycles of recurrent selection in red bean breeding and of obtaining new lines. In cycle zero, $F_{3;5}$ and $F_{3;6}$ families were evaluated. In cycle one, the families were extracted in generation F_5 and evaluated in generations $F_{5;6}$ and $F_{5;7}$. As the families were evaluated in different years and generations, the estimate of genetic progress was obtained by simultaneously evaluating the 30 best lines obtained at the end of each cycle in experiments conducted through three crop seasons. After two cycles of recurrent selection, genetic progress, in the mean value of the crop seasons, was 7.5% for grain yield, 7% for grain appearance, 33.4% for resistance to rust and 13.2% for resistance to angular leaf spot. Lines of red beans were obtained with potential for being included in future Value for Cultivation and Use (VCU) testing for Minas Gerais, Brazil.

Key words: *Phaseolus vulgaris*, quantitative genetics, plant breeding

INTRODUCTION

The common bean crop has great variability in seed coloring. This fact leads to some types of common beans sold regionally receiving little to no attention in breeding programs. In the case of bright colored red beans, which is the most consumed type in the Zona da Mata of Minas Gerais, the Common Bean Program of the Universidade Federal de Viçosa (Federal University of Viçosa) (UFV) has striven to obtain new cultivars to meet the needs of producers (Carneiro et al. 2006).

As the demand for red beans has been ever greater and the cultivars with this type of seed are not satisfactory in regard to grain yield, disease resistance and upright plant architecture, obtaining new lines is fundamental. In this process, the use of recurrent selection has been expanded in the common bean crop, with examples in breeding of various characteristics (Singh et al. 1999, Cunha et al. 2005, Ramalho et al. 2005a, Silva et al. 2007, Arantes et al. 2010).

Recurrent selection is a dynamic method in which the best individuals or families selected in a cycle of recurrent selection are recombined in a directed, organized and pre-determined manner, keeping the breeder from losing time defining which lines should be crossed, or even keeping the

program from losing continuity. In other breeding methods, crosses are made between lines with desirable phenotypes with a view toward selecting individuals that gather the characteristics of interest from the different parents in only one stage. In contrast, in recurrent selection, the breeder undertakes planning to carry out various selection cycles. Thus, the favorable alleles are accumulated in stages and the breeding program is more dynamic and organized.

In recurrent selection programs, the estimate of genetic progress should be obtained periodically for the purpose of guiding the breeder in carrying out the following cycles and also to assisting the breeder in making important decisions regarding the alternatives that may increase genetic gain. To estimate genetic progress from recurrent selection, various alternatives have been used, among them, the use of common controls in evaluation of the families in the different cycles (Amaro et al. 2007, Menezes Júnior et al. 2008); the use of S_2 and S_3 families chosen according to greater yield (Ranalli 1996, Singh et al. 1999); comparison of $S_{1;2}$ families simultaneously extracted in populations of various selection cycles (Silva et al. 2007); and the use of the best lines identified in the different cycles (Ramalho et al. 2005a).

In light of the above, this study was performed for the purpose of estimating genetic progress after two cycles of

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recurrent selection in red bean breeding and of obtaining lines with a view toward composition of Value for Cultivation and Use (VCU) testing for the state of Minas Gerais, Brazil.

MATERIALS AND METHODS

The experiments were conducted in the Experimental Field of Coimbra belonging to the Plant Science Department of the Universidade Federal de Viçosa (Federal University of Viçosa) (UFV), municipality of Coimbra (lat 20° 45' S, long 42° 51' W and alt 690 m asl), state of Minas Gerais. To begin the recurrent selection program, the cultivar Vermelhinho, the only one with red beans, used by farmers of the Zona da Mata in Minas Gerais, was crossed with the following cultivars and elite lines: Aporé, Pérola, IAPAR31, IAPAR81, AN9022180 and LR720982CP, with carioca-type beans (cream color with beige streaks) and AFR19521, AFR19535, AB136 and Vermelho2157, with red beans. Eighteen hybrid combinations derived from single crosses, double crosses and back crosses were generated, always involving the cultivar Vermelhinho, as described by Menezes Júnior et al. (2011).

The recurrent selection program was conducted by evaluating families for two generations and recombination of the best families for obtaining the following cycle. In cycle zero (C_0) $F_{3:5}$ and $F_{3:6}$ families were evaluated and $F_{3:7}$ families recombined. In cycle one (C_1), the families were extracted in the F_5 generation and evaluated in the $F_{5:6}$ and $F_{5:7}$ generations, with the recombination being performed using $F_{5:8}$ families. Experimental details are presented in Table 1. In each cycle, after selection of the best families for recombination, they continued being evaluated for the purpose of extraction of the lines.

In the recombination phase, for obtaining the cycle one (C_1) population, as well as 17 ($F_{3:7}$) families selected in cycle zero, three new parents were included (VR-3,

VR-2 and BRS Timbó). These three lines, as well as being productive, are sources of resistance to angular leaf spot and rust, important diseases in the common bean crop. The recombination of the 20 parents (17 $F_{3:7}$ families and three new lines) was carried out using a circulant diallel cross in which each parent participated in two crosses.

In cycle zero, the families were evaluated only in regard to grain yield (kg ha^{-1}). In cycle one, however, in addition to grain yield (YIELD), grain appearance (GA), plant architecture (PA) and severity of rust (RUST) were evaluated in the $F_{5:6}$ generation, and angular leaf spot (ALS) in the $F_{5:7}$ generation. Grain appearance was evaluated considering a grading scale ranging from 1 to 5, in which 1 refers to the typical red bean with seed coat shininess, not flattened, elliptical format and average 100 seed weight from 22 to 24 g, and 5 to the bean outside the red standard (Menezes Júnior et al. 2011). Evaluation of plant architecture was also carried out by means of a grading scale ranging from 1 to 5 in which 1 refers to the growth habit II plant, upright, with one stem and with increased height of the lowest pod, and 5 refers to the growth habit III plant, with long internodes and very prostrate growth (Collicchio et al. 1997). Severity of rust was evaluated using a six-degree grading scale (Stavelly et al. 1983, adapted), with 1 being absence of visible pustules (immune) and 6 being severe disease symptoms, resulting in premature leaf drop. To evaluate the severity of angular leaf spot, a nine-degree grading scale was used, as described by Van Schoonhoven and Pastor-Corrales (1987), with 1 being plants without disease symptoms, and 9 being severe disease symptoms, resulting in premature leaf drop.

Before proceeding with data analysis, the basic presuppositions of analysis of variance were tested. The observations were submitted to analysis of variance by generation, considering all the effects of the model as random, except for the mean value, according to the following statistical

Table 1. Experimental details of evaluation of red bean families in the two cycles of recurrent selection

Generation	C_0		C_1	
	$F_{3:5}$	$F_{3:6}$	$F_{5:6}$	$F_{5:7}$
No. of families	243	243	380	160
No. of controls	13	13	20	9
Crop Year	2002	2002	2007	2008
Crop Season	dry	winter	winter	dry
Design	lattice	lattice	lattice	lattice
No. of replications	3	3	2	3
Plot size	2 2m rows	2 2m rows	1 2m row	2 2m rows
Traits evaluated	yield	yield	yield	yield
	-	-	grain appearance	grain appearance
	-	-	plant architecture	plant architecture
	-	-	rust	angular leaf spot

model: $Y_{ikl} = m + p_i + r_k + b_{l(k)} + e_{ikl}$, in which Y_{ikl} is the value observed in the plot that received treatment i in block l , within replication k ; m is the general mean value of the experiment; p_i is the effect of treatment i ; r_k is the effect of replication k ; $b_{l(k)}$ is the effect of block l within replication k ; e_{ikl} is the experimental error associated with observation Y_{ikl} , assuming that the errors are independent and normally distributed, with mean value zero and variance σ^2 . After that, joint analysis of variance was performed using the adjusted mean values of the treatments, according to Ramalho et al. (2005b). Based on the expected mean squares, genetic variance ($\hat{\sigma}_p^2$), phenotypic variance ($\hat{\sigma}_F^2$), variance of the family x generation interaction ($\hat{\sigma}_{(P \times G)}^2$) and heritability in the broad sense (h^2) were estimated.

As evaluations of the families in the two selection cycles were performed in different years and generations ($F_{3:5}$ and $F_{3:6}$ in cycle zero and $F_{5:6}$ and $F_{5:7}$ in cycle one), the strategy used to estimate genetic progress (GP) from recurrent selection was comparison of the lines obtained at the end of each cycle. Thus, the 30 best lines of the zero cycle and the 30 best of cycle one were selected for simultaneous evaluation.

The 60 lines (30 from cycle C_0 and 30 from cycle C_1) were evaluated together with the controls Vermelhinho and Ouro Vermelho in the winter crop season of 2008, dry season and winter season of 2009. A randomized block design was used with three replications and plots of two two-meter rows. In addition to grain yield (YIELD) in $kg\ ha^{-1}$, grain appearance (GA), plant architecture (PA) and severity of rust (RUST) and angular leaf spot (ALS) were evaluated, using the grading scale described above.

Observations were submitted to analysis of variance per environment, considering the effects of treatments

and the mean value as fixed, according to the statistical model: $Y_{ij} = m + t_i + r_j + e_{ij}$ in which: Y_{ij} is the value observed in the plot that received treatment i within block j ; m is the general mean of the experiment; t_i is the effect of the treatment i ($i = 1, 2, 3, \dots, 62$); r_j is the effect of the replication j ($j = 1, 2$ and 3) and e_{ij} is the experimental error associated with observation Y_{ij} , assuming that the errors are independent and normally distributed, with zero mean value and variance σ^2 .

After that, using the mean values of the treatments, joint analysis of variance was performed for each characteristic, according to the procedure described by Ramalho et al. (2005b). The mean values of the lines were compared with the mean value of the cultivar Ouro Vermelho by the Dunnett test at 1% probability.

Genetic progress (GP) from recurrent selection was obtained using the following estimator:

$$GP(\%) = [(\bar{X}_{C_1} - \bar{X}_{C_0})/\bar{X}_{C_0}] \times 100$$

in which: \bar{X}_{C_1} is the mean value of the 30 lines of cycle one and \bar{X}_{C_0} is the mean value of the 30 lines of cycle zero.

RESULTS AND DISCUSSION

The success of selection in recurrent selection programs is dependent on the existence of variability. Variability for grain yield was shown by the significant effect ($P < 0.05$) of the family source of variation in the two selection cycles. In cycle one, the presence of variability in the population for grain appearance, plant architecture and reaction to rust and angular leaf spot was also shown by the significant effect ($P < 0.01$) of the family source of variation (Table 2).

Table 2. Summary of analyses of individual and joint (Joint) variance of grain yield ($kg\ ha^{-1}$) (YIELD) in the C_0 and C_1 cycles and of grades of grain appearance (GA), plant architecture (PA) and severity of rust (RUST) and angular leaf spot (ALS) of the C_1 cycle in reference to evaluation of the segregating families of the recurrent selection program, with the respective estimates of genetic variance ($\hat{\sigma}_p^2$), phenotypic variance ($\hat{\sigma}_F^2$), variance of the family x generation interaction ($\hat{\sigma}_{(P \times G)}^2$) and heritability in the broad sense (h^2)

Generation	Cycle (C_0)						Cycle (C_1)							
	YIELD			YIELD			GA	PA	RUST	ALS				
	$F_{3:5}$	$F_{3:6}$	Joint	$F_{5:6}$	$F_{5:7}$	Joint	$F_{5:6}$	$F_{5:7}$	Joint	$F_{5:6}$	$F_{5:7}$	Joint	$F_{5:6}$	$F_{5:7}$
MS _{Families}	343159.4**	762054.8**	622250.4*	532405.5**	335791.6**	439539.0*	1.68**	0.55**	1.03**	0.53**	0.21**	0.47**	1.70**	2.36**
CV (%)	12.9	12.6	13.2	14.4	12.2	12.9	14.6	15.6	16.3	14.5	8.3	11.8	22.8	22.9
$\hat{\sigma}_p^2$	62732.4	236064.4	23214.4	145608.5	56193.1	26250.3	0.513	0.142	0.124	0.117	0.036	0.04	0.663	0.339
LI ¹	45825.6	196618.4	19575.8	111387.9	36966.8	21316.1	0.442	0.109	0.101	0.084	0.024	0.032	0.554	0.209
LS	91136.7	288759.6	27976.8	198524.4	95615.7	33130.7	0.603	0.193	0.157	0.174	0.059	0.05	0.808	0.646
$\hat{\sigma}_F^2$	114386.5	254018.3	103708.4	266202.7	111930.5	91570.6	0.56	0.182	0.172	0.263	0.069	0.097	0.851	0.788
$\hat{\sigma}_{(P \times G)}^2$	-	-	126184.1	-	-	45004.3	-	-	0.052	-	-	0.029	-	-
h^2	54.8	92.9	22.4	54.7	50.2	28.7	91.7	78.2	71.8	45.3	52.4	42.6	77.6	42.8
LI ²	43.9	91.2	0.1	44.4	35.4	2.6	90.1	71.7	61.5	32.9	37.8	21.5	72.6	25.3
LS	63.9	94.4	39.7	63.1	62.1	47.8	93.0	83.4	79.4	55.4	64	57.9	81.8	56.7

¹ Lower and upper limits of genetic variance, obtained according to Ramalho et al. (2005b); ² Lower and upper limits of heritability obtained, according to Knapp et al. (1985); MS_{Families} – Mean square of families; CV (%) – Coefficient of variation; *, ** Significant at 5 and 1% of probability.

Estimates of the genetic and phenotypic parameters (Table 2) also manifested the existence of variability among the families for all the traits evaluated, corroborating the results from analyses of variance. Observe that the lower limit of genetic variance in all situations was positive, indicating that genetic variance among the families must be different from zero at 95% confidence level. Estimates of heritability (h^2) also confirmed the presence of variability among the families. In all cases, the lower limit of the h^2 was positive indicating that the estimates obtained at the 95% confidence level should be different from zero. It is fitting to mention that these estimates are in the broad sense; however, as dominance is not expressive in the $F_{3:5}$, $F_{3:6}$, $F_{5:6}$ and $F_{5:7}$ generations, it may be inferred that a large part of the variance present in the numerator of h^2 must be additive (Moreto et al. 2007).

In cycle one, the contribution of variance of the family x generation interaction in relation to genetic variance ($\hat{\sigma}_{(F \times G)}^2 / \hat{\sigma}_p^2$) was expressive for plant architecture and for grain appearance (Table 2). For grain yield, the estimate of variance of the family x generation interaction was greater than genetic variance in the two cycles (Table

2). The genotype x environment interaction has been expressive in most of the studies undertaken in the state of Minas Gerais with the common bean crop (Carneiro et al. 2002, Cunha et al. 2005, Melo et al. 2006).

As the evaluation of the families in the two cycles of recurrent selection was carried out in different years and generations ($F_{3:5}$ and $F_{3:6}$ in cycle zero and $F_{5:6}$ and $F_{5:7}$ in cycle one), the strategy used to estimate genetic progress with recurrent selection was a comparison of the lines obtained at the end of each cycle. A significant effect of the lines was observed for all the characteristics evaluated (Table 3). Variation was also detected ($P < 0.01$) among the lines within the groups (C_0 and C_1), except for angular leaf spot among the lines of cycle one (C_1). The contrast of C_0 vs. C_1 was not significant only for plant architecture, indicating that there was no genetic progress for this characteristic. For the other characteristics, a significant effect ($P < 0.01$) was detected for the C_0 vs. C_1 contrast.

The line x environment interaction was significant ($P < 0.01$) for all the traits (Table 3), indicating that the behavior

Table 3. Summary of joint analyses of variance of yield (kg ha⁻¹) (YIELD) and grades of grain appearance (GA), plant architecture (PA) and severity of rust (RUST) and angular leaf spot (ALS) in reference to evaluation of red bean lines of the recurrent selection program

SV	df	YIELD	GA	PA	RUST	ALS	
		MS	MS	MS	MS	df	MS
Environments	2	55652010.2**	5.44**	4.48**	37.13**	1	348.56**
Treatments	61	786657.9**	1.12**	0.85**	21.12**	61	3.57**
Lines (L)	59	766137.5**	1.14**	0.88**	20.44**	59	3.26**
C_0	29	806027.1**	1.14**	0.61**	23.14**	29	2.62**
C_1	29	617868.2**	1.05**	1.16**	12.02**	29	2.04
C_0 vs. C_1	1	3909153.9**	3.75**	0.19	186.10**	1	56.83**
Controls (T)	1	177607.9	0.68*	0.01	2.74*	1	2.09**
L vs. T	1	2606407.7**	0.13	0.30	80.07**	1	23.55**
Treatments x Environments	122	370530.5**	0.21**	0.29**	0.71**	61	1.27**
Lines x Environ.	118	378809.7**	0.21**	0.29**	0.73**	59	1.28**
C_0 x Environments	58	364750.0**	0.20**	0.21*	0.73*	29	1.14**
C_1 x Environments	58	389436.9**	0.22**	0.35**	0.71*	29	1.23**
C_0 vs. C_1 x Environments	2	478350.6*	0.32	0.73**	1.31	1	6.69**
T x Environments	2	41448.5	0.05	0.10	0.05	1	0.08
L vs. T x Environments	2	211144.5	0.01	0.44	0.21	1	1.84
Mean Error	366	134563.5	0.12	0.15	0.48	244	0.65
Mean		2366	2.33	3.90	2.98		5.70
Mean C_0		2293	2.42	3.88	3.50		6.06
Mean C_1		2464	2.25	3.91	2.33		5.26
Ouro Vermelho		2091	2.05	4.00	4.67		6.67
Vermelinho		1892	2.44	4.05	5.45		7.50
CV (%)		15.5	14.8	9.9	23.2		14.1

*, ** Significant at 5 and 1% of probability.

of the lines was not consistent in the different environments. For the groups of lines (C_0 and C_1) the interaction was also significant ($P < 0.05$) for all the characteristics.

In addition to estimating genetic progress with recurrent selection, these experiments were conducted to identify lines superior to the Ouro Vermelho cultivar for the purpose of composing VCU testing for Minas Gerais. The lines RVC0-1, RVC0-5 and RVC0-28 of cycle zero had lower grades than the Ouro Vermelho cultivar for severity of rust and angular leaf spot (Table 4). These lines also had grades less than or equal to the standard cultivar Ouro Vermelho for grain appear-

ance and plant architecture and grades greater than or equal to Ouro Vermelho for productive performance. The C_1 lines that most stood out were RVCI-12, RVCI-20 and RVCI-28.

The estimate of genetic progress (GP) was obtained for each environment and for the mean value of the three evaluations (Table 5). For grain yield, the GP estimate in the winter crop season was 8.5% in 2008 and 9.6% in 2009, whereas in the dry crop season the progress was 2.9%. The difference in the estimates may be attributed to the occurrence of rust and angular leaf spot since, in the winter crop season, the climatic conditions favor the occurrence of rust, while in the dry crop

Table 4. Mean values of grain yield (kg ha^{-1}) (YIELD) and grades of grain appearance (GA), plant architecture (PA) and severity of rust (RUST) and angular leaf spot (ALS) of red bean lines derived from two cycles of recurrent selection evaluated in three environments

Lines	YIELD	GA	PA	RUST	ALS	Lines	YIELD	GA	PA	RUST	ALS
RVC0-1	2419a	2.3a	3.8a	1.1a	5.2a	RVCI-1	2591a	1.7a	4.2a	1.4a	5.0a
RVC0-2	2239a	2.1a	3.7a	5.1a	6.8a	RVCI-2	2203a	2.4a	4.1a	2.7	5.5a
RVC0-3	1969a	2.1a	3.6a	5.0a	6.5a	RVCI-3	2318a	2.3a	4.0a	1.3	5.3a
RVC0-4	2404a	2.1a	4.2a	4.1a	6.5a	RVCI-4	2362a	1.8a	4.1a	4.0a	5.2
RVC0-5	2467a	2.0a	4.3a	2.4	4.8	RVCI-5	2537a	2.7	3.2	1.9	5.0
RVC0-6	2080a	1.7a	4.1a	1.2	5.2	RVCI-6	2296a	1.8a	4.2a	1.2	5.2
RVC0-7	2112a	2.6a	3.9a	1.3	5.3a	RVCI-7	2341a	2.1a	4.2a	1.2	4.5
RVC0-8	2024a	2.1a	3.8a	1.8	5.8a	RVCI-8	1980a	2.0a	3.9a	4.9a	6.3a
RVC0-9	2361a	2.8	3.6a	3.0	5.8a	RVCI-9	2336a	2.1a	4.1a	3.9a	5.8a
RVC0-10	2622	2.5a	3.5a	3.0	6.8a	RVCI-10	2485a	2.1a	4.3a	1.4	5.2
RVC0-11	1885a	2.1a	3.7a	5.4a	7.2a	RVCI-11	2592a	2.3a	4.3a	4.0a	5.0
RVC0-12	1787a	2.5a	3.8a	5.3a	6.5a	RVCI-12	2776	2.4a	4.4a	1.3	4.7
RVC0-13	1819a	2.4a	3.8a	5.0a	6.8a	RVCI-13	2719	2.1a	3.7a	1.0	5.7a
RVC0-14	2059a	2.2a	4.0a	5.0a	6.5a	RVCI-14	2742	2.2a	3.7a	2.8	6.2a
RVC0-15	2237a	2.3a	4.0a	4.7a	5.5a	RVCI-15	2486a	2.2a	3.9a	1.7	5.7a
RVC0-16	2411a	2.5a	4.2a	4.6a	6.0a	RVCI-16	2719	2.2a	3.9a	3.6	5.8a
RVC0-17	2368a	2.6	4.1a	4.2a	5.8a	RVCI-17	2685	2.9	4.2a	1.1	5.3a
RVC0-18	2347a	3.1	3.7a	4.4a	6.2a	RVCI-18	2757	2.6	4.2a	1.3	6.2a
RVC0-19	2022a	2.9	3.8a	4.8a	6.3a	RVCI-19	2420a	2.1a	4.2a	3.9a	5.2
RVC0-20	2335a	3.0	4.0a	4.1a	6.3a	RVCI-20	3200	2.1a	4.2a	2.0	3.7
RVC0-21	2641	2.2a	4.1a	2.2	6.0a	RVCI-21	2573a	3.0	3.7a	3.4	4.3
RVC0-22	2782	2.9	4.0a	1.1	5.3a	RVCI-22	1919a	2.7	3.6a	4.3a	5.7a
RVC0-23	2670	3.2	4.0a	1.2	5.8a	RVCI-23	2353a	2.2a	3.4	2.3	5.2
RVC0-24	1997a	2.3a	3.3	4.9a	6.5a	RVCI-24	2389a	2.1a	3.2	2.8	5.8a
RVC0-25	2194a	2.2a	3.4	5.1a	7.3a	RVCI-25	2248a	2.4a	3.4	2.3	5.0
RVC0-26	2097a	2.7	3.5a	4.6a	6.5a	RVCI-26	2507a	2.4a	3.7a	2.0	5.2
RVC0-27	2729	2.3a	4.1a	2.1	5.3a	RVCI-27	2535a	1.5	4.5a	1.4	5.5a
RVC0-28	2678	2.4a	4.2a	1.2	5.0	RVCI-28	2487a	2.3a	3.4	1.1	4.5
RVC0-29	2899	2.4a	4.3a	1.7	5.5a	RVCI-29	2056a	2.6	4.0a	2.0	5.5a
RVC0-30	2148a	2.3a	3.9a	5.2a	6.3a	RVCI-30	2296a	2.4a	3.6a	1.3	4.8
O. Vermelho	2091	2.1	4.0	4.7	6.7	O. Vermelho	2091	2.1	4.0	4.7	6.7

¹ Mean values followed by the letter *a* in the column do not statistically differ from the Ouro Vermelho cultivar (O. Vermelho), by the Dunnett test at 1% probability

Table 5. Estimates of genetic progress (GP%) for grain yield (YIELD), grain appearance (GA), plant architecture (PA) and resistance to rust (RUST) and angular leaf spot (ALS), after two cycles of recurrent selection in red beans

	YIELD (kg ha ⁻¹)		GA (grades)		PA (grades)		RUST (grades of severity)		ALS (grades of severity) ¹	
	Mean	Variation	Mean	Variation	Mean	Variation	Mean	Variation	Mean	Variation
Winter 2008										
C ₀	2771	1906 - 3889	2.41	1.83 - 2.83	3.78	2.83 - 4.50	3.72	1.00 - 6.00	-	-
C ₁	3006	2103 - 4561	2.17	1.33 - 2.83	3.67	2.33 - 4.50	2.46	1.00 - 5.33	-	-
GP (%)	8.5	-	10.0	-	2.9	-	33.9	-	-	-
Dry Season 2009										
C ₀	1766	990 - 2463	2.56	1.83 - 3.67	3.99	3.00 - 4.83	2.90	1.00 - 5.00	6.90	5.67 - 8.67
C ₁	1817	1190 - 2188	2.49	1.83 - 3.33	4.10	3.17 - 4.83	1.92	1.00 - 4.00	6.38	4.67 - 7.67
GP (%)	2.9	-	2.7	-	-2.8	-	33.8	-	7.5	-
Winter 2009										
C ₀	2343	1547 - 3022	2.29	1.17 - 3.17	3.86	3.50 - 4.17	3.88	1.00 - 6.00	5.21	3.67 - 7.00
C ₁	2568	1783 - 2931	2.09	1.17 - 3.50	3.97	3.33 - 4.50	2.60	1.00 - 5.33	4.14	2.33 - 6.00
GP (%)	9.6	-	8.7	-	-2.8	-	33.0	-	20.5	-
Joint										
C ₀	2293	1787 - 2899	2.42	1.67 - 3.22	3.88	3.28 - 4.28	3.50	1.11 - 5.45	6.06	4.84 - 7.34
C ₁	2464	1919 - 3200	2.25	1.50 - 3.00	3.91	3.17 - 4.50	2.33	1.00 - 4.89	5.26	3.67 - 6.34
GP (%)	7.5	-	7.0	-	-0.8	-	33.4	-	13.2	-

¹The severity of angular leaf spot was evaluated only in the dry and winter crop seasons of 2009.

season, the conditions are more favorable to the occurrence of angular leaf spot. As the lines of cycle one were around 33% more resistant to rust in relation to the cycle zero lines, it is possible that the greater level of resistance to rust has contributed to greater yield of these lines, leading to greater GP in the winter crop season. In contrast, in the dry crop season, the greater occurrence of angular leaf spot and the low level of resistance of the lines of the two cycles negatively affected productivity and consequently the GP in this crop season.

Considering the mean value of the three environments, the GP for grain yield was 7.5%, which represents 171 kg ha⁻¹ (Table 5). In the literature, estimates of genetic progress with recurrent selection in the common bean crop for grain yield range from 3.3 to 55% (Ranalli 1996, Singh et al. 1999, Ramalho et al. 2005a, Silva et al. 2010). Evaluating the lines obtained in four cycles of recurrent selection for carioca bean breeding, Ramalho et al. (2005a) observed genetic progress of 5.7% per cycle for grain yield. In autogamous plants, comparison among GP estimates are difficult due to differences in the methodologies used in carrying out the recurrent selection programs.

The GP for grain appearance was also greater in the winter crop season (Table 5). Here, the greater occurrence of angular leaf spot may also have contributed to the lower GP estimate in the dry crop season. In this case, the disease hurt bean formation, affecting their appearance. Therefore,

there was a tendency to level out the grain appearance grades of the lines of the two cycles, resulting in lower GP. Considering the three evaluations, the GP was 7%. In carioca beans, estimates of genetic progress with recurrent selection for grain appearance have been reported at around 10% (Ramalho et al. 2005a, Menezes Júnior et al. 2008).

In regard to resistance to rust, genetic progress was above 33% in the three environments and in the mean value of the evaluations (Table 5). For angular leaf spot, considering the mean value of the two environments in which this disease was evaluated, genetic progress was 13.2%. It is worth emphasizing that genetic progress in this case is a result of reduction in severity of the disease, i.e., increase in resistance to the pathogen. In the literature, estimates of genetic progress for resistance to rust were not found. For angular leaf spot, Amaro et al. (2007) obtained genetic progress of 6.3% per cycle, after six cycles of phenotypic recurrent selection.

For plant architecture, it may be said that there was no genetic progress since the C₀ vs. C₁ contrast was not significant (Table 3). This fact was already expected because in the choice of the parents used in composition of the population base, this characteristic was not taken into consideration. As the recommended red bean cultivars are unsatisfactory in regard to plant architecture, the inclusion of parents with upright stand becomes necessary in the population in the following cycles.

It is important to emphasize that to obtain the cycle one population, three new parents were included (VR-3, VR-2 and BRS Timbó) for the purpose of improving the level of resistance to rust and angular leaf spot in the population. Thus, part of the genetic progress obtained must be attributed to the effect of these parents. The possibility of introducing new parents during the recombination phases is one of the advantages of recurrent selection (Geraldini 1997, Ramalho et al. 2001), making the process much more dynamic. This strategy was also successfully used by Ramalho et al. (2005a).

After two cycles of recurrent selection, genetic progress in the mean of the three crop seasons evaluated was 7.5% for grain yield, 7% for grain appearance, 33.4% for resistance to rust and 13.2% for resistance to angular leaf spot, proving the efficiency of recurrent selection in common bean breeding.

Dois ciclos de seleção recorrente no melhoramento de feijão vermelho

Resumo - Este trabalho foi realizado com os objetivos de estimar o progresso genético após dois ciclos de seleção recorrente no melhoramento de feijão vermelho e obter novas linhagens. No ciclo zero foram avaliadas famílias $F_{3;3}$ e $F_{3;6}$. No ciclo um as famílias foram extraídas na geração F_5 e avaliadas nas gerações $F_{5;6}$ e $F_{5;7}$. Como as famílias foram avaliadas em anos e gerações diferentes, a estimativa do progresso genético foi obtida avaliando simultaneamente as 30 melhores linhagens obtidas no final de cada ciclo, em experimentos conduzidos por três safras. Após dois ciclos de seleção recorrente, o progresso genético, na média das safras, foi de 7,5% para produtividade de grãos, 7% para aspecto de grãos, 33,4% para resistência a ferrugem e 13,2% para resistência a mancha angular. Foram obtidas linhagens de feijão vermelho com potencial para serem incluídas em futuros ensaios de Valor de Cultivo e Uso (VCU) para Minas Gerais, Brasil.

Palavras-chave: *Phaseolus vulgaris*, genética quantitativa, melhoramento vegetal

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