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Genetic progress after four cycles of recurrent selection for yield and grain traits in common bean

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Summary

The objective of this study was to evaluate the genetic progress after four cycles of recurrent selection in common bean. The base segregating population was obtained from 10 parents, and derived the $S_{0:1}$ and $S_{0:2}$ families that were evaluated. The $S_{0:3}$ families with higher grain yield and grain color, like the standard carioca were selected, and were intercrossed to generate the population of the following cycle. This process was repeated for four cycles. The best families were evaluated in each cycle by many generations and locations, and the five best lines of each cycle were identified. The 20 lines thus obtained were evaluated in two growing seasons, sown in July and November 2002. The grain yield (kg/ha) and grain type (scale of scores) were evaluated. Genetic progress was confirmed for both traits. The mean annual gain with selection for the grain type was 10.5% and 5.7% for grain yield, with no evidence of variability reduction in the population. These results show that recurrent selection is a good alternative for improving common bean quantitative traits.

Introduction

The main alternative to make self-pollinating plant breeding more dynamic and probably more efficient is the use of recurrent selection as proposed for open pollinating plants (Hallauer, 1986). Its efficiency for self-pollinating plants was demonstrated by Fouilloux & Bannerot (1988). Recurrent selection has been successfully applied for some time in some self-pollinating plant species such as soybean (Uphoff et al., 1997; Wilcox, 1998), wheat (Wang et al., 1996; Wiersma et al., 2001), rice (Rangel et al., 1998) and oats (Koeyer et al., 1999). There are also some successful studies specifically on the common bean (*Phaseolus vulgaris*) using recurrent selection (Beaver & Kelly, 1994; Garcia et al., 2003; Ranalli, 1996; Singh et al., 1999). However, the results presented referred to one or two selection cycles.

No reports were found in Brazil of recurrent selection in common bean. As the cultivation of this legume is predominantly with carioca (Voysest, 2000) grain type, that is, brown striped cream beans, there is an additional restriction in the variability because of the need to select only individuals or families with this grain type. Considering that many genes are involved in grain yield and grain color inheritance (Basset, 1996; Leakey, 1988), recurrent selection is a good option to increase the frequency of the favorable alleles by recombination in the successive selective cycles, increasing the chance of selecting individuals and/or families that associate high grain yield and grain color commercially acceptable.

In this study the genetic progress after four cycles of recurrent selection was estimated based on the performance of the select lines with high grain yield and grain color like the standard carioca.

Material and methods

The recurrent selection program was conducted in the experimental area at the Universidade Federal de

Lavras (UFLA) located at 918 m altitude, 21°14′S and 40°17′W. Starting in 1990 the base population was obtained involving the following parents: BAT 477, IAPAR 14, FT 84-292, Jalo, A-252, A-77, Ojo de Liebre, ESAL 645, Pintado and Carioca (Table 1). Firstly a diallel cross was performed to obtain the bi-parental hybrids. Some combinations were not obtained due to genetic incompatibility (Singh & Gutierrez, 1984; Vieira et al., 1989). The bi-parental hybrids were later intercrossed to obtain the double hybrids. One hundred and fifty F_2 ($=S_0$) seeds of each double hybrid, with grain color like the standard carioca, were mixed to obtain the original population, I cycle (C-I) in the S_0 generation. The conduction scheme adopted is shown in Figure 1.

After evaluating the $S_{0:1}$ and $S_{0:2}$ families, the latter in two or three environments, the families with higher grain yield and grain color like the standard carioca were selected. They were then intercrossed using the $S_{0:3}$ plants that were sown in pots, and used at least six individuals of each family. The recombination among families was set up by a circulant diallel where each family participated in two hybrids. From then onwards the procedure was similar to that adopted in C-I. The best families were always evaluated in at least three growing seasons in three locations.

The families, now lines, that had been outstanding in this selection process, were evaluated again, in the experiment called elite line assessment, which include promising lines identified in other breeding programs conducted in the region. These experiments were carried out in three growing seasons for two years and in each 25–36 lines were evaluated. This same procedure applied to assess the C-I family was repeated with the II cycle (C-II), III cycle (C-III) and IV cycle (C-IV).

The efficiency of the recurrent selection was estimated based on the performance of the five best lines from each selection cycle, selected in the respective elite line experiments. Thus 20 lines were identified, that is, five from each selection cycle.

These 20 lines and the Pérola cultivar used as control were evaluated in the county of Ijaci, MG, Brazil (latitude 21°13′S, 915 m altitude) sown in July 2002. A randomized complete block design with five replications was adopted. The plot consisted of two 4-m long rows, spaced of 45 cm with 15 seeds per linear meter. Another experiment was sown in November 2002 in Lavras, MG, Brazil, similar to the previous experiment, except that 14 replications were used.

The experiments were set up according to the crop management recommendations for the common bean. The grain yield and grain type data were scored. Grain type was evaluated only in the first evaluation, by a scale of scores ranging from 1 to 5 presented by Ramalho et al. (1998) where: 1 – typical carioca grain type: cream colored with light brown stripes, pale

Table 1. Some characteristics of common bean lines used in recurrent selection

Lines	Cycle	Race	Growth habit	Grain	
				Color	Size
BAT 477	C-I	Mesoamerica	II	Beige	Small
IAPAR 14	C-I	Mesoamerica	III	Brown striped cream	Small
FT 84-292	C-I	Mesoamerica	II	Brown striped cream	Small
Jalo	C-I	Nueva Granada	III	Yellow	Large
A-252	C-I	Mesoamerica	III	Brown striped cream	Small
A-77	C-I	Mesoamerica	I	Brown striped cream	Small
Ojo de Liebre	C-I	Durango	III	Brown striped cream	Medium
ESAL 645	C-I	Mesoamerica	II	Brown striped cream	Small
Pintado	C-I	Nueva Granada	III	Red speckled cream	Large
Carioca	C-I	Mesoamerica	III	Brown striped cream	Small
P-85	C-II	Mesoamerica	III	Brown striped cream	Small
P-103	C-II	Mesoamerica	III	Brown striped cream	Small
H-4	C-III	Mesoamerica	III	Brown striped cream	Small
AN 910522	C-III	Mesoamerica	III	Brown striped cream	Small
ESAL 624	C-III	Mesoamerica	II	Brown striped cream	Small
Carioca MG	C-III	Mesoamerica	II	Brown striped cream	Small

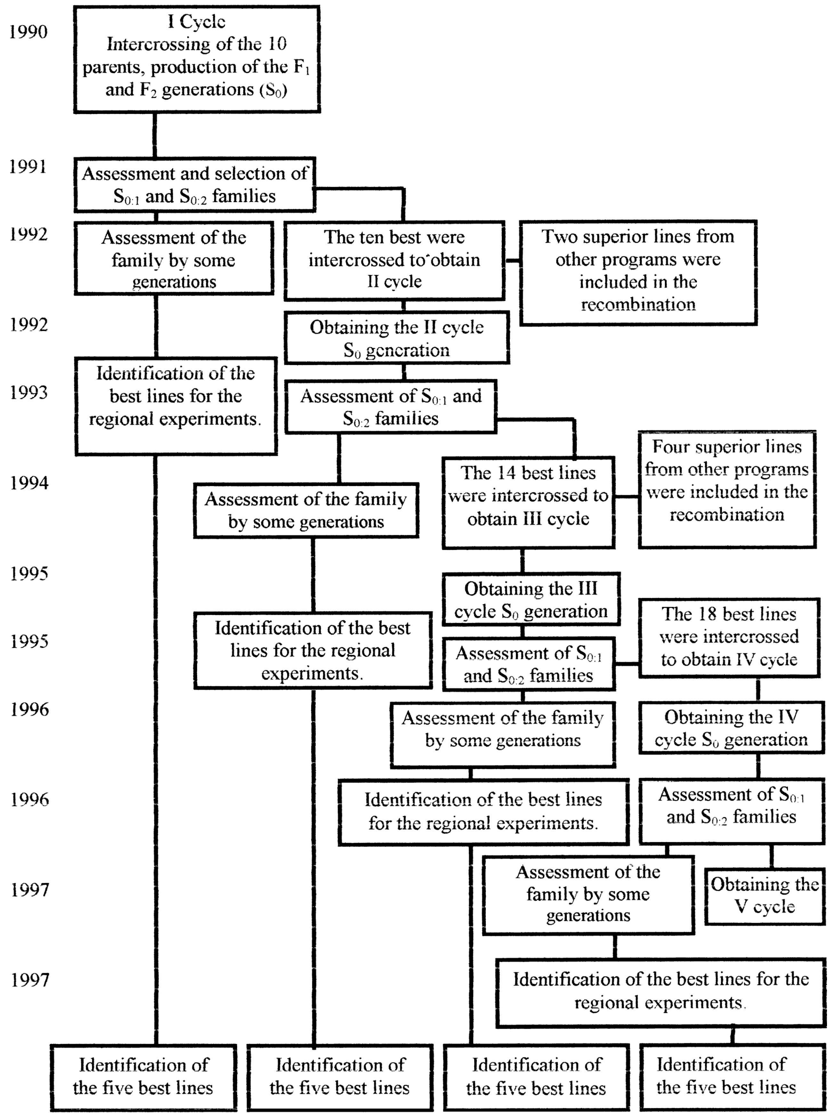

Figure 1. Scheme of the procedure adopted to recurrent selection in the common bean breeding.

background, without corona, mean weight of 100 grains 22–24 g, and non flattened grains; 2 – carioca grain type deficient in one of the characteristics mentioned in the standard: 3 – carioca grain type deficient in two of the characteristics mentioned in the standard; 4 – carioca grain type deficient in three of the characteristics mentioned in the standard; 5 – cream colored grain with dark brown stripes, dark background, with corona, mean weight of 100 seeds less than 22 g, and flattened grains. The scores were established by three professionals with experience in the common bean cropping.

The yield data were submitted to analysis of variance by growing season and then joint analysis was performed according to methodology presented by Steel et al. (1997). The mean grain scores were also submitted to analysis of variance considering the score of each evaluator as a replication. Means were grouped by Scott & Knott (1974) test. Using the mean data the progress with selection was estimated by the least squares method (Vencovsky & Barriga, 1992).

The assessment of the $S_{0:2}$ families of the VI cycle was considered to verify the presence of some residual variability in the population. In this case 223 families plus two controls were evaluated in two locations, Lavras, and Lambari (21°31′S latitude, 45°22′W longitude, 845 m altitude) in a 15 × 15 lattice design with three replications, and plots of two 2-m long rows, with 15 plants per linear meter. Grain yield was evaluated and analysis of variance was performed according to methodology presented by Steel et al. (1997). The covariance was estimated between the mean performance of the families in the two locations ($cov_{Lav,Lam}$) that corresponds to the genetic variance ($\sigma^2{}_G$) among the families without interaction. Heritability (h^2) for selection on the mean of the two locations was obtained by the expression $h^2 = \sigma^2_G/\sigma^2_F = \sigma_G{}^2/(MS_{families}/6)$. The lower and upper h^2 limits were estimated, using the expression proposed by Knapp et al. (1985).

Results and discussion

The results were presented by growing season because the performance of the lines was not coincident in the two growing seasons. Table 2 shows the mean grain yield results. Although there was variation in the grain yield of the lines among and within the recurrent selection cycles, in advanced selection cycles there was always at least one line with higher yield than all those of the previous cycle. What is most interesting however in this study is the mean performance of the five lines within each selection cycle. The mean yield increased with the cycles in both growing seasons.

The linear regression equation was estimated from the mean yield of each selection cycle. The means fitted very well to the regression line with a R^2 greater than 91%. The estimate of the coefficient of linear regression (b) was also positive in both seasons, agreeing with the previous statement that the mean yield of the lines selected increased with the selection cycles. In the trial carried out in the cold growing season, sown in July, the gain observed with recurrent selection was 7.2% and in the crop sown in the warm season in November it was 4.3%.

The difference in the estimates of gain obtained in the first trial compared to the second can be attributed, at least in part, to the fact that in the first trial the seeds were removed from the dry and cold chamber for planting in the experiment. Especially those of the first cycle had been stored for a long period, that may have contributed to reduce germination, emergence and vigor, with reflections in the grain yield. In the second trial all the seeds had the same age. It should also be emphasized that in the first trial, conducted in the cold growing seasons, the environmental conditions were better than in the warm season, and may have contributed to the superior lines expressing their genetic potentials.

Comparison among gains with recurrent selection in self-pollinating plants is not easy mainly because of the differences in the methodologies used. Methodologies used include: comparison among the S_0

Table 2. Grain yield, kg/ha, obtained in the evaluation of the best lines from the I, II, III and IV cycles of recurrent selection in experiments sown in two growing seasons, July and November 2002

	Growing seasons							
	July				November			
Lines	C-I	C-II	C-III	C-IV	C-I	C-II	C-III	C-IV
1	3050 A[1]	3200 A	3450 A	3478 A	2256 B	2267 B	2434 A	2547 A
2	2845 B	2728 B	2900 B	2967 B	2106 B	2478 A	2617 A	2170 B
3	2261 C	2750 B	3184 A	3350 A	2447 A	2511 A	2539 A	2747 A
4	2411 C	2478 C	2822 B	3272 A	2409 A	2406 A	2356 A	2572 A
5	2770 B	2822 B	2884 B	3339 A	1886 B	2417 A	2361 A	2711 A
Mean	2667	2767	3047	3281	2222	2417	2461	2547
Control mean (Perola)	2472 C				2614 A			
General mean	2939				2411			
Coefficient of variation (%)	13.0				17.0			
Coefficient of linear regression	212.07*				103.31*			
R^2 (%)	97.2				91.9			
Progress with selection (%)	7.2				4.3			

[1]Means followed by the same letter in each season, belong to the same group according to Scott & Knott (1974) test ($P < 0.05$).
*Significant at $p = 0.05$ by t test.

populations obtained after each recombination; the use of the common controls in the assessment of the families in each cycle; the use of S_2 and S_3 families taken randomly (Olmedo et al., 1995); the use of S_2 and S_3 families chosen based on their high grain yield (Ranalli, 1996; Singh et al., 1999), and finally, the use of the best lines identified in the different cycles. This last procedure was adopted in the present study, although no report was found of its previous use. It is a more efficient procedure than the previous ones, because the lines were chosen after several generations of evaluation in many locations and sowing periods. Thus the effect of the genotype by environment interaction is reduced, there is greater confidence in identifying the superior lines, and in conclusions, the gain is realized in each cycle.

There are other factors besides the difference in the gain evaluation procedure of the selective cycles, that make the comparison of present results with those found in the literature difficult. They include the number of selection cycles and the trait under selection. Some results were found with recurrent selection in common bean for the grain yield (Ranalli, 1996; Singh et al., 1999). In these studies, as already mentioned, the S_2 families were used for the comparisons. Singh et al. (1999) estimated a mean gain of 15% per cycle after two selection cycles. High gain for grain yield with recurrent selection has been reported in several other self-pollinating species (Koeyer at al., 1999; Olmedo et al., 1995; Uphoff et al., 1997).

In the present study emphasis was directed to grain type especially in the two first selection cycles. Farmers and wholesalers are very demanding about grain appearance. In the case of the carioca type, the requirements are even greater in Brazil, especially for the grain background color, that should be as pale as possible, with light brown stripes. Furthermore, the 100 grains weight should be 22–25 g and the grain should not be flattened. The results of the scores for grain types (Table 3) showed that there was success with selection. The estimate of the linear regression coefficient was $b = -0.32$, that indicates progress with selection of 10.5% per cycle compared to the mean score of the families in the original cycle.

No previous report was found on the response to selection for the grain type in common bean cropping. However, given the number of genes involved, more than 18 have been identified for color alone (Basset, 1996; Leakey, 1988), it is easy to understand that recurrent selection is the main alternative for improving characteristics involved with grain quality as the results obtained in the present study show.

Table 3. Mean scores for grain type obtained in the evaluation of the best lines from I, II, III and IV cycles of recurrent selection

	Recurrent selection cycles			
Lines	C-I	C-II	C-III	C-IV
1	3.17[1] B[2]	1.83 A	1.67 A	1.50 A
2	2.67 B	2.17 A	2.67 B	1.50 A
3	3.33 B	2.67 A	2.50 B	2.17 A
4	3.17 B	2.17 A	2.67 B	1.83 A
5	3.00 B	2.00 A	2.67 B	2.00 A
Line mean	3.07	2.17	2.43	1.90
Control mean			2.5 B	
General mean			2.4	
Coefficient of variation (%)			18.0	
Coefficient of linear regression			-0.32 ($P \leq 0.12$)	
R^2 (%)			69.7	
Progress with selection (%)			10.5	

[1]Score 1 corresponds to the grains within the carioca commercial standard and 5 outside the standard.
[2]Mean followed by the same letter belong to the same group by the Scott & Knott (1974) test ($P < 0.05$).

The difference in the recurrent selection used in this study compared to those mentioned in the literature is that in each selection cycle two or four lines were introduced during recombination. This way part of the gain with selection may be attributed to the lines that were added during recombination. This is a great advantage of recurrent selection in self-pollinating plants, and enables the introduction of lines that are outstanding in experiments conducted in the region or obtained from other projects in the breeding program. Thus the process is much more dynamic because at each cycle new lines can be added for recombination.

The maintenance of genetic variability in the populations with the selection cycles was checked by the evaluation of $S_{0:2}$ families from VI cycle. It is important to point out that data from the VI cycle were chosen because they were obtained more recently, but similar results were also obtained for the V cycle, whose best lines are still being evaluated and therefore are not part of this study. The results of the joint analysis of variance presented in Table 4 show that the family effect was highly significant, the estimates of the genetic covariance of the mean grain yield of the families in the two locations, and the heritability confirm that there is still wide genetic variability in the population. The parents (Table 1), specially those of the base population, are from different genic pools, and they should have increased the genetic variability of the population, as mentioned by Singh (1989), which is being slowly liberated through the sucessive intercrossing.

Table 4. Summary of the joint analysis of variance of grain yield (kg/ha) obtained in the evaluation of the $S_{0:2}$ families from the VI cycle of recurrent selection in two locations, sown in July 2001

Variation source	DF	MS
Locations (L)	1	83253762.75**
Families (F)	224	843988.00**
L × F	224	453166.75
Mean error	812	395227.25
Mean	4132	
Coefficient of variation (%)	15.21	
$Cov_{Lav,Lam}(\sigma_G{}^2)$	65136.75	
Heritability (h^2) (%)	46.31	
Lower limit of h^2 (%)	30.00	
Upper limit of h^2 (%)	59.00	

**Significant at $p = 0.01$ by F test.

References

Basset, M.J., 1996. List of genes – *Phaseolus vulgaris* L. Ann Rep Bean Improv Coop 39: 1–19.

Beaver, J.S. & J.D. Kelly, 1994. Comparison of selection methods for dry bean populations derived from crosses between gene pools. Crop Sci 34: 34–37.

Fouilloux, G. & H. Bannerot, 1988. Selection methods in the common bean (*Phaseolus vulgaris*). In: P. Gepts (Ed.), Genetic resources of *Phaseolus* beans, pp. 503–542. Kluwer Academic, Dordrecht, The Netherlands.

Garcia, R., R.A. Robinson, J.A. Aguilar, S. Sandoval & R. Guzman, 2003. Recurrent selection for quantitative resistance to soil-borne diseases in beans in the Mixteca region, Mexico. Euphytica 130: 241–247.

Hallauer, A.R., 1986. Compendium of recurrent selection methods and their applications. CRC Rev Plant Sci 3: 1–33.

Knapp, S.J., W.W. Stoup & W.M. Ross, 1985. Exact confidence intervals for heritability on a progeny mean basis. Crop Sci 25: 192–194.

Koeyer, D.L., De, R.L. Phillips & D.D. Stuthman, 1999. Changes in genetic diversity during seven cycles of recurrent selection for grain yield in oat, *Avena sativa* L. Plant Breed 118: 37–43.

Leakey, C.L.A., 1988. Genotypic and phenotypic markers in common bean. In: P. Gepts (Ed.), Genetic resources of *Phaseolus* beans, pp. 245–327. Kluwer Academic, Dordrecht, The Netherlands.

Olmedo-Arcega, O.B., E.M. Elias & R.G. Cantrell, 1995. Recurrent selection for grain yield in durum wheat. Crop Sci 35: 714–719.

Ramalho, M.A.P., L.H. Pirola & A. de F.B. Abreu, 1998. Alternativas na seleção de plantas de feijoeiro com porte ereto e grão tipo carioca. Pesquisa Agropecuária Brasileira 33: 1989–1994.

Ranalli, P., 1996. Phenotypic recurrent selection in common bean (*Phaseolus vulgaris* L.) bsed on performance of S_2 progenies. Euphytica 87: 127–132.

Rangel, P.H.N., F.J.P. Zimmermann & P.C.F. Neves, 1998. Estimativas de parâmetros genéticos e resposta â seleção nas populações de arroz irrigado CNA-IRAT 4PR e CNA-IRAT 4ME. Pesquisa Agropecuária Brasileira 33: 905–912.

Scott, A.J. & M.A. Knott, 1974. Cluster analysis method for grouping means in the analysis of variance. Biometrics 2: 110–114.

Singh, S.P., 1989. Patterns of variation in cultivated common bean (*Phaseolus vulgaris*, Fabaceae). Econ Bot 43: 39–57.

Singh, S.P. & J.A. Gutiérrez, 1984. Geographical distribution of the Dl1 and Dl2 genes causing hybrid dwarfism in *Phaseolus vulgaris* L., their association with seed size, and their significance to breeding. Euphytica 33: 337–345.

Singh, S.P., H. Terán, C.G. Munõz & J.C. Takegami, 1999. Two cycles of recurrent selection for seed yield in common bean. Crop Sci 39: 391–397.

Steel, R.G.D., J.H. Torrie & D.A. Dickey, 1997. Principles and procedures of statistics: A biometrical approach, 3rd edn. McGraw-Hill, New York.

Uphoff, M.D., W.R. Fehr & S.R. Cianzio, 1997. Genetic gain for soybean seed yield by three recurrent selection methods. Crop Sci 37: 1155–1158.

Vencovsky, R. & P. Barriga, 1992. Genética biométrica no fitomelhoramento. Soc. Brasileira de Genét., Ribeirão Preto, Brazil.

Vieira, A.L., M.A.P. Ramalho & J.B. dos Santos, 1989. Crossing incompatibility in some bean cultivars utilized in Brazil. Rev Brasileira de Genét 12: 169–171.

Voysest, O., 2000. Mejoramiento genético del frijol (*Phaseolus vulgaris* L.). Legado de variedades de América Latina 1930–1999. CIAT, Cali, Colombia.

Wang, X.W., J.R. Lai, L. Fan & R.B. Zhang, 1996. Effects of recurrent selection on populations of various generations in wheat by using the Tai Gu single dominant male-sterile gene. J Agric Sci 126: 397–402.

Wiersma, J.J., R.H. Busch, G.G. Fulcher & G.A. Hareland, 2001. Recurrent selection for kernel weight in spring wheat. Crop Sci 41: 999–1005.

Wilcox, J.R., 1998. Increasing seed protein in soybean with eight cycles of recurrent selection. Crop Sci 38: 1536–1540.