Crop Breeding and Applied Biotechnology 11: 50-58, 2011
Brazilian Society of Plant Breeding. Printed in Brazil

Common bean breeding to improve red grain lines

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Received 20 May 2010

Accepted 16 November 2010

ABSTRACT - *The purpose of this study was to evaluate the performance potential of red bean lines, derived from populations of the first cycle of recurrent selection in the common bean breeding program of the Federal University of Viçosa, Minas Gerais. In the $F_{3:5}$, $F_{3:6}$ and $F_{3:7}$ generations, 243 families from 18 segregating populations were evaluated. These families were conducted by the bulk-within-families method and from the best, 154 lines were obtained and evaluated in the dry season of 2006 ($F_{7:9}$) and of 2007 ($F_{7:10}$), Coimbra - MG. The estimates of genetic and phenotypic parameters revealed variability among families. The method bulk within F_3-derived families proved useful for bean breeding. The most promising lines that may be included in future tests of value for cultivation and use (VCU), and will possibly be recommended for planting in the state of Minas Gerais, were derived from the populations Vermelhinho/AN9022180//Vermelhinho/Vermelho2157, Vermelhinho//Vermelhinho/ IAPAR81,Vermelhinho/LR720982// Vermelhinho/AB136 and Vermelhinho/AB136//Vermelhinho/ Vermelho2157.*

Key words: Phaseolus vulgaris *L., recurrent selection, selection within families, red bean.*

INTRODUCTION

In Brazil, the common bean types with best market acceptance are the carioca and black groups. The efforts of the main breeding programs of this legume were therefore focused on these grain types, with significant gains for yield, disease resistance, plant architecture, earliness and grain quality (Ramalho et al. 2005a, Melo et al. 2006, Silva et al. 2007, Botelho et al. 2008, Menezes Júnior et al. 2008, Ragagnin et al. 2009). However, some bean types, although not very significant at a national level, are important in certain regions of the country. This is the case, e.g., for red bean, widely cultivated in the Zona da Mata of Minas Gerais.

Since bean breeding programs focus mainly on carioca and black bean, producers in regions with preference for other grain types are forced to use local traditional varieties, which are generally uncompetitive, compared with the improved cultivars. In the case of red bean, the cultivar called Vermelhinho, used by farmers in the Zona da Mata of Minas, has a number of undesirable characteristics, especially with regard to pathogen susceptibility (Alzate-Marin et al. 2006). Besides, the yield potential of this cultivar is low compared to improved cultivars.

Another red bean cultivar called Vermelho 2157, regardless of the higher yield potential and better pathogens resistance, is not used by producers in the Zona da Mata Mineira, since the grains are large and their color is irregular. This limits the use, since such grains have no commercial value (Vieira 2005). Consequently, the demand is high for new commercial cultivars in this group.

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To meet this demand, the common bean program of the Federal University of Viçosa (UFV) was also used for the improvement of red bean in the late 1990s. A recent result of this work was the recommendation of the cultivar Ouro Vermelho (Carneiro et al. 2006), with 30% higher yield than Vermelhinho. The release of this cultivar has led to significant yield increases and better market supply of red bean, benefiting both producers and consumers. However, as the demand for red bean has been increasing in the region, new cultivars must be obtained, better than those used by producers. Thus, aside from being more productive, the spectrum of pathogen resistance of new cultivars should be greater and plant architecture better.

Since the various phenotypes of interest are distributed in different parents, it is almost impossible to unite all these phenotypes in a single selection cycle, some authors have suggested the use of recurrent selection (Hallauer 1992), i.e., the cycles of continuous selection and recombination (Geraldi 1997). This strategy has been used with great success in bean breeding to obtain improved lines for various traits of interest (Singh et al. 1999, Ramalho et al. 2005a, Amaro et al. 2007, Menezes Júnior et al. 2008). The purpose of this study was to evaluate the performance potential of red bean lines of the common bean breeding program of the Federal University of Viçosa, derived from populations of the first cycle of recurrent selection.

MATERIAL AND METHODS

The experiments were conducted in an experimental field in Coimbra of the Federal University of Viçosa (UFV), in Coimbra, state of Minas Gerais (lat 20º 45' S, long 42º 51' W, alt 690 m asl).

In the beginning of the red bean breeding program of the Federal University of Viçosa, the only red bean cultivar available to farmers in the Zona da Mata Mineira, Vermelhinho, was crossed with the following lines: Aporé, Pérola, IAPAR31, IAPAR81, AN9022180, LR720982CP, AFR19521, AFR19535, AB136, and Vermelho 2157. Segregating populations were established by single, double and back-crosses with cv Vermelhinho 18 (Table 1), representing the basis for a recurrent selection program of the UFV. The crosses were made in a greenhouse following the procedure without emasculation described by Peternelli et al. (2009).

The 18 populations were advanced in bulk for two generations. A total of 243 families derived from plants with the standard red grain color grown in the region Zona da Mata in Minas Gerais were evaluated for grain yield for three generations, $F_{3:5}$, $F_{3:6}$ and $F_{3:7}$, together with 13 controls, in the two of the three possible growing seasons, i.e., in the dry season (sowing Feb/Mar) and winter (sowing Jun/Jul) of 2002 and dry season of 2003, respectively. Each plot consisted of two 2-m rows. During the assessments, families were advanced by the bulk-within-family method. The regional cultural practices for common bean were applied and sprinkler irrigation, whenever rainfall was insufficient (experimental details in Table 2).

Table 1. Genealogy of the 18 populations used to breed red bean lines

Population	Cross	Genealogy
1	RVC072	Vermelhinho/AB136//Vermelhinho/AFR19521
2	RVC040	Vermelhinho//Vermelhinho/AN9022180
3	RVC043	Vermelhinho//Verme lhinho/Pérola
4	RVC069	Vermelhinho/AN9022180//Vermelhinho/Vermelho2157
5	RVC053	Vermelhinho/AB136//Vermelhinho/Vermelho2157
6	RVC041	Vermelhinho//Vermelhinho/IAPAR31
7	RVC038	Vermelhinho//Vermelhinho/Aporé
8	RVC061	Vemelhinho/Pérola//Vermelhinho/AFR19 521
9	RVC065	Vermelhinho/IAPAR31//Vermelhinho/AFR19535
10	RVC039	Vermelhinho//Vermelhinho/LR720982CP
11	RVC042	Vermelhinho//Vermelhinho/IAPAR81
12	RVC057	Vermelhinho/Aporé//Vermelhinho/AFR19521
13	RVC066	Vermelhinho/Pérola//Vermelhinho/AB136
14	RVC052	Vermelhinho/IAPAR31//Vermelhinho/AB136
15	RVC067	Vermelhinho/LR720982CP//Vermelhinho/AB136
16	RVC054	Vermelhinho/AFR19521//Vermelhinho/Vermelho2157
17	RVC071	Vermelhinho/AB136//Vermelhinho/Vermelho2157
18	RVC068	Vermelhinho/LR720982CP//Vermelhinho/AF R19521

The grain yield data in kg ha^{-1}, were subjected to analysis of variance per generation, considering all model effects random, except the mean (Cruz et al. 2004), based on the following statistical model: $Y_{ikl} = m + p_i + r_k + b_{l(k)} + e_{ikl}$, where Y_{ikl} is the value observed in the plot of treatment i in block l, within replication k; m is the overall mean, p_i is the treatment effect i (i = 1, 2, 3 ,..., 256), i.e, involving the 243 families and 13 controls; r_k is the effect of replication k (k = 1, 2 and 3); $b_{l(k)}$ is the effect of block l within replication k; e_{ikl} is the experimental error associated with observation Y_{ikl}, assuming independent and normally distributed errors with zero mean and variance σ^2 . Later, analysis of variance was conducted, using the treatment means, adjusted according to Ramalho et al. (2005b).

Based on the expected mean squares the genetic variance (GV), the phenotypic variance (PhV) and the variance of the interaction family x generations (VI_{FxG}) were estimated (Ramalho et al. 2005b). broad-sense

Table 2. Experimental details of the evaluation in segregating families and lines of the first cycle of recurrent selection of the red bean improvement program of the UFV

Generation	Families			Lines	
	$F_{3:5}$	$F_{3:6}$	$F_{3:7}$	$F_{7:9}$	$F_{7:10}$
Families/Lines	243	243	243	154	154
Controls	13	13	13	15	15
Year	2002	2002	2003	2006	2007
Growing season	Dry	Winter	Dry	Dry	Dry
Design	Lattice	Lattice	Lattice	Lattice	Lattice
Replications	3	3	3	3	3
Evaluated traits	Yield	Yield	Yield	Yield	Yield
	-	-	-	-	Plant architecture
	-	-	-	-	Grain appearance

heritability (h^2) was also estimated for selection based on the family mean (Vencovsky and Barriga 1992) and the frequency distribution for grain yield obtained, according to the procedure proposed by Ramalho et al. (2005b).

Families that were outstanding in terms of yield and grain appearance were used for line extraction. Thus, 154 plants were selected with the main traits of interest. These plants were multiplied ($F_{7:8}$ generation) and later evaluated in plots of two 2-m rows, in the dry season of 2006 ($F_{7:9}$) and of 2007 ($F_{7:10}$), for plant architecture, yield and grain appearance (further details in Table 2). Grain appearance was rated on a 1 – 5 scale, where 1 refers to the typical red bean, shiny, not flattened, elliptical shape and mean 100-seed weight between 22 and 24 g; 2 for a red grain with deficiency in one of the cited standard traits; 3 for red grain with deficiency in two of the cited standard traits; 4 for red grain with deficiency in three of the cited standard traits; and 5 for nonstandard red bean grain. Plant architecture was also assessed on a 1-5 scale described by Collicchio et al. (1997), where: 1 refers to an indeterminate growth habit, type II, erect, with a stem and high insertion of the first pod and grade 5 for growth habit III, with long internodes and very prostrate.

Data analysis of grain yield (kg ha^{-1}) was performed using a similar procedure to that described earlier in the process of evaluating families. Initially the individual analyses were performed and subsequently the combined analysis, considering treatment effects and mean as fixed (Cruz et al. 2004). For the grades of grain type and plant architecture the treatment effects and mean were also considered as fixed in the individual analyses. The line means were compared with the standard control, Ouro Vermelho, by the Dunnett test at 5% probability. Analyses were performed using software Genes (Cruz 2006) and MSTAT-C Michigan State University (1991).

RESULTS AND DISCUSSION

Family performance

Significant differences (P < 0.01) were detected among families of different populations in the three generations studied, indicating variation (Table 3). It must be pointed out that the generation effect was confounded with the effect of years and growing seasons, since the

Table 3. Summary of the individual and combined analyses of grain yield (kg ha^{-1}) in the evaluations of the families $F_{3:5}$, $F_{3:6}$ and $F_{3:7}$, with the respective estimates of the genetic variance among family means (GV), phenotypic variance in the family means (PhV), variance of the family x generation interaction (VI_{FxG}) and heritability (h^2) in the family mean

Parameters	Generation			Combined
	$F_{3:5}$	$F_{3:6}$	$F_{3:7}$	
$MS_{Families}$	343159.4**	762054.8**	416918.1**	610150.9**
Mean/Families	3066	1818	2433	2439
Mean/Vermelhinho	3198	1175	2444	2272
CV(%)	12.9	12.6	20.3	16.2
GV	62732.4	236064.4	58127.5	17128.9
LI[1]	45825.6	196618.4	38438.5	8806.6
LS	91136.7	288759.6	98059.5	46715.2
PhV	114386.5	254018.3	138972.7	67794.5
$VI_{(FxG)}$	-	-	-	101845.8
h^2	54.8	92.9	41.8	25.3
LI[2]	43.9	91.2	27.8	7.4
LS	63.9	94.4	53.5	40.2

[1] Lower and upper limits of the genetic variance obtained according to Ramalho et al. (2005b)
[2] Lower and upper limits of heritability obtained according to Knapp et al. (1985)
** significant at 1% probability by the F test.

generations were, obviously, evaluated at different times. The family x generations interaction (growing seasons) was significant (P < 0.01), indicating that families performed differently in different generations and that assessments should be conducted in various environments. In most studies with common bean in the state of Minas Gerais, the interaction of family x growing season was significant for grain yield (Carneiro et al. 2002, Cunha et al. 2005, Melo et al. 2006, Moreto et al. 2007).

Interestingly, the family mean was higher than the mean of the standard cultivar Vermelhinho in the three assessments (Table 3), indicating the possibility of selecting families with better performance than of this standard control. It is also noteworthy that the lower limit of the genetic variance was positive in all situations, indicating that the genetic variance between families is different from zero. The variability between families was also confirmed by heritability estimates (h^2) that were greater than zero in all cases, at 95% confidence, since the lower limit of h^2 was positive. It should be noted that these h^2 estimates are in the broad sense, however, since dominance is not significant in the $F_{3:5}$, $F_{3:6}$ and $F_{3:7}$, generations, the h^2 estimates can be considered in the narrow sense (Moreto et al. 2007).

To visualize the superiority of families, compared to the control Vermelhinho, the frequency distribution was obtained based on grain yield (Figure 1A). It was observed that the mean yield of a large number of families was higher than of the control (Figure 1A). It is worth remembering that the tested families had been advanced by bulk within families and the selection of lines with superior mean performance among these families is expected to be possible.

Of the 243 families tested, five were promoted to the Test of Value for Cultivation and Use (VCU) growing season 2003-2004, (partnership of UFLA, UFV, Epamig and Embrapa Rice and Beans), leading to the recommendation of Ouro Vermelho for the state of Minas Gerais (Carneiro et al. 2006).

The lines evaluated in this study were selected from 43 families of 17 populations (Table 1). Only population 18, cross RVC068, was not used. For the final evaluations, 154 lines were selected.

Line performance

The individual analysis revealed that, in general, lines of a same population did not differ in grain yield and plant architecture. The source of variation among populations (groups of lines) was significant (P < 0.01) for all traits, indicating better performance of some populations.

The combined analysis (Table 4) showed that the line x year interaction was significant (P < 0.01) for yield, indicating that the line performance was not consistent in different years. The same observation was made in the evaluation of families. The significance of the line x year interaction complicates the selection of promising lines in different environments and demonstrates that assessments should be conducted at different times. Couto et al. (2008), evaluated carioca grain lines in southern Minas Gerais, which also performed differently in different environments. The authors suggested, in the particular case of common bean, that best lines should be selected based on the mean of multiple environments.

In the partitioning of the line x year interaction, it was observed that the interaction between lines of each population and years was in most cases insignificant (Table 4), whereas the source of variation population x year was significant (P < 0.01). The mean of the lines (2876 kg ha^{-1}) was clearly higher than of cultivar Ouro Vermelho (2778 kg ha^{-1}) (Table 4) and even than of Ouro Negro (2780 kg ha^{-1}), considered a reference in yield.

Dunnett's test (5% probability) indicated that 151 lines (98%) had a mean yield equal to or higher than the standard control Ouro Vermelho. The grain scores ranged from 1.1 to 3.6, and 89 lines (57.8%) had grades below 2, statistically equal to the grade of standard control Ouro Vermelho (1.4). It is worth mentioning that grain appearance is a limiting feature for the recommendation of a bean cultivar, since consumers are rather picky about this aspect. Therefore, the number of red-grained lines with performance potential to be included in VCU trials is noteworthy. Comparing plant architecture however only four lines performed better than the control, as revealed by Dunnett test.

To show the superiority of lines over the control, the frequency distribution was calculated based on grain yield (Figure 1B). A considerable number of lines had a higher mean yield than the control Ouro Vermelho, demonstrating the efficiency of selection within the segregating families.

The superiority of lines over the means of families can also be demonstrated by the deviation from common controls, since the evaluations were conducted in different years and there are environmental and interaction effects in the trait expression. The mean grain yield of each population and the deviations from the mean of the common controls (Vermelhinho, Vermelho 2157, AFR-140, Pérola, Talismã, and Ouro Negro) are shown in Table 5. It was observed that the deviations of the line means from the mean of the

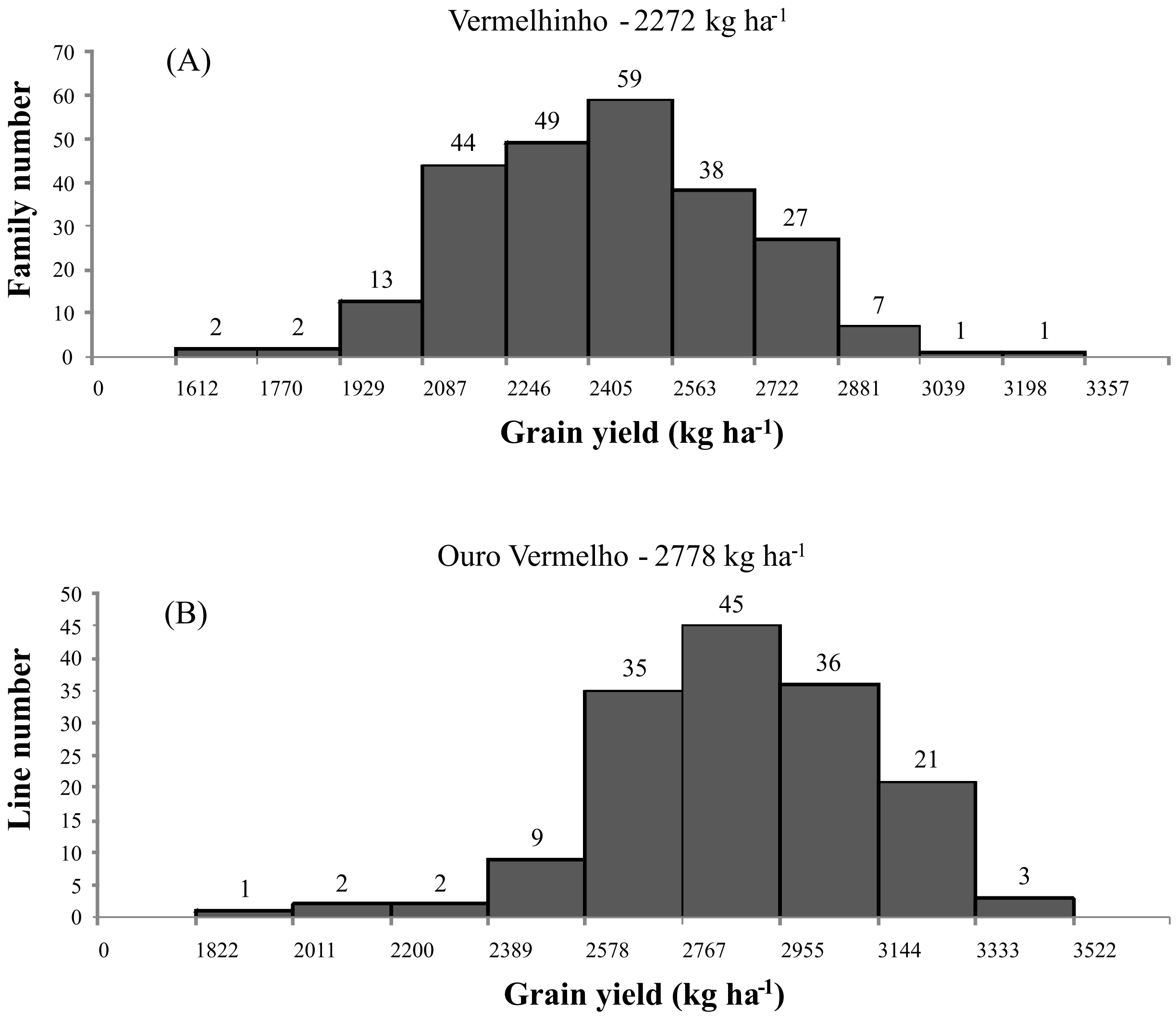

Figure 1. Histogram of the combined grain yield (kg ha^{-1}) of the families $F_{3:5}$, $F_{3:6}$ and $F_{3:7}$ **(A)** and of the lines $F_{7:9}$ and $F_{7:10}$ **(B).**

common controls were higher than the deviations of the family means, suggesting that selection within families was effective to breed more productive lines. Since the number of evaluated lines and families was different, the deviations were obtained from 10, 20 and 50 families and highest-yielding lines compared to the checks. The superiority of the lines over the family means was once again confirmed (Table 5).

The population group with highest grain yield was number 11 (Vermelhinho//Vermelhinho/IAPAR81) and 15 (Vermelhinho/LR720982//Vermelhinho/AB136). These populations not only have a high mean yield, but also the highest number of lines among the most productive. In particular, of the 10 lines evaluated of population 15, four were among the 20 most productive (20 +) and two among the 10 most productive (10 +) (Table 5). Other noteworthy populations are 4 (Vermelhinho/AN9022180//Vermelhinho/Vermelho2157) and 17 (Vermelhinho/AB136//Vermelhinho/Vermelho2157), which have high yields as well as the parent cultivar Vermelho 2157, a source of resistance to common bacterial blight and common mosaic, which are important diseases in red common bean.

Populations of group 4 (Vermelhinho/AN9022180//Vermelhinho/Vermelho2157), 11 (Vermelhinho//Vermelhinho/IAPAR81), 15 (Vermelhinho/LR720982//Vermelhinho/AB136) and 17 (Vermelhinho/AB136//Vermelhinho/Vermelho2157) are the most promising for the breeding of red bean lines with high yield potential.

Table 4. Summary of the combined analysis of variance of grain yield (kg ha^{-1}), obtained in the evaluation of the lines $F_{7:9}$ and $F_{7:10}$ in 2006 and 2007

Source of variation	**df**	**MS**	**P-value**
Year	1	239339003.6	0.000
Treatment	168	475310.8	0.000
Lines	153	385411.6	0.000
Population 1	6	89529.5	0.725
Population 2	19	214501.6	0.096
Population 3	7	238645.4	0.127
Population 4	9	331326.3	0.018
Population 5	8	410137.9	0.005
Population 6	9	280861.0	0.048
Population 7	7	168478.9	0.335
Population 8	3	264181.4	0.147
Population 9	8	288896.0	0.049
Population 10	8	276795.1	0.061
Population 11	7	406816.8	0.007
Population 12	8	169245.7	0.329
Population 13	6	152746.3	0.401
Population 14	8	489179.9	0.001
Population 15	9	122955.4	0.585
Population 16	7	136392.8	0.487
Population 17	8	215287.8	0.169
Among populations	16	1536329.7	0.000
Controls	14	889816.8	0.000
Lines vs. Controls	1	8426810.1	0.000
Treatment x Year	168	384643.3	0.000
Lines x Year	153	367524.8	0.000
Population 1 x Year	6	25113.3	0.984
Population 2 x Year	19	82431.2	0.934
Population 3 x Year	7	143038.5	0.452
Population 4 x Year	9	160978.1	0.367
Population 5 x Year	8	527436.6	0.000
Population 6 x Year	9	104642.7	0.700
Population 7 x Year	7	272392.3	0.076
Population 8 x Year	3	131696.2	0.444
Population 9 x Year	8	34714.0	0.984
Population 10 x Year	8	70634.9	0.871
Population 11 x Year	7	366453.7	0.016
Population 12 x Year	8	106145.4	0.674
Population 13 x Year	6	206014.4	0.213
Population 14 x Year	8	619993.4	0.000
Population 15 x Year	9	182353.3	0.270
Population 16 x Year	7	57123.7	0.910
Population 17 x Year	8	143013.0	0.459
Among populations x Year	16	1935182.7	0.000
Controls x Year	14	587449.3	0.000
Lines vs. Controls x Year	1	91512.2	0.430
Mean error	600	147600.3	
Mean of the lines	2876 kg ha^{-1}		
Ouro Vermelho	2778 kg ha^{-1}		
Ouro Negro	2780 kg ha^{-1}		
CV	12.6 %		

Table 5. Mean grain yield (kg ha^{-1}) and deviations compared to the common controls in the evaluation of families and lines

Population	Families				Lines					
	NF	Mean	CC	Deviation	NL	Mean	CC	Deviation	NL (20+)	NL (10+)
1	29	2506	2537	-31	7	2791	2697	94	0	0
2	33	2642	2537	105	20	2884	2697	187	2	1
3	7	2399	2537	-138	8	2811	2697	114	0	0
4	1	2562	2537	25	10	2944	2697	247	2	2
5	4	2395	2537	-142	9	2341	2697	-356	0	0
6	20	2433	2537	-103	10	2918	2697	221	1	0
7	6	2435	2537	-102	8	2949	2697	251	1	0
8	14	2244	2537	-293	4	3006	2697	309	1	0
9	15	2275	2537	-262	9	2843	2697	146	1	0
10	18	2322	2537	-215	9	2834	2697	137	1	1
11	11	2429	2537	-108	8	3029	2697	332	3	2
12	7	2341	2537	-196	9	2963	2697	266	1	0
13	14	2316	2537	-221	7	2791	2697	94	0	0
14	22	2457	2537	-79	9	2983	2697	286	2	1
15	13	2453	2537	-84	10	3103	2697	406	4	2
16	8	2452	2537	-85	8	2708	2697	10	0	0
17	18	2519	2537	-18	9	2973	2697	276	1	1
18	3	2268	2537	-269	-	-	-	-	-	-
Mean	-	2439	2537	- 98	-	2876	2697	178	-	-
Mean (10+)	-	2998	2537	461	-	3289	2697	592	-	-
Mean (20+)	-	2926	2537	389	-	3250	2697	553	-	-
Mean (50+)	-	2808	2537	271	-	3148	2697	451	-	-

CC = Mean of the common controls; NF = number of tested families; NL = number of tested lines; NL(20+) = number of lines among the 20 most productive; NL(10+) = number of lines among the 10 most productive; Mean(10+) = mean of the 10 most productive; Mean(20+) = mean of the 20 most productive; Mean (50+) = mean of the 50 most productive.

The bulk method in F_3-derived families proved promising as a strategy for common bean improvement.

Lines with a better performance potential than of the red bean cultivars Vermelhinho and Ouro Vermelho were obtained, which may be included in future VCU trials and later recommended for planting in the state of Minas Gerais.

ACKNOWLEDGEMENTS

The authors acknowledge the CNPq, CAPES and FAPEMIG for the financial support of the research activities in the Common Bean Program of the Federal University of Viçosa.

Melhoramento do feijoeiro visando a obtenção de linhagens de grãos vermelhos

RESUMO - *Este trabalho foi realizado com o objetivo de avaliar o potencial de linhagens de feijão vermelho, oriundas de populações do primeiro ciclo de seleção recorrente do programa de melhoramento do feijoeiro da Universidade Federal de Viçosa. Foram avaliadas 243 famílias, provenientes de 18 populações segregantes, nas gerações $F_{3:5}$, $F_{3:6}$ e $F_{3:7}$. Essas famílias foram conduzidas pelo método do "bulk dentro de famílias" e daquelas com maior potencial, foram extraídas 154 linhagens, avaliadas nas safras da seca de 2006 ($F_{7:9}$) e seca de 2007 ($F_{7:10}$), em Coimbra - MG. As estimativas dos parâmetros genéticos e fenotípicos evidenciaram a presença de variabilidade entre as famílias. O método do "bulk dentro de famílias" derivadas de plantas F_3 mostrou-se promissorcomo estratégia de melhoramento do feijoeiro. Linhagens com maior potencial para inclusão nos futuros ensaios de valor de cultivo e uso (VCU) para Minas Gerais foram extraídas das populações Vermelhinho/AN9022180//Vermelhinho/ Vermelho2157,Vermelhinho//Vermelhinho/IAPAR81,Vermelhi-nho/LR720982//Vermelhinho/AB136 e Vermelhinho/AB136// Vermelhinho/Vermelho2157.*

Palavras-chave: Phaseolus vulgaris *L., seleção recorrente, seleção dentro de famílias, feijão vermelho.*

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