

Genetic progress in traits of yield, phenology and morphology of common bean

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ABSTRACT - *The genetic progress achieved by the research institutions that registered common bean cultivars in the State of Rio Grande do Sul between 1998 and 2005 was estimated in traits of yield, phenology and morphology of common bean, with the aim to orient future genetic breeding studies. A total of 75 genotypes were evaluated, in variable number in the seven years, in a random block design with three replications. Positive genetic gains were verified for the yield traits (grain yield and components), while negative genetic gains were stated for the phenological (flowering and cycle) and morphological traits (lodging, insertion height of first and last pod). Our results demonstrated the efficiency of the adopted breeding strategies in the development of germplasm with higher and earlier grain yield. For the morphological traits however, the focus of the programs should be reevaluated.*

Key words: *Phaseolus vulgaris* L., genetic gain, environmental gain, breeding strategy.

INTRODUCTION

In breeding programs, conducted for a given time in a region, the efficiency must be permanently evaluated to observe the advances (Cruz and Carneiro 2003). For this purpose, the estimation of genetic progress is useful and helps breeders make decisions about the program strategies, whether they ought to be pursued or if changes are required.

For common bean, a mean annual genetic gain in grain yield of 1.90% was observed in Minas Gerais (Abreu et al. 1994), of 1.99% in Paraná (Fonseca Júnior

et al. 1996), 1.21% in Santa Catarina (Elias et al. 1999), and of 0.74% and 0.88% in Rio Grande do Sul (Antunes et al. 2000, Ribeiro et al. 2003). In the state of São Paulo, elite lines developed by the main national programs of genetic breeding were evaluated in 25 environments, and the predicted genetic gain through selection in the best line, Gen 96A31, was 16.25% (Chiorato et al. 2005). The yield gain achieved in Brazil can be considered significant, in other words, the adopted breeding strategies are efficient in the development of common bean cultivars with a higher grain yield.

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However, nearly no information is available on the modifications in the traits of yield, phenology and morphology that contributed to this technological advance. In the Central Depression region of Rio Grande do Sul, a negative mean annual genetic gain of 0.43 cm was observed for the insertion height of the first pod and of -1.87 cm for the insertion height of the last pod, i.e., the architecture of common bean plants diminished (Ribeiro et al. 2003). In four years of evaluation, these authors further observed that the mean annual genetic gain of the cycle and 100-seed weight was positive and of small magnitude (0.50 days and 0.58 grams, respectively), indicating a low increase in these traits. The data suggest the need of a reevaluation of the improvement strategies presently used for morphologic and phenological traits of common bean.

Different methodologies can be used to estimate genetic gain (Ribeiro et al. 2003). The estimates should be interpreted taking the period of reference, the germplasm and the environmental conditions of the trials into consideration. Based on data collected in 120 trials, from 1991 to 2004, in Santa Catarina, Elias et al. (2005) observed a mean annual genetic gain for grain yield of 37.81 kg ha⁻¹ year⁻¹ by the linear regression method, and of 27.52 kg ha⁻¹ year⁻¹ by the method that identifies common genotypes in two successive years (Vencovsky et al. 1988).

Gain estimates do normally not express the real contribution of the genetic and environmental variance to the study traits. The objective of this study was therefore to estimate the genetic progress of traits of yield, phenology and morphology of common bean obtained by the research institutions that registered common bean cultivars in the State of Rio Grande do Sul, from 1998 to 2005, as an orientation for future studies of genetic breeding.

MATERIAL AND METHODS

Seven experiments were conducted in an area of the plant science department of the Universidade Federal de Santa Maria, in Santa Maria, Rio Grande do Sul (RS), in the growing seasons of 1998/1999 until 2004/2005, with sowing in September or October. Santa Maria lies in the Central Depression region of Rio Grande do Sul (lat 29°42'S, long 53°49'W, 95 m asl); the climate type is Cfa – temperate, rainy, with well-distributed rainfall throughout the year, and subtropical.

The experiments evaluated common bean genotypes of the trial of Value for Cultivation and Use (VCU), in variable number each year (Table 1), in a random block design with three replications. Each plot contained four rows of 4 m length, spaced 0.50 m apart, with 12 seeds per meter, and an evaluated area of 3 m².

Table 1. Common bean genotypes evaluated in the growing seasons from 1998/1999 to 2004/2005

Growing season	Common bean genotypes under study
1998/1999	Carioca, Diamante Negro, FE 821732, FPGCF 058, FPGCF 101, M89148-2, M 8985-2, M91-012, Macotaço, MT 95202057, Pérola, SM 89153, TB 94-06, TB 94-08, TB 94-09, TB 94-20, TB 95-01, TB 95-02, TB 95-03 and TPS Nobre
1999/2000	Carioca, M 8985-2, Macotaço, MT 95202057, Pérola, SM 89153, TB 95-01, TB 95-02, TPS Nobre, BRS Expedito, LM 92204133, LM 93204217, LM 95102835, M 8990, SM 8915, SM 9704, SM 9708, TB 96-08, TB 97-07 and TB 97-13
2000/2001	Diamante Negro, MT 95202057, TPS Nobre, BRS Expedito, LM 92204133, M 8990, TB 97-13, CI 9637, CI 9690, CI 9844, CI 9849, CI 9867, CNFP 8078, CNFP 8087, CNFP 8097, CNFP 8100, CNFP 8104, LP 98-13, SM 9707, SM 9809, TB 96-09, TB 96-11 and BRS Valente
2001/2002	Diamante Negro, TPS Nobre, BRS Expedito, LM 92204133, TB 97-13, CI 9637, CI 9690, CI 9844, CI 9867, CNFP 8078, CNFP 8097, CNFP 8100, CNFP 8104, LP 98-13, SM 9809, TB 96-11, BRS Valente and TB 96-13
2002/2003	TPS Nobre, BRS Expedito, TB 97-13, CI 9637, CI 9690, CI 9844, CNFP 8078, CNFP 8100, CNFP 8104, TB 96-11, BRS Valente, TB 96-13, CNFP 7775, CNFP 7777, Guabijú, Radiante, Soberano and TB 98-20
2003/2004	Diamante Negro, TB 94-09, TPS Nobre, BRS Expedito, TB 97-13, CNFP 8104, LP 9813, TB 96-11, BRS Valente, TB 96-13, Guabijú, FTS Soberano, TB 98-20, Chocolate, CNFP 10138, CNFP 7966, CNFP 7972, CNFP 7994, CNFP 8000, CNFP 9328, Graúna (LP 9801), Preto Comprido, TB 98-01, TB 98-02, Uirapuru and Vermelho Itajaí
2004/2005	Carioca, Pérola, BRS Expedito, TB 97-13, SM 9809, TB 96-13, Guabijú, TB 98-20, CHP 9954, CNFC 8202, CNFP 7762, Guapo Brillhante, LP 01-51, LP 99-79, SCS 202 Guará and SM 9906

In the seven years of experimentation, 75 genotypes were evaluated (advanced lines and cultivars) developed by the breeding programs that register common bean cultivars in RS: Embrapa Clima Temperado, Embrapa Arroz e Feijão, Instituto Agrônomo do Paraná and Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina.

The soil is classified as an Alisoil and conventionally tilled. The fertilization was applied in the sowing furrow, based on to the chemical soil analysis. Nitrogen fertilization was split in two applications of 40 kg ha⁻¹ nitrogen in the growth stages of the first and third trifoliolate leaves - V3 and V4, respectively. The cultural treatments, insect and weed control were carried out whenever necessary, to rule out competition (Cepef 2003).

The plants were harvested and threshed by hand and, after removing the impurities, the beans were sun and oven-dried to a mean moisture of 12%. The grain yield in the evaluated area (3 m²) was quantified and the value transformed into kg ha⁻¹. The other yield traits - number of pods per plant, number of seeds per pod and weight of 100 seeds, were determined in five randomly collected plants, in the evaluated plot. The plant population was evaluated in the same area (3 m²), when the plants attained physiologic maturity.

The phenological traits - number of days from sowing to emergence, number of days from emergence to flowering and number of days from emergence to physiologic maturity (cycle) - were evaluated on a scale proposed by Ciat (1987), to characterize the stages V2, R6 and R9, respectively.

The lodging degree was evaluated on a 1-9 grade scale, where 1 = upright plant and 9 = lodged plant. The insertion height of the first and last pod was measured in five plants collected randomly in the area of evaluation, as the distance from the soil level to the insertion points of the first and the last pod, respectively.

The genetic progress of the traits of yield, phenology and morphology was determined by the methodology described by Vencovsky et al. (1988). Thus, the data of genotype sets evaluated in a particular period of time provide estimates of the mean progress, of the variance and the error of this mean, based on the weighted minimum squares. Every year, new genotypes are produced by the breeding program and included in

competition trials while other genotypes are outmatched and excluded (Cruz and Carneiro 2003).

The total estimated gain corresponds to the sum of the genetic gain + environmental gain. In percentage, we calculated the genetic gain (%): genetic gain/total gain*100 and environmental gain (%): environmental gain/total gain*100. The program GENES (Cruz 2001) and Office Excel were used to run the analyses.

RESULTS AND DISCUSSION

The coefficient of experimental variation varied from 0.97% (number of days from emergence to physiologic maturity - experiment of 1998/1999) to 38.73% (number of pods plant⁻¹ - experiment of 2001/2002). In general, the experimental precision was highest for the weight of 100 seeds, number of days from sowing to emergence, number of days from emergence to flowering and number of days from emergence to physiologic maturity; the estimates were least precise for grain yield, number of pods plant⁻¹, lodging and first pod insertion height (Table 2).

It was observed that in the trials of Value for Cultivation and Use conducted in the state of Rio Grande do Sul, in the growing seasons from 1998/1999 to 2004/2005, few new genotypes were included for evaluation in some years (2001/2002 and 2002/2003), while in other years the number of newly included genotypes was high (Tables 1 and 3). The number of genotypes maintained and excluded in the VCU was rather variable from one year to the other, which demonstrates the dynamics of breeding programs.

A mean genetic gain of 38.59 kg ha⁻¹ year⁻¹ was obtained for grain yield in Santa Maria, RS, between 1998/1999 and 2004/2005 (Table 4). This value represents 3.38% of the mean of the regional yield of 1.140 kg ha⁻¹ of the first harvest of 2003/04 in Rio Grande do Sul (Conab 2005). This index exceeds the value of 0.74% observed by Antunes et al. (2000) and the percentage of 0.88% verified previously by Ribeiro et al. (2003), in Santa Maria - RS. It is also superior to the values observed in other states: 1.90% in Minas Gerais (Abreu et al. 1994), 1.99% in Paraná (Fonseca Júnior et al. 1996) and 1.21% in Santa Catarina (Elias et al. 1999). It is believed that the inclusion of common bean lines with a higher grain yield potential contributed to estimates of greater magnitude.

Table 2. Degrees of freedom (DF) and mean squares in relation to the traits grain yield, number of pods plant⁻¹, number of seed pods⁻¹, weight of 100 seeds, plant population, number of days from sowing to emergence (emergence), number of days from emergence to flowering (flowering), number of days from emergence to physiological maturity (cycle), lodging, first-pod insertion height (first pod) and last-pod insertion height (last pod) for the causes of variation, mean and coefficient of variation (CV) of common bean cultivars in seven years of evaluation

Sources of variation	d.f.	Mean square ⁽¹⁾										
		Grain yield (kg ha ⁻¹)	Number of pods plant ⁻¹	Number of seed pods ⁻¹	Weight of 100 seeds (g)	Population (plants 3m ⁻²)	Emergence (days)	Flowering (days)	Cycle (days)	Lodging ⁽²⁾	First pod (cm)	Last pod (cm)
1998/1999												
Block	2	51476	46.40	0.52	6.38	1.05	1.27	2.92	1.27	12.60	2.08	279.23
Cultivar	19	526212**	44.74**	0.24 ^{ns}	25.57**	373.77**	1.72**	4.59**	7.71**	7.04**	12.33**	148.29**
Error	38	177528	14.11	0.15	2.54	22.51	0.65	1.34	0.65	1.67	4.44	47.29
Mean	-	2903.68	17.97	5.31	23.80	49.50	8.97	39.97	82.93	5.60	12.73	51.49
CV(%)	-	14.51	20.90	7.32	6.69	9.58	9.01	2.89	0.97	23.08	16.56	13.35
1999/2000												
Block	2	1027144	48.14	0.49	3.57	362.47	2.22	1.87	2.22	18.35	0.60	50.82
Cultivar	19	395519**	31.02**	0.42*	18.90**	121.91*	5.98 ^{ns}	7.63*	9.23*	12.29**	9.28**	97.54**
Error	38	129143	9.95	0.17	2.16	52.03	4.02	3.27	4.02	2.81	3.39	29.61
Mean	-	3005.27	16.34	4.70	24.11	50.83	16.02	43.87	81.43	5.45	8.98	37.23
CV(%)	-	11.96	19.30	8.89	6.10	14.19	12.52	4.12	2.46	30.74	20.51	14.61
2000/2001												
Block	2	744026	2.93	0.30	17.96	1067.63	4.54	1.54	71.17	5.18	7.41	268.15
Cultivar	23	523476**	7.22*	0.57**	18.96**	325.57*	0.37 ^{ns}	15.18**	26.39**	4.62*	37.73 ^{ns}	161.38 ^{ns}
Error	46	129514	3.72	0.22	6.34	152.20	0.35	2.38	7.38	2.24	24.24	111.40
Mean	-	1545.24	8.66	4.79	20.66	65.29	5.46	39.54	78.29	6.32	14.70	33.23
CV(%)	-	23.29	22.30	9.80	12.19	18.90	10.89	3.90	3.47	23.68	33.49	31.76
2001/2002												
Block	2	126338	37.13	0.48	1.18	6.35	0.02	2.46	2.07	2.24	24.61	368.03
Cultivar	17	506846*	61.84**	0.35 ^{ns}	8.53**	943.85**	1.39**	11.59**	15.56**	11.53**	81.65*	122.41 ^{ns}
Error	34	236240	22.76	0.27	2.96	60.27	0.12	3.84	3.19	2.71	39.94	91.80
Mean	-	1460.00	12.32	4.46	18.67	63.52	6.93	39.26	72.57	6.37	25.49	55.83
CV(%)	-	33.29	38.73	11.69	9.21	12.22	4.93	4.99	2.46	25.85	24.79	17.16
2002/2003												
Block	2	79290	17.69	0.19	18.08	245.13	⁽³⁾	0.17	12.46	0.02	144.97	383.54
Cultivar	17	105989**	29.57**	1.00**	35.51**	182.80**	-	34.67**	69.56**	0.03 ^{ns}	285.44**	716.22**
Error	34	23512	10.60	0.23	3.09	47.13	-	1.34	6.21	0.04	70.98	247.64
Mean	-	493.67	9.86	3.27	13.39	49.35	7.00	36.11	82.09	8.96	33.54	74.45
CV(%)	-	31.06	33.01	14.56	13.13	13.91	-	3.21	3.04	2.18	25.12	21.14
2003/2004												
Block	2	1136161	10.39	0.33	1.44	549.59	0.09	4.97	3.13	1.17	18.15	234.35
Cultivar	25	413085**	19.67**	1.58**	86.32**	291.00**	0.27*	29.50**	25.44**	6.09**	20.17**	104.96**
Error	50	133825	4.93	0.30	1.78	72.56	0.13	1.23	1.17	1.57	5.97	28.89
Mean	-	1594.65	10.29	4.42	20.29	60.29	7.22	39.83	77.94	3.68	16.62	39.94
CV(%)	-	22.94	21.57	12.33	6.58	14.13	4.99	2.78	1.39	34.02	14.70	13.46
2004/2005												
Block	3	29070	2.48	0.37	1.97	4.44	0.71	0.43	2.21	0.46	5.57	9.12
Cultivar	15	314391**	19.50**	1.29**	28.86**	315.23**	2.92 ^{ns}	18.41**	14.57**	6.60**	17.56**	86.86**
Error	45	69892	4.64	0.13	2.26	34.36	1.91	3.49	4.73	1.04	6.15	22.34
Mean	-	1705.52	11.56	4.79	17.78	61.97	8.31	36.20	71.75	3.13	19.39	43.27
CV(%)	-	15.50	18.64	7.46	8.45	9.46	16.62	5.16	3.03	32.57	12.79	10.92

⁽¹⁾ **, * = significant effect at 5% and 1% probability, respectively, by the F test; ^{ns} = non-significant effect by the F test.

⁽²⁾ Grade scale from one to nine (1 = upright plant; 9 = lodged plant).

⁽³⁾ no residual variance (Error mean square = 0).

Table 3. Number of common bean genotypes: new in relation to the previous year (newly included), kept by for evaluation in the following year (maintained), excluded from the evaluation in the following year (excluded) and evaluated in the year (total)

Growing season	Newly included	Maintained	Excluded	Total
1998/1999	0	9	11	20
1999/2000	11	6	14	20
2000/2001	17	17	6	23
2001/2002	1	12	6	18
2002/2003	6	10	8	18
2003/2004	16	5	21	26
2004/2005	11	16	0	16

Table 4. Balance of the genetic and environmental gain of the common bean breeding program - mean and in parentheses percentage of the seven years of evaluation of the traits grain yield, number of pods plant⁻¹, number of seed pods⁻¹, weight of 100 seeds, plant population, number of days from sowing to emergence (emergence), number of days from emergence to flowering (flowering), number of days from emergence to physiological maturity (cycle), lodging, first-pod insertion height (first pod) and last-pod insertion height (last pod)

Trait	Gain		
	Genetic	Environmental	Total
Grain yield (kg ha ⁻¹)	38.59(-10.94 ²)	-391.47(110.94 ³)	-352.87(100.00)
Number of pods plant ⁻¹	0.05(11.95)	0.35(88.05)	0.40(100.00)
Number of seed pods ⁻¹	0.00(-0.83)	-0.43(100.83)	-0.43(100.00)
Weight of 100 seeds (g)	0.23(-9.96)	-2.53(109.96)	-2.30(100.00)
Population (plants 3m ⁻²)	0.74(-19.93)	-4.43(119.93)	-3.69(100.00)
Emergence (days)	0.06(4.18)	1.26(95.82)	1.32(100.00)
Flowering (days)	-0.10(28.52)	-0.26(71.48)	-0.36(100.00)
Cycle (days)	-0.42(23.02)	-1.40(76.98)	-1.81(100.00)
Lodging ⁽¹⁾	-0.10(-22.90)	0.52(122.90)	0.43(100.00)
First pod (cm)	-0.92(-17.28)	6.26(117.28)	5.34(100.00)
Last pod (cm)	-1.11(-12.32)	10.10(112.32)	8.99(100.00)

⁽¹⁾ Grade scale from one to nine (1 = upright plant; 9 = lodged plant).

⁽²⁾ genetic gain (%): genetic gain/total gain*100.

⁽³⁾ environmental gain (%): environmental gain/total gain*100.

It is worth pointing out that the negative environmental gain of high magnitude (-391.47 kg ha⁻¹ year⁻¹) for grain yield evidenced that the environmental conditions – mainly those related to water stress and excess, occurrence of diseases and/or plagues – were less favorable for common bean cultivation in the Central Depression region of Rio Grande do Sul.

The genetic gain for grain yield was positive (38.59 kg ha⁻¹ year⁻¹) due to the higher number of pods per plant (0.05 pods plant⁻¹ year⁻¹), higher weight of 100 seeds (0.23 g 100 seeds⁻¹ year⁻¹) and greater plant population (0.74 plants year⁻¹). For the number of seeds per pod, the substitution of genotypes between 1998/1999 to 2004/2005 caused practically no alteration, probably because all evaluated genotypes belonged to the species *Phaseolus vulgaris* L., which normally have

up to eight seeds per pod. One may say that under unfavorable environmental conditions, the number of seeds per pod is lower, as the negative environmental gain of -0.43 shows.

The interpretation of the results for the yield traits (grain yield and components), allows the conclusion that the strategies used in the breeding programs of the southern region are adequate, in view of the positive genetic gain. The annual genetic gain for these traits is however expected to be low, owing to the marked effect of the environmental conditions.

Regarding the phenological traits, the genetic gain for the number of days from sowing to emergence was positive (0.06 days year⁻¹), indicating that the evaluated genotypes take longer to emerge, which is undesirable. In spite of the delayed emergence, the genetic gain for

number of days until flowering and for cycle was negative, suggesting that the development of earlier common bean genotypes was one of the objectives of the breeding programs (Table 4). Besides, a negative environmental gain was verified, which allows the conclusion that the environmental conditions – above all those related to water stress and excess, occurrence of diseases and/or plagues – were less favorable, representing 71.48% and 76.98% of the reduction of the number of days until flowering and for the cycle, respectively.

With respect to the morphological traits, a reduction in plant lodging has been targeted in common bean breeding. This can be verified by the negative genetic gain in lodging degree of -0.10 year^{-1} , i.e., more upright plants have been maintained in the VCU evaluations. However, the insertion heights of the first and the last pod were reduced by $0.92 \text{ cm year}^{-1}$ and $1.11 \text{ cm year}^{-1}$, respectively. A negative genetic gain for insertion height of first and of last pod had already been observed by Ribeiro et al. (2003), in Santa Maria – RS. This aspect is particularly important, since the use of common bean cultivars of upright growth with less lodging makes mechanical harvesting possible and avoids the deterioration of pods that touch the soil, under high humidity conditions (a quite common situation in the region when harvest draws near). The first pod should therefore be inserted at a greater height and the branches not be too long, while the last-pod insertion height should be higher.

Therefore, special attention should be paid to reduce plant lodging, elevate the insertion height of the first pod and to develop plants with denser and shorter branching. The development of common bean cultivars with upright growth should also be prioritized to meet the market demands, since common bean is no longer exclusively a crop of subsistence agriculture in Brazil. In this sense, the strategies of breeding programs must be reevaluated. Innovations could result in the development of germplasm with traits that meet the needs of rural producers. It may further be concluded that the annual genetic gain for phenological and morphological traits evaluated in common bean are of small magnitude, due to the marked effect of the environmental conditions.

CONCLUSIONS

The breeding strategies of the programs that registered common bean cultivars in the state of Rio Grande do Sul, between 1998 and 2005, were effective in the development of germplasm with higher and earlier grain yield. The priorities for morphological traits must however be reevaluated, since lines with lower first-pod insertion height are being established.

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Progresso genético de características da produção, fenológicas e morfológicas do feijão

RESUMO - O objetivo desse trabalho foi estimar o progresso genético de características da produção, fenológicas e morfológicas de feijão obtido pelas instituições de pesquisa que registraram cultivares de feijão no Estado do Rio Grande do Sul, durante o período de 1998 a 2005, com a finalidade de orientar futuras pesquisas no melhoramento genético. Assim, 75 genótipos foram avaliados, em número variável nos sete anos, em delineamento de blocos ao acaso, com três repetições. Ganhos genéticos positivos foram verificados para as características da produção (rendimento dos grãos e seus componentes), enquanto que ganhos genéticos negativos foram constatados para as características fenológicas (floração e ciclo) e morfológicas (acamamento, altura de inserção de primeira e de última vagem). Os resultados obtidos evidenciam que as estratégias de melhoramento adotadas estão sendo eficientes no desenvolvimento de germoplasma com maior produtividade e precocidade. No entanto, para as características morfológicas, as prioridades deverão ser revistas pelos programas.

Palavras-chave: *Phaseolus vulgaris* L., ganho genético, ganho ambiental, estratégia de melhoramento.

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