Adaptability and stability of soybean genotypes evaluated using three backcrosses generations: BC4, BC5 and BC6

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ABSTRACT

An adaptability and stability study by the traditional and Lin and Binns methods (1988) was carried out to assess the genotypic stem canker resistance of three backcross generations (BC4, BC5 and BC6) in three environments. The study consisted of genotype trials carried out in the towns of Florestal, Capinopolis and Rio Paranaiba, in Minas Gerais state during the 1997/98 growing season. The experiments assessed the recurrent (FT-Cristalina) and donor (Doko BC) parents and 13 derived lines, five from the BC6 generation (UFV95-370A2156, UFV95-370A2142, UFV95-370A2133, UFV95-370A2121 and UFV95-370A2115); four from BC5 (UFV95-370A2022, UFV95-370A2021, UFV95-370A2020 and UFV95-370A2019); and four from BC4 (UFV95-370A667, UFV95-370A666, UFV95-370A65 and UFV95-370A661). The Lin and Binns (1988) method was more efficient in discriminating the genotypes. The UFV95-370A2021 line belonging to the BC5 generation showed the best genotypic performance among the studied genotypes, and also showed the second best yield mean in the experiments. The UFV95-370A665 line, belonging to the BC4 generation, had the poorest genotypic behavior and also presented the lowest mean yield in the experiments. As the backcross generation advanced, there was a simultaneous improvement in the genotypic performance of the individuals in these generations, most probably because of the greater recuperation of the recurrent parent in each generation. This suggests the need for at least five to six backcrosses to obtain genotypes as adapted as the recurrent parent.

KEY WORDS: Soybean, adaptability, stability, backcross, breeding.

INTRODUCTION

A breeding program based on the backcross method may take several years to release a new version of the recurrent parent. If for some reason the cultivar used as recurrent parent becomes no longer competitive on the market, the this new version may not be successful (Borém, 1997). Therefore, the choice of the recurrent parent and the speed of release of the new materials are highly important. According to Openshaw et al. (1994), the use of molecular markers to identify individuals that show greater genotype similarity to the recurrent parent and reduce the number of backcross generations could be a helpful technique.

However, when agronomically superior varieties are used as donor parents there may be no need for complete recuperation of the recurrent parent, thus reducing the number of backcross generations needed to release the new cultivar (Borém, 1997).

The objective of this study was to assess the performance of soybean genotypes in different backcross generations, using a donor parent with superior agronomic characteristics. The evaluation procedure adopted was based on the adaptability and stability of the genotypes assessed using the traditional and the Lin and Binns (1988) methods.

MATERIAL AND METHODS

Data from three genotype trials of the Soybean Breeding Program at the Federal University of Viçosa carried out in the towns of Florestal, Capinopolis and Rio Paranaiba, in Minas Gerais state during the 1997/98 growing season were used in this study.

Each experiment involved two commercial cultivars used as parents and 13 derived lines belonging to different backcross generations (Table 1).

Seedlings from each backcross generation were inoculated with the *Diaporthe phaseolorum* f. sp. *meridionalis* fungus that causes stem canker in soybean, using the adaptation proposed by Yorinori

(1991) of the fungi mycelia colonized toothpick method described by Crall (1952) and Keeling (1982). The fungus isolate CH08 used for inoculation was provided by the National Soybean Research Center.

The experimental design used in the field experiments was the randomized complete block with three replications. The experimental plots consisted of four 5m long lines spaced at 0,5m. The useful area was formed by the two central lines after elimination of 0,5m from each end, in a total of 4,0m^2.

The soil was prepared by the conventional system. For planting, the seeds were not inoculated with *Bradyrhizobium japonicum* because the cropping area had been cultivated with inoculated soybean in previous years. The sowing density was sufficient to provide a final plant population of approximately 20 plants per linear meter. Fertilizer was applied according to the soil analysis of each location. Weeds and pests were controlled whenever necessary.

Grains of the useful area were harvested and dried naturally in the sun to approximately 12% moisture. The grain weight per plot was converted in kg/ha for all experiments.

Statistical Analyses

Individual analysis of variance was carried out for each experiment. These analyses aimed to evaluate the residual variance for a homogeneity test. A joint analysis of variance was then carried out involving all environments. In this analysis, the genotype effects were considered fixed and the others, random effects.

Table 1. Cultivars and lines used in the study, with their respective generations.

Cultivars/Lines	Genotype Characteristic/Backcross Generation
Doko RC	Donor parent
FT-Cristalina	Recurrent parent
UFV95370A2156	BC6
UFV95370A2142	BC6
UFV95370A2133	BC6
UFV95370A2121	BC6
UFV95370A2115	BC6
UFV95370A2022	BC5
UFV95370A2021	BC5
UFV95370A2020	BC5
UFV95370A2019	BC5
UFV95370A667	BC4
UFV95370A666	BC4
UFV95370A665	BC4
UFV95370A661	BC4

Adaptability and Stability analyses

The stability parameter and, or, phenotypic adaptability was assessed by the traditional and by the Lin and Binns (1988) methods.

Traditional Method

The traditional method consists in joint analysis of the experiments, considering all the environments followed by the partition of the sum of the squares due to the environments and to genotype x environment interaction in the sum of the squares of environment within each genotype. The variation of environments within each genotype is used as a stability estimate so that the genotype which has the lowest mean square that is, least variance, will be considered the most stable. This method has the advantage of coping with cases where there is a small number of environments (Cruz and Regazzi, 1997).

The estimator of the stability parameter is given by:

$$QM(A/G_i) = \frac{r}{(a-1)}\left[\sum_{j=1}^{a} Y_{ij}^2 - \frac{1}{a}(Y_{i.})^2\right]$$

where r is the number of replications; a is the number of locations and Yij is the yield of the ith cultivar in the jth location.

Lin and Binns Method (1988)

The Lin and Binns method (1988) is based on the mean square of the distance between the mean of the cultivar and the maximum mean response at all the locations. Knowing that the maximum response is an upper limit for each location, the smallest mean square distance considering all the environments will indicate the superiority of the cultivar in question. In this methodology, the parameter used to estimate the genotypic performance is given by:

$$P_i = \frac{\sum_{j=1}^{a}(Y_{ij} - M_j)^2}{2a}$$

where P_i is the estimator of the adaptability and stability parameter of the ith cultivar; Y_{ij} is the yield of the ith cultivar in the jth location; and M_j is the maximum response observed among all the cultivars in the jth location.

The P_i statistic of the Lin and Binns methodology (1988) concerns a hypothetical cultivar with general adaptation, whose regression coefficient has been considered equal to unit, and is comparable to the Eberhart and Russel (1966) method. The P_i statistic, which is based on the calculation of the square of the distance in relation to the maximum response in each environment and not to the simple distance, has variance properties, that is, it weighs the performance of the genotypes across the environments evaluating behavior stability (Carneiro, 1998). Further, it shows the advantage of using a single parameter to estimate the adaptability and stability performance of a genotype, helping the resultant interpretation process.

RESULTS AND DISCUSSION

Analysis of Variance

Table 2 shows the grain yield means (kg/ha) of the soybean cultivars and lines assessed in the three environments.

The data indicate the presence of large variability for grain yield, which ranged from 1.875 kg/ha in Rio Paranaiba to 3.265 kg/ha in Capinopolis. It is worth mentioning the performance of line UFV95370A2141 with mean yield of 2.820 kg/ha in Florestal, line UFV95370A2021 with 3.265 kg/ha in Capinopolis and Doko BC cultivar with 2.587 kg/ha in Rio Paranaiba. There was also variability in the location yield means, which ranged from 2.123,83 kg/ha in Rio Paranaiba to 2.906,22 kg/ha in Capinopolis. Variability of the mean values within each location and by location is required for the behavior stability and adaptability study.

Homogeneity of the residues of the individual analysis of variance was detected by the Hartley F max test (1950) and a joint analysis of variance was performed.

Table 3 shows the result of the joint analysis of variance. There was a significant genotype x environment interaction effect indicating, therefore, that the genotypes have different behavior in the assessed environments justifying the adaptability and stability study.

Adaptability and stability performance

Traditional method

Table 4 shows the results of the joint analysis of the experiments for grain yield regarding the partitioning of the sum of the squares of the environment and the genotype by environment interaction effects in environment within each genotype effects.

According to the traditional method, the genotype

Table 2. Mean yield (kg/ha) of soybean cultivars and lines in three locations in Minas Gerais state [1/]

Cultivars and lines	Generations	Environments		
		Florestal	Capinópolis	Rio Paranaíba
Doko RC	Prog.	2438.33	2989.17	2587.50
FT-Cristalina	Prog.	2605.00	2454.17	2020.83
UFV95370A2156	BC6	2660.83	3102.50	2055.83
UFV95370A2142	BC6	2820.00	2900.83	1950.00
UFV95370A2133	BC6	2479.17	3176.67	2020.83
UFV95370A2121	BC6	2495.00	3201.67	2550.00
UFV95370A2115	BC6	2664.17	3090.00	1891.67
UFV95370A2022	BC5	2762.50	3033.33	2425.00
UFV95370A2021	BC5	2398.33	3265.00	1991.67
UFV95370A2020	BC5	2721.67	2845.00	2125.00
UFV95370A2019	BC5	2515.00	2658.33	1875.00
UFV95370A667	BC4	2420.00	2876.67	2450.00
UFV95370A666	BC4	2475.00	2695.00	1958.33
UFV95370A665	BC4	2285.83	2820.00	2055.83
UFV95370A661	BC4	2468.33	2485.00	1900.00
Mean		2547.28	2906.22	2123.83

[1/] The numbers in bold refer to the highest yields.

which presents the lowest mean square will be considered the most stable. Table 5 presents the classification of the 15 genotypes studied in decreasing order of stability, with their respective yield means.

The UFV95-37A2142 line (BC6) showed the most stable performance and yield mean superior to the general mean of the experiments. The UFV95-370A2121 (BC6) line was the least stable genotype among those tested, although its yield mean was superior to the general mean.

There was no very clear tendency of genotype clustering according to backcross generations since three of the five most stable genotypes were from different backcross generations.

According to Cruz and Regazzi (1997) the concept of stability, expressed by the minimum variance among environments, does not meet the needs of plant breeding, possibly because the genotypes which maintain regular behavior among the environments are generally not high yielding. It is observed, however, that when the five most stable genotypes, UFV95-370A2142, Doko BC, FT-Cristalina, UFV95-370A2021 and UFV95-370A665 were considered, three presented yield means above the general mean (UFV95-370A2021, Doko BC e UFV95-370A2142). These means ranked second, third and fifth best among all general means, respectively. Similar results were obtained by Carneiro (1998) suggesting the possibility of obtaining genotypes with high and small variations among environments.

Table 3. Summary of the joint analysis of variance of grain yield of soybean cultivars and lines in the three studied environments.

S.V.	D.F.	S.S.	M.S.
Blocks/Environments	6	382047.22	63674.54
Environments (E)	2	13804180.28	6902090.14 [1/]
Genotypes (G)	14	2608951.67	186353.69 ns
GxE	28	359819.55	128506.80 [1/]
Residue	84	3247311.11	38658.46
C.V. (%)	7.78		

[1/] significant at the 1% level of probability; ns - not significant.

Table 4. Joint analysis of soybean grain yield for cultivars and lines for the three locations, and the stability parameter (MSE/Gi) of the traditional method.

S.V.	D.F.	S.S.	M.S.
Environments (E)	2	13804180.2778	6902090.1389
Genotypes (G)	14	2608951.6667	186353.6905
GxE	28	3598190.5556	128506.8056
E/G	30	17402371.7059	580079.0569
E/G- Doko RC	2	487004.1678	243502.0839
E/G- 2	2	1656605.5565	828302.7783
E/G- 3	2	1667518.0549	833759.0274
E/G- 4	2	2032526.6913	1016263.3456
E/G- 5	2	927072.4432	463536.2216
E/G- 6	2	2214093.2161	1107046.6080
E/G- 7	2	557326.3883	278663.1942
E/G- 8	2	2537866.8781	1268933.4391
E/G- 9	2	889622.2992	444811.1496
E/G- FT-Cristalina	2	551779.1675	275889.5838
E/G- 11	2	1043755.5549	521877.7775
E/G- 12	2	391488.8895	195744.4447
E/G- 13	2	858022.1203	429011.0601
E/G- 14	2	922184.7231	461092.3615
E/G- 15	2	665505.5552	332752.7776
Residue	84	3247311.1111	38658.4656

The Lin and Binns Method (1988)

Table 6 shows the estimates of the mean grain yield and of the P_i statistic in decreasing order of stability for the 15 soybean genotypes assessed in the three environments. According to this methodology, genotypic stability and adaptability is estimated by a P_i single parameter. Lower P_i values indicate greater adaptability and stability performance of the cultivar under analysis.

The UFV95-3701A2021 line, which belongs to the BC5 generation, scored best in terms of genotypic performance among the studied genotypes and also presented the second best yield mean in the experiments. The UFV95-370A665 line, which belongs to the BC4 generation, showed the lowest genotypic stability performance and also the lowest yield mean in the experiments.

According to this methodology, there was a tendency

Table 5. Classification of 15 soybean genotypes in the three environments studied in decreasing order of stability, according to the traditional method, and their respective mean yield (kg/ha).

Genotypes	Generations	$MS(E/G_i)$	Yield (kg/ha)	
			Means	Classification
UFV95-370A2142	RC6	195744.4447	2582.2222	5
Doko RC	Progenitor	243502.0839	2671.6667	3
FT-Cristalina	Progenitor	275889.5838	2360.0000	13
UFV95-370A2021	BC5	278663.1942	2740.2778	2
UFV95-370A665	BC4	332752.7776	2284.4444	15
UFV95-370A661	BC4	429011.0601	2376.1111	12
UFV95-370A2115	BC6	444811.1496	2563.8889	6
UFV95-370A666	BC4	461092.3615	2387.2222	11
UFV95-370A2133	BC6	463536.2216	2748.8889	1
UFV95-370A667	BC4	521877.7775	2349.4444	14
UFV95-370A2156	BC6	828302.7783	2606.3889	4
UFV95-370A2022	BC5	833759.0274	2556.9444	8
UFV95-370A2019	BC5	1016263.3456	2558.8889	7
UFV95-370A2020	BC5	1107046.6080	2548.6111	10
UFV95-370A2121	BC6	1268933.4391	2551.6666	9
General mean			2525.7778	

Table 6. Estimates of the grain yield means (kg/ha), of the general P_i values and of the percentage of the P_i value associated to the genetic effect (EGP_i) for the 15 soybean genotypes assessed in three locations in Minas Gerais state.

Genotypes	Generation	Means	P_i [1/]	EGP_i
UFV95-370A2021	BC5	2740.2778	1.3896	82.5535
UFV95-370A2133	BC6	2748.8889	1.8507	54.4339
Doko RC	Progenitor	2671.6667	3.6958	64.9830
UFV95-370A2142	BC6	2582.2222	5.4951	86.6590
UFV95-370A2156	BC6	2606.3889	5.5734	72.5834
UFV95-370A2115	BC6	2563.8889	6.6662	80.1744
UFV95-370A2019	BC5	2558.8889	7.4180	74.2699
UFV95-370A2121	BC6	2551.6666	8.8803	64.7690
UFV95-370A2022	BC5	2556.9444	8.9837	62.0465
UFV95-370A2020	BC5	2548.6111	8.9848	65.1739
UFV95-370A666	BC4	2387.2222	12.7671	99.3269
UFV95-370A661	BC4	2376.1111	13.9962	94.6463
UFV95-370A667	BC4	2349.4444	16.1454	90.7693
FT-Cristalina	Progenitor	2360.0000	17.0797	82.4905
UFV95-370A665	BC4	2284.4444	20.0787	91.5663
General mean		2525.7778		

[1/] Values multiplied by 10^{-4}

to discriminate the genotypes in backcross generation groups. The BC4 generation lines behaved as those of lowest genotypic performance among the genotypes studied, occupying the last five positions in the classification, together with the recurrent parent (FT-Cristalina). These lines also present the lowest yield means of the experiments, below the general mean.

The BC6 generation genotypes presented a tendency to show superior genotypic performance than the genotypes of the previous generations. They occupied four out of the six highest positions, with the BC5 genotypes placed in the intermediary positions.

This behavior was expected based on the recuperation of the recurrent parent at each backcross generation, that is, the mean recuperation in BC6, BC5 and BC4, was respectively, 99,22; 98,44; and 96,87%. In other studies, the FT-Cristalina cultivar was shown to be highly adaptable and stable. This could not be observed in this study as stem canker occurred in two (Capinopolis and Rio Paranaiba) of the three locations where the experiments were set up, limiting the performance of this cultivar.

The donor parent, Doko RC, occupied the third position in the general classification, and the recurrent parent, FT- Cristalina the fourteenth, that is, penultimate position. As previously reported, a better performance was expected of the FT-Cristalina cultivar. One of the most probable causes for this low genotypic performance was the occurrence of stem canker mainly in Rio Paranaiba that limited the yield of this cultivar.

Compared to the traditional methodology, the Lin and Binns (1988) showed greater efficiency in classifying the genotypes. In the traditional methodology the FT-Cristalina cultivar and the UFV95-370A665 line were classified among the five genotypes with best adaptability. This classification is related to a concept of phenotypic stability that is of little interest in plant breeding (Cruz and Regazzi, 1997) since, as happened in this case, it may be associated with low mean yield, sometimes even inferior to the general mean. In the Lin and Binns methodology (1988), these genotypes occupied the last positions.

At least six generations of backcrosses are recommended for complete recovery of the recurrent parent. However, when agronomically superior varieties are used as donor parents, it is presumed there is no need for complete recovery, and a lower number of generations can be used (Borém, 1997). On the other hand, it should be noted that as the backcross generation advanced there was simultaneous improvement in the genotypic performance of the individuals within these generations. This was probably due to a greater recuperation of the recurrent parent at each backcross, therefore suggesting the need of at least five or six backcrosses to obtain genotypes as adapted as the recurrent parent.

RESUMO

Adaptabilidade e estabilidade de comportamento de genótipos de soja em três gerações de retrocruzamentos: RC4, RC5 E RC6

Objetivando avaliar o comportamento de três diferentes gerações de retrocruzamentos (RC4, RC5 e RC6), para introdução de resistência ao cancro da haste da soja, frente às variações ambientais (performance genotípica), foi feito estudo de adaptabilidade e estabilidade pelos métodos tradicional e de Lin e Binns (1988). O estudo compreendeu três ensaios de avaliação de genótipos instalados nas cidades de Florestal, Capinópolis e Rio Paranaíba, pertencentes ao Estado de Minas Gerais, no ano agrícola de 1997/98, e envolveu a avaliação dos parentais recorrente (FT-Cristalina) e doador (Doko RC) e de 13 linhagens, sendo cinco delas pertencentes à geração RC6 (UFV95-370A2156, UFV95-370A2142, UFV95-370A2133, UFV95-370A2121 e UFV95-370A2115); quatro, à RC5 (UFV95-370A2022, UFV95-370A2021, UFV95-370A2020 e UFV95-370A2019); e quatro, à RC4 (UFV95-370A667, UFV95-370A666, UFV95-370A65 e UFV95-370A661). O método de Lin e Binns (1988) mostrou-se mais eficiente para a discriminação dos genótipos. A linhagem UFV95-370A2021, pertencente à geração RC5, foi identificada como a de melhor performance genotípica entre os genótipos estudados, além de apresentar também a segunda melhor média de produtividade de grãos dos ensaios. A linhagem UFV95-370A665, pertencente à geração RC4, comportou-se como a de performance genotípica mais baixa, além de apresentar também a menor média de produção dos ensaios. Observou-se que, na medida em que se avançava a geração de retrocruzamento, ocorria simultaneamente melhora da performance genotipica dos indivíduos nestas gerações, provavelmente pela maior recuperação do parental

recorrente a cada geração, sugerindo, portanto, a necessidade de pelo menos cinco a seis retrocruzamentos para obtenção de genótipos tão adaptados quanto ao parental recorrente.

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