Seed yield combining ability among soybean genotypes in two locations

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ABSTRACT

The genotype x location interaction is an important parameter in soybean and can influence variance estimates and general and specific combining ability effects. This research to evaluate the general (GCA) and specific (SCA) combining abilities and their interactions with locations in a diallel cross system. These parameters can facilitate the identification of most promising bi-parental combinations. The six parents: (1) Hartwig, (2) Conquista, (3) USP 1-11, (4) USP 2-16, (5) MTBR 123.800, (6) USP 5-19 and the 15 crosses in the F_2 generation were evaluated in a randomized complete block design, in two locations during the 1998/99 crop season. The two locations (ESALQ and Anhembi) are contrasting in topography and in physical and chemical soil properties. Data on seed yield were analyzed using an adaptation of Griffing's method 2, model mixed B for complete diallel crosses in more than one environment. The following conclusions were obtained: both effects GCA and SCA were important; the location (L) effect was significant, with Anhembi being more favorable than ESALQ for expressing the genotypic performance in terms of seed yield; the effects of GCA x L and SCA x L also were significant; high SCA effects occurred in crosses between parents contrasting in terms of magnitude and sign of GCA; the largest GCA effect occurred for Conquista (in two locations), USP 1-11 (in ESALQ), and MTBR 123800 (in Anhembi); the largest SGA effects were observed in the crosses Hartwig x USP 1-11 (1 x 3) and Conquista x USP 5-19 (2 x 6), the first being more stable than the second in the two locations; the contribution of s_{ii} (specific combining ability of the parental i with itself) parameter showed to be important for the expression of heterosis, parental divergence and potential of the crosses in developing superior inbred lines.

KEY WORDS: Soybean, diallel analysis, combining ability, genotype x environment interaction.

INTRODUCTION

The soybean crop occupies an important position in Brazilian agriculture, being cultivated in all Brazilian regions, from the traditional South and Southeast to the most recent Central, West, Northeast and North. This wide occupation is dependent of cultivars with adaptation to the different agriculture-climate conditions; and to have success, it is necessary that the initial phases of a breeding program are well developed. Among these, the parent selection may be viewed as one of the most critical aspects, because the success of the program depends directly on this stage.

Traditionally, the work in soybean breeding uses the synthesis of bi-parental crosses and the conduction of segregating populations to homozygosis, through different methodologies, aiming to release genetic variability for selection and development of new cultivars with favorable traits. However, the breeders usually have difficulties when they need to select parents whose crosses produce progenies with high seed yielding potential. In that context, diallel crosses are quite efficient, because they evaluate each population individually and in hybrid combinations, early in the generations of inbreeding. This method supplies parameter estimates that are used in parental selection for hybridization and in the understanding of the genetic effects involved in the expression of the traits that compose the objectives of the breeding program (Cruz and Regazzi, 1994).

The terms, general combining (GCA) and specific combining abilities (SCA), were defined for the first time by Sprague & Tatum (1942), and represent the performance of genotypes in crosses. GCA characterizes the average performance of a genotype in a series of hybrid combinations and is mainly associated with additive gene action. SCA is used to characterize the performance of a specific hybrid combination in relation to the average of its parents and is predominantly associated with genetic effects involving dominance. Ramalho et al. (1993) mentioned GCA as a parameter of larger practical importance for the breeder, since it gives information about the participation of additive gene effects in the variation range of the segregating generations of a cross, allowing to trace the best strategies for the breeding program.

In soybean, the methodology presented by Griffing (1956) is quite used. This methodology, which estimates the general and specific combining abilities of the parents in a diallel cross, was developed for four types of diallel tables, corresponding to four methods.

The most commonly used is method 2, which includes the n parents and the [n(n-1)/2] crosses in the generation F_1, without reciprocal crosses; and the second in use is method 4, which involves only the group of F_1s, without parents and reciprocals. More recently, these two methods have also been used in generation F_2 (Freire Filho, 1988; Nass, 1989; Pimentel, 1991; Sharma and Phul, 1994; Pulcinelli, 1997; Soldini, 1998; Gadag et al., 1999).

To obtain more consistent information, it is important to evaluate the diallel in experiments across several environments (locations, years, sowing dates). The joint analysis of these experiments includes, the variation sources found in individual analyses and the interactions of the main effects with environments. Singh (1973 a,b; 1979), Oliveira et al. (1987), Morais et al. (1991), and Ferreira et al. (1993) have developed methodologies of joint analysis for diallels evaluated in more than one environment. There are few references (Paschal and Wilcox, 1975; Sharma et al., 1993) on the joint analysis of experiments across environments involving Griffing's method 2.

The objective of the present work was to evaluate the combining abilities of six soybean parents and identify the most promising crosses from experiments carried out in two contrasting locations.

MATERIAL AND METHODS

Six soybean genotypes: (1) Hartwig, (2) USP 1-11, (3) Conquista, (4) USP 2-16, (5) MT BR 123800 and (6) USP 5-19 were crossed in a complete diallel mating system, without reciprocal crosses. These parents were selected for seed yield, agronomic performance and resistance to diseases. The experiments were developed at two locations: ESALQ and Anhembi Experimental Station, both located in Piracicaba, State of São Paulo, Brazil, at south 22°42'30'' latitude, west 47°39'00'' longitude, and an altitude of 543 meters. The area in ESALQ's headquarters has a hilly relief and very fertile soil (kandiudalfic eutrudox, "terra roxa estruturada eutrófica") with a clay texture. The Anhembi Experimental Station, located about 60 km from the ESALQ's headquarters, has a flat relief and the soil (typic udifluvent, a soil type commonly found in Brazilian savannahs or "cerrados") is dystrophic alluvial with acidity neutralized by lime application.

The 21 treatments were formed by six parents and 15 crosses in F_2 generation. They were grown in randomized block design experiments, with six replications in each location (ESALQ and Anhembi). The experimental plot was represented by 12 hills of individual plants spaced 0.80m x 0.80m, covering an area of 7.68 m^2. Sowing was done in the month of November, by placing 12 seeds per hill and random thinning to one plant per hill after 15 days.

The seed yield data were analyzed using the computer program Genes (Cruz, 1997) through an adaptation of the method 2, model mixed B of Griffing for complete diallels in experiments evaluated in more than one environment, in which all the effects are controlled, except the experimental error (Singh, 1973a,b; 1979). This methodology is based on the following mathematical model:

$$Y_{ijk} = m + l_k + g_i + g_j + s_{ij} + lg_{ik} + lg_{jk} + ls_{ijk} + e_{ijk}$$

where m is the general average of the diallel; l_k is the environmental (location) effect of order k; g_i and g_j are the effects of the general combining abilities of the parents i and j, respectively; s_{ij} is the effect of the specific combining ability between the parents i and j; $s_{ij}=s_{ii}$ is the effect of specific combining ability of the parental i with itself; e_{ijk} is the experimental error; the other parameters correspond to the interactions of the effects (g_i, g_j, s_{ij}, s_{ii}) with locations.

RESULTS AND DISCUSSION

According to Table 1, in ESALQ, the mean of seed yield ranged from 36.0 g/plant (Hartwig) to 101.7 g/plant (USP 1-11) among the parents; the cross means varied from 75.9 g/plant (USP 2-16 x USP 5-19 or 4 x 6) to 120.4 g/plant (Conquista x USP 1-11 or 2 x 3). In Anhembi, the variation limits were 61.0 g/plant (Hartwig) and 114.0 g/plant (USP 1-11) for parents and from 85.4 g/plant (MTBR 123.800 x USP 5-19 or 5 x 6) to 135.8 g/plant (USP 2-16 x MTBR 123.800 or 4 x 5) for crosses. All parents were higher yielding in Anhembi than in ESALQ, proving a more favorable adaptation to the savannah environment with the lime-corrected soil. On the other hand, nine crosses were more productive in Anhembi and the remaining six yielded better in ESALQ. Considering the two locations together, four crosses with seed yield about 120.0 g/plant can were depicted: Hartwig x USP 1-11 (1 x 3), Hartwig x USP 2-16 (1 x 4), USP 1-11 x MTBR 123.800 (3 x 5) and USP 2-16 x MTBR 123.800 (4 x 5). Distinction should be given to the cross Hartwig x USP 1-11 (1 x 3) for maintaining high seed yield in the two locations showing a tendency of stability.

Table 1 - Seed yield means (g/plant, six replications) of six parents and 15 diallel crosses (F_2) at ESALQ (E) and Anhembi (A).

Parents		1-Hartwig	2-Conquista	3-USP 1-11	4-USP 2-16	5-MTBR 123800	6-USP 5-19
1-Hartwig	E	36.0	116.8	115.4	111.0	108.9	107.6
	A	61.0	110.8	120.0	125.9	114.8	115.5
	$\bar{x}$	48.5	113.8	117.7	118.4	111.8	111.6
2-Conquista	E		71.6	120.4	106.9	93.1	97.9
	A		103.1	92.3	110.8	104.7	96.8
	$\bar{x}$		87.4	106.4	108.8	98.9	97.4
3-USP 1-11	E			101.7	118.7	99.4	94.6
	A			114.0	101.9	135.0	92.9
	$\bar{x}$			107.8	110.3	117.2	93.6
4-USP 2-16	E				72.6	103.0	75.9
	A				73.3	135.8	98.3
	$\bar{x}$				73.0	119.4	87.1
5-MTBR 123-800	E					70.9	87.1
	A					90.0	85.4
	$\bar{x}$					80.4	86.2
6-USP 5-19	E						64.7
	A						85.4
	$\bar{x}$						75.0

The individual variance analysis (Table 2) showed that Anhembi had a yield average of almost 10% above the average observed in ESALQ. However, the experimental error of Anhembi was about 90% higher, which was reflected in a coefficient of experimental variation approximately 25% higher. In spite of this, the two locations showed very satisfactory levels of experimental precision. In these individual analyses, the main variation sources (parents and crosses) were highly significant, but the contrast among them (P vs F_2) was not significant in ESALQ and had small significance (5%) in Anhembi.

The joint analysis of variance for the two locations

Table 2 - Mean squares and significance of the sources of variation in individual analysis of variance for seed yield in ESALQ and Anhembi.

SV	DF	MS	
		ESALQ	Anhembi
Replications	5	606.98**	653.09*
Treatments(T)	20	2828.05**	2145.55**
Parents (P)	5	6325.16**	3791.58**
Crosses (F_2)	14	1748.94**	1610.39**
P vs F_2	1	450.15 ns	1447.64*
Error	100	117.66	223.57
Mean (g/plant)		94.01	103.23
C.V. (%)		11.54	14.48

** and * : respectively, significant at 1 and 5% probability by the F test.

Table 3 - Mean squares and significance of the joint analysis of variance (ESALQ and Anhembi), for seed yield in soybean.

SV	DF	MS
Locations (L)	1	5335.48*
Treatments (T)	20	4189.03**
Parents (P)	5	8426.30**
Crosses (F_2)	14	2946.83**
P vs F_2 (G)	1	141.64 ns
T x L	20	786.57**
P x L	5	1690.45**
F_2 x L	14	394.51**
G x L	1	1756.15**
Error	200	170.61
Mean (g/plant)		98.62
C.V. (%)		13.24

** and *: respectively, significant at 1 and 5% probability of F test.

The diallel analysis (Table 4) evidenced significance of the variances due to the general combining ability (GCA) and specific combining ability (SCA), as well as the variances due to interactions among genetic and location effects (GCA x L and SCA x L). Consequently, parents and crosses should be selected and recommended for specific locations. In fact, previous researches with soybean also showed that GCA and SCA interacted with environment (Kunta et al., 1985; Pulcinelli, 1997) and, because of that, recommendation should be specific.

Table 5 shows again the favorable effect of Anhembi relatively to ESALQ for the good performance of the genotypes. In terms of general combining ability (g_i) there was prominence for the parents USP 1-11 and Conquista in ESALQ, and for MTBR 123800 and Conquista in Anhembi. Table 5 still displays that the parental genotype Conquista also had the smallest estimate of genotype x location interaction.

In terms of specific combining ability (sij) there was an expressive prominence of the cross Hartwig x USP 1-11 (1 x 3), in ESALQ and in Anhembi; this cross also presented the advantage of possessing one with the smallest interaction to the locations (lsijk), as it can be verified in Table 5. After this, the cross Conquista x USP 5-19 (2 x 6), with positive and low lsijk interaction, had outstood in the two locations. In Anhembi, several other crosses showed positive values of $\hat{s}_{ij}$, but all them had relatively high estimates of lsijk interaction.

Table 4 - Joint diallel analysis of two locations (ESALQ and Anhembi), for seed yield in soybean.

SV	DF	MS
Locations (L)	1	889.25**
GCA	5	2255.75**
SCA	15	179.16**
GCA x L	5	307.74**
SCA x L	15	72.05**
Error	200	28.44

**: significant at 1% probability of F test.

Another interesting fact observed in Table 5, already evidenced previously in soybean (Sharma and Phul, 1994), is that the crosses with the largest values of SCA-involved parents contrasting in GCA, that is, parents presenting high values and inverse $\hat{g}_i$ signs. Such combinations can result in transgressive segregation, if the genes with addictive effects are complementary and act in the same direction of maximum expression of the trait (Gadag et al., 1999). In terms of s_{ij}, the most outstanding cross was Hartwig x USP 1-11 (1 x 3). This cross still has the particularity of involving a parent (Hartwig) that is exotic in relation to Brazilian germplasm, a fact that can indicate a favorable contribution of the genetic diversity among the parents for a high value of SCA. Therefore, crosses between divergent parents, with high value of SCA (or s_{ij}) can be explored through breeding methods, by selecting favorable segregated individuals that lead to obtaining superior lines (Sharma and Phul, 1994). The cross Hartwig x USP 1-11 (1 x 3) presents the additional advantage of having genes segregating for resistance to the soybean cyst nematode (*Heterodera glycines*, Ichinohe), that are present in the two parents, although more concentrated in Hartwig (Anand,1992).

In the method 2 of Griffing, the magnitude of the parameter s_{ii} is an indication of the diversity of the parental i in relation to the average of the other parents; a positive sign of s_{ii} indicates that the heterosis manifested in the hybrids of the parental

Table 5 - Estimates of general combining ability (GCA or $\hat{g}_i$), specific combining ability (SCA or $\hat{s}_{ij}$), locations ($\hat{l}_k$), and interactions ($l\hat{g}_{ik}$, $l\hat{s}_{iik}$ and $l\hat{s}_{ijk}$), for seed yild obtained using method 2, model 1 of Griffing method.

	GCA			
	ESALQ		Anhembi	
Parents	$\hat{g}_i$	$l\hat{g}_{ik}$	$\hat{g}_i$	$l\hat{g}_{ik}$
G_1 - Hartwig	-25.5708	-4.3729	-16.8250	4.3729
G_2 - Conquista	11.2542	0.7333	9.7875	-0.7333
G_3 - USP 1-11	12.2167	5.5896	1.0375	-5.5896
G_4 - USP 2-16	7.9792	2.7958	2.3875	-2.7958
G_5 - MTBR 123800	-0.4833	-5.9792	11.4750	5.9792
G_6 - USP 5-19	-5.3958	1.2333	-7.8625	-1.2333
	SCA			
	ESALQ		Anhembi	
	$\hat{s}_{ii}$	$l\hat{s}_{iik}$	$\hat{s}_{ii}$	$l\hat{s}_{iik}$
S_{11} - Hartwig	-6.8679	0.8054	-8.4786	-0.8054
S_{22} - Conquista	0.2821	6.1429	-12.0036	-6.1429
S_{33} - USP 1-11	1.9571	7.4804	-13.0036	-7.4804
s_{44} - USP 2-16	8.7321	7.4179	-6.1036	-7.4179
s_{55} - MTBR 123800	9.9571	0.1679	-9.6214	-0.1679
s_{66} - USP 5-19	3.8821	2.9929	-2.1036	-2.9929
	$\hat{s}_{ij}$	$l\hat{s}_{ijk}$	$\hat{s}_{ij}$	$l\hat{s}_{ijk}$
s_{12} (Hartwig x Conquista)	-8.0929	-7.5009	6.9089	7.5009
s_{13} (Hartwig x USP 1-11)	21.0446	-2.7571	26.5589	2.7571
s_{14} (Hartwig x USP2-16)	-3.8179	5.8366	-15.4911	-5.8366
s_{15} (Hartwig x MTBR123800)	2.9446	5.4116	-7.8786	-5.4116
s_{16} (Hartwig x USP 5-19)	1.6571	-2.6009	6.8589	2.6009
s_{23} (Conquista x USP 1-11)	-2.0804	-4.0134	5.9464	4.0134
s_{24} (Conquista x USP 2-16)	-2.2429	-6.3696	10.4964	6.3696
s_{25} (Conquista xMTBR123800)	4.1196	6.9054	-9.6911	-6.9054
s_{26} (Conquista x USP 5-19)	7.7321	-1.3071	10.3464	1.3071
s_{34} (USP 1-11 x USP 2-16)	-7.3054	-5.7259	4.1464	5.7259
s_{35} (USP 1-11 x MTBR123800)	-12.6429	-0.8009	-11.0411	0.8009
s_{36} (USP 1-11 x USP 5-19)	-2.9304	-1.6634	0.3964	1.6634
s_{45} (USP 2-16 x MTBR123800)	-2.1054	-10.0071	17.9089	10.0071
s_{46} (USP 2-16 x USP 5-19)	-1.9929	1.4304	-4.8536	-1.4304
s_{56} (MTBR123800xUSP5-19)	-12.2304	-1.8446	-8.5411	1.8446
$\hat{l}_k$		-4.6095		4.6095

i would be negative, while a negative sign of s_{ii} would be an evidence of positive heterosis (Freire Filho, 1988; Cruz and Regazzi, 1994). It is observed in the Table 5 that the genotype x location interaction influenced the magnitude and the signs of s_{ii}. In ESALQ, the two more divergent parents were MTBR 123800 and USP 2-16.

Differently, in Anhembi, the most divergent parents were USP 1-11 and Conquista. In terms of hyhrid heterosis, ESALQ presented only one parent (Hartwig) with positive heterosis (negative s_{ii}), while all the parents showed this tendency in Anhembi, specially parents USP 1-11 and Conquista. The negative and relatively high values of s_{ii} in the two locations explain the favorable performance of the crosses with Hartwig, even in those combinations in which the estimates of other parameters were not favorable.

Because soybean cultivars are inbred lines, the high values of s_{ij} and s_{ii} have practical importance if they are associated to complementary genes and genetic diversity, instead of dominance effects and heterosis. The prominent crosses like Hartwig x USP 1-11 (1 x 3) can be considered to have complementary genes and an appropriate level of genetic diversity for originating high frequency of inbred lines superior in seed yield.

CONCLUSIONS

a) The effects of general combining ability (GCA) and specific combining ability (SCA) were important;
b) The two locations (L) were contrasting, with Anhembi more favorable than ESALQ in the manifestation of seed yield;
c) The interactions GCA x L and SCA x L cannot be disregarded in diallel studies with soybean;
d) High SCA effects occurred in crosses between parents contrasting in magnitude and sign of GCA;
e) The highest estimates of GCA were related to parents Conquista (in the two locations), USP 1-11 (in ESALQ), and MTBR 123800 (in Anhembi);
f) The highest SCA estimates occurred in the crosses Hartwig x USP 1-11 (1 x 3) and Conquista x USP 5-19 (2 x 6), in the two locations;
g) The contribution of the parameter s_{ii} (specific combining ability of the parental i with itself) was important for the expression of heterosis, divergence among parents and the potential of the crosses in developing superior inbred lines.

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RESUMO

Capacidade de combinação para produtividade entre genótipos de soja em dois locais

A interação genótipos x locais tem sido um importante parâmetro em soja, podendo influenciar as estimativas de variâncias e de efeitos das capacidades geral e específica de combinação. Esse estudo teve como objetivo avaliar em dialelo as capacidades geral e específica de combinação e suas interações com locais, além de identificar os cruzamentos mais promissores. Seis parentais (1) Hartwig, (2) Conquista, (3) USP 1-11, (4) USP 2-16, (5) MTBR 123.800, (6) USP 5-19 e os 15 cruzamentos dialélicos na geração F_2, sem recíprocos, foram avaliados no delineamento de blocos ao acaso, em dois locais, durante o ano agrícola 1998/99. Os dois locais (ESALQ e Anhembi) são contrastantes no relevo e nas propriedades físicas e químicas do solo. Os dados de produtividade de grãos foram analisados utilizando-se uma adaptação do método 2, modelo misto B de Griffing, na qual os cruzamentos e os parentais do dialelo completo são avaliados em vários ambientes. As seguintes conclusões foram obtidas: os efeitos das capacidades geral (CGC) e específica (CEC) de combinação foram importantes. O efeito de locais (L) mostrou-se significativo, sendo Anhembi mais favorável que ESALQ para o desempenho dos genótipos em produtividade de grãos. As interações CGC x L e CEC x L também foram significativas. Efeitos elevados de CEC ocorreram nos cruzamentos entre parentais contrastantes na magnitude e nos sinais da CGC. Os maiores destaques em CGC envolveram os parentais Conquista (nos dois locais), USP 1-11 (na ESALQ) e MTBR 123.800 (em Anhembi). Os maiores destaques em CEC foram os cruzamentos Hartwig x USP 1-11 (1 x 3) e Conquista x USP 5-19 (2 x 6), sendo o primeiro mais estável que o segundo, nos dois locais. A contribuição do parâmetro s_{ii} (capacidade específica de combinação do parental i com ele próprio) mostrou-se importante na expressão da heterose, da divergência entre os parentais e para inferir o potencial dos cruzamentos em desenvolver linhagens puras.

REFERENCES

Anand, S. C. 1992. Registration of *Hartwig* soybean. Crop Science. 32(4):1069-1070.

Cruz, C. D. 1997. Programa GENES: aplicativo computacional em genética e estatística. UFV, Viçosa.

Cruz, C. D. and Regazzi, A. D. 1994. Modelos biométricos aplicados ao melhoramento. UFV, Viçosa.

Ferreira, D.F. ; Rezende, G. D. S. P. and Ramalho, M. A. P. 1993. An adaptation of Griffing's method IV of the complete diallel cross analysis for experiments repeated in several environments. Revista Brasileira de Genética. 16(2): 357-366.

Freire Filho, F. R. 1988. Análise genética de um dialelo entre genótipes precoces de soja (*Glycine max* (L.) Merrill. 224p. M.S.

Thesis. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo. Piracicaba

Gadag, R. N.; Upadhyaya, H.D. and Goud, J.V. 1999. Genetic analysis of yield, protein, oil and other related traits in soybean. Indian Journal of Genetics and Plant Breeding. 59(4): 487-492.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel cross systems. Australian Journal Biological Sciences. 9(4): 463-493.

Kunta, T.; Edwards,L.H.; Mcnew, R.W. and Dinkins,R. 1985. Heterosis performance and combining ability in soybeans. Soybean Genetics Newsletter. 12: 97-99.

Morais, A.R.; Oliveira, A.C.; Gama, E.E.G. and Souza Junior, C.L. 1991. A method for combined analysis of the diallel crosses repeated in several environments. Pesquisa Agropecuária Brasileira. 26(3): 371-381.

Nass, L. L. 1989. Potencialidade de genotypes de soja (*Glycine max* (L.) Merrill) para cultivo de inverno avaliada por cruzamentos dialélicos. 112p. M.S.Diss. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo. Piracicaba.

Oliveira, A.C.; Morais, A.R.; Souza Junior, C.L. and Gama, E.E.G. 1987. Análise de cruzamentos dialélicos parciais repetidos em vários ambientes. Revista Brasileira de Genética. 10(3): 517-553.

Phascal, E. H. and Wilcox, J. R. 1975. Heterosis and combining ability in exotic soybean germplasm. Crop Science. 15(3): 344-349.

Pimentel, A. M. 1991. Cruzamentos dialélicos em soja com ênfase em teor de proteína e produção de grãos. 150p. M.S. Diss. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo, Piracicaba.

Pulcinelli, C. E. 1997. Avaliação de cruzamentos dialélicos em soja em gerações avançadas de endogamia. 165p. M.S. Thesis. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo. Piracicaba

Ramalho, M.A.P.; Santos, J.B. and Zimmerman, M.J.O. 1993. Genética quantitativa aplicada em plantas autógamas: aplicação ao melhoramento do feijoeiro. UFG, Goiânia . 217p.

Sharma, S. K.; Mehta, H. and Sood, V.K. 1993. Effect of cropping systems on combining ability and gene action for grain yield and its components in soybean. Field Crops Research. 34(1): 15-22.

Sharma, S.R. and Phul, P.S. 1994. Combining ability analysis in soybean. Indian Journal of Genetics and Plant Breeding. 54(3): 281-286.

Singh, D. 1973a. Diallel analysis over different environments. The Indian Journal of Genetics & Plant Breeding. 33(2): 127-136.

Singh, D. 1973b. Diallel analysis for combining ability over several environments - II. The Indian Journal of Genetics & Plant Breeding. 33(3): 469-482.

Singh, D. 1979. Diallel analysis for combining ability over environments. The Indian Journal of Genetics & Plant Breeding. 39(3): 383-386.

Soldini, D.O. 1998. Potencial genético de cruzamentos dialélicos parciais de soja com ênfase nas produtividades de grãos e óleo. 78p. M.S. Thesis. Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo. Piracicaba.

Sprague, G. F. and Tatum, L. A. 1942. General vs. specific combining ability in single crosses of corn. Journal of the American Society of Agronomy. 34(63): 923-932.

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