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Combining ability in common bean cultivars under drought stress

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Abstract

This paper aimed at selecting parents to compose a common bean breeding program for drought tolerance. General and specific combining abilities were evaluated under controlled conditions, using drought tolerant parents (BAT 477 and SEA 5), elite cultivars developed at IAC (IAC Alvorada and IAC Carioca Tybatã) and their progenies obtained from a complete diallel, including the reciprocals. Sowing was done in soil following a randomized block design with three replications for both experiments, the control with irrigation and the drought stress experiment imposed from pre-flowering stage. Plants remained under drought stress for 30 days. Physiological and morphological traits as well as yield components and grain yield were evaluated, detecting additive and non-additive effects controlling these traits. The parents used in this study had contributed in different proportions in the crosses they participated in. Regarding the drought stress condition in the pre-flowering stage, the parents SEA 5 and IAC Alvorada presented greater positive effects for the general combining ability for the yield and weight of one thousand seeds, whereas the parent SEA 5 also showed a positive effect for the number of seeds per pod, suggesting the increase of these traits in the crosses they participated in. The hybrid combinations SEA 5 × IAC Alvorada showed a positive result for grain yield, related to the higher positive effect for specific combining ability and because they have as parents the cultivars which confer the best positive values for general combining ability.

Key words: *Phaseolus vulgaris*, common bean, plant breeding, diallel, drought tolerance.

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is an important legume for human consumption and is considered the main source of vegetable protein for direct consumption. Bean is widely grown under dry conditions in Latin America. The drought is among the main limiting factors for its production, being able to reduce significantly the production of grains, in areas cultivated without irrigation (Rosales et al., 2012).

Climate change in the coming decades will be dramatic, resulting in decreased water availability and increasing air temperature in the main areas of agricultural production in the world. In this context, the increased population growth combined with climate change and the need for food production on a large scale will require the cultivation of plants more adapted to stress conditions (McClean et al., 2011). Upon the intensification of a biotic stresses, several research groups on the genetic improvement of beans have implemented multidisciplinary programs to analyze a biotic stresses aimed at identifying drought tolerant genotypes, exploring their genetic variability, such as early maturity, deep rooting for greater absorption of water, physiological adaptation through stomatal conductance, along with satisfactory grain yield in stressed crops (Blair et al., 2012).

Singh et al. (2001) registered the line SEA 5 as a drought tolerant cultivar, derived from interracial crosses between the races Mesoamerican and Durango, and one of the parents originating the line was the cultivar BAT 477, also described by the authors as drought tolerant. Later, Terán & Singh (2002) also observed productive superiority of the genotype SEA 5 in both water deficit and under irrigated condition, using BAT 477 and San Cristobal 83 as tolerant controls. Studying the root system by means of a screening using soil tube system to evaluate the impact of drought on different genotypes of beans, Rao et al. (2006) found that SEA 5 and BAT 477 remained among the genotypes with deeper roots.

Genetic and physiological mechanisms related to the responses of plants to water stress are important for the selection of superior materials for drought tolerance. Another important factor is the timing of water shortage for the evaluation of bean genotypes and according to

Massignam et al. (1998), Stone & Silveira (2012), Didonet & Silva (2004), the reproductive phase is appropriate because of the reduction caused in genotype yield.

In plant breeding programs, selecting genotypes for new cultivars development is one of the main objectives and the efficiency is increased by careful evaluation of the parents to compose the crossings (Machado et al., 2002). Among the methods of genetic analysis, the studies using diallel crosses have an important role (Oliveira et al., 1997). The methodology of Griffing (1956) is commonly used, which estimates the effects and sums of squares of the effects of general and specific combining abilities (Cruz et al., 2004).

Considering the prior description of the cultivars SEA 5 and BAT 477, considered as tolerant to drought and the yield efficiency and quality of grains of the elite cultivars IAC Alvorada and IAC Carioca Tybatã, this study aimed to investigate the behavior of these four cultivars as parents, in diallel scheme, to compose a breeding program aimed at obtaining drought tolerant lines.

2. MATERIAL AND METHODS

Hybridizations were carried out in a complete diallel scheme, including the reciprocals, between four cultivars of bean, two drought tolerant cultivars (BAT 477 and SEA 5) and two cultivars developed by the bean breeding program at the Agronomic Institute - IAC (IAC Alvorada and IAC Carioca Tybatã), which were selected on the basis of yield potential and quality of grain.

Hybridizations were performed in the morning, between 7am. and 11am. Three staggered sowings were made from May to July to synchronize flowering depending on the cycle variability of the four cultivars. Subsequently, F_2 seeds were obtained by selfing F_1 generation seeds.

The four parents and the ten F_2 progenies obtained, including the reciprocals, were evaluated in February 2012, under protected conditions and planting directly in to the soil. At first, it was planned to obtain twelve progenies in a complete diallel scheme involving four parents, however, it was not possible to obtain the progenies derived from combinations SEA 5 × BAT 477 and IAC Alvorada × IAC Carioca Tybatã.

Irrigation was automated with drippers spaced every 0.15 m and flow of 0.90 L h^{-1}. Irrigations were applied twice daily for six minutes in the morning in the irrigated experiment; in the water deficit experiment, the irrigation was the same until the time of applying the drought stress. Cultural practices were performed according to crop requirements.

This was a randomized block design with three replications for the two experiments with and without drought stress. The experimental plots consisted of a single row, two meters long, and 0.5 m between the rows, with 13 plants per meter. Water restriction in the stressed condition was applied on the same day for all genotypes according to the pre-flowering stage (R5 stage).

The plants remained under water stress for 30 days. This period was defined due to the high leaf abscission and senescence, low leaf water potential (Ψ_w) (Boyer, 1976) and soil matric potential (Ψ_m), with values near –199 kPa, at 0.40 m depth, indicating total water shortage. Soil Ψ_m was evaluated using the Watermark meter (30-KTCD-NL). In this period when plants showed pronounced symptoms of stress, the assessments were conducted by measuring the traits of dry matter of shoots, leaf area (Area Integrator - LI-3100C), stomatal conductance (porometer Type AP4) and leaf water potential (Scholander pressure chamber - 3115) evaluated at 13 pm. After the period of drought stress, irrigation was resumed until physiological maturity.

At physiological maturity, it was evaluated five plants per plot, counting the number of pods per plant (NPP), number of seeds per pod (NSP), one thousand seed weight (SW), plant height (PH) and grain yield (GY).

For diallel analysis of the condition irrigated and drought stress, we used the Griffing's (1956) model 1, where the combinations corresponding to the parents and their crosses, including reciprocals, are evaluated. For the analysis, we estimated the general (GCA) and specific combining (SCA) abilities. Estimates were made for the two missing combinations.

Analyses were performed using the software GENES (Cruz, 2001) according to the statistical model (1):

$$Y_{ij} = m + g_i + g_j + s_{ij} + r_{ij} + \overline{\varepsilon_{ij}} \quad (1)$$

wherein:

Y_{ij}: mean value of the hybrid combination (i # j) or of the parents (i = j);

m : overall mean;

g_i, g_j: effects of general combining ability of the ith and jth parents (i, j = 1, 2 ... p);

s_{ij}: effect of specific combining ability for crossing between the parents of i and j order rij: reciprocal effect measuring the differences provided by the parent i or j when used as male or female in the cross ij;

$\overline{\varepsilon_{ij}}$: average experimental error associated with observation of the ij order

3. RESULTS AND DISCUSSION

The analysis of variance showed significance for genotypes in most traits evaluated under water deficit conditions, except the traits LA, DMS and SC, evidencing the existence of variability between the parents and their progeny under drought stress, favoring the selection. In the irrigated condition, the analysis of variance evidenced significant differences between genotypes for the traits, SW, NSP, PH, LA, SC and Ψ_w (Table 1).

In general, the coefficients of variation (CV) (Table 1) were of low to medium magnitude, indicating good accuracy in experimental data collection, which is desirable, since it allows to obtain a better response to selection. Also, the experiment under full irrigation showed the highest overall means for all traits. The GY exhibited the largest reduction due to the water restriction and according to Silveira et al. (1981), this variable decreases with increasing number of days under water deficit conditions. These results were expected, since the bean crop is sensitive to water stress and the trend is a reduction in traits combined with the lower leaf water potential because of drought conditions.

There was a difference in leaf water potential between the two water conditions; with an overall means of genotypes were, respectively, –0.58 and –0.94 MPa, proving the efficiency of stress. Behavior differences were found only under drought, where the leaf Ψ_w varied between –0.73 and –1.20 MPa. Guimarães et al. (2006) registered minimum values of 0.97 and –1. 07 MPa for leaf Ψ_w evaluated in the period of maximum intensity of solar radiation in two bean cultivars subjected to water stress during the reproductive period.

This difference in water potential between the two water conditions reflected in a reduction of 53% in GY. Figure 1 illustrates that the genotype 10 (IAC Alvorada × BAT 477) presented the highest average yield under irrigated conditions and the genotypes 9 (SEA 5 × IAC Alvorada) and 12 (IAC Carioca Tybatã × IAC Alvorada) showed the highest GY under drought conditions. The genotypes 7 (BAT 477 × IAC Alvorada), 11 (IAC Alvorada × SEA 5) and 14 (IAC Carioca Tybatã × SEA 5) stood out with respect to GY, considering both water conditions, however, the first two (7: BAT 477 × IAC Alvorada and 11: IAC Alvorada × SEA 5) especially for the irrigated and the latter one (14: IAC Carioca Tybatã × SEA 5) for the drought stress.

The breakdown of the diallel analysis of variance with respect to drought stress (Table 1) showed significant differences between the parents for general combining ability (GCA) for the traits GY, SW, NSP and PH. Significant effects were also found for GCA in the irrigated condition for the following traits: SW, NSP, PH, LA and Ψ_w. Considering the specific combining ability (SCA) under drought stress, there was a significant effect for the traits GY, NPP, DMS and SC. In the irrigated contition, there was significant effect for SCA only for the trait SC. These significant results evidence the occurrence of additive and non-additive effects in controlling these traits, and indicate that the four parents used in the study contributed differently in the crossings they participated, due to variability presented.

There was significance for the reciprocal effect for GY under drought stress. Regarding irrigated condition, we observed a reciprocal effect for SW, SC and Ψ_w. In this way, according to Ramalho et al. (2000), one should take into consideration the parental behavior, which can be used either as female (pollen recipient), or as male (pollen donor). Baldissera et al. (2012) evaluated the crosses from six bean parents without stress induction and founding

Table 1. Summary of analysis of variance for combining ability referring to yield (GY), one thousand grain weight (SW), number of pods per plant (NPP), number of seeds per pod (NSP), plant height (PH), total leaf area (LA), dry weight of shoots (DMS), stomatal conductance (SC), leaf water potential (Ψw) measured at 13 pm. of bean genotypes under conditions of drought stress and full irrigation

Source of Variation	DF	Means quare – Drought stress								
		GY (kg ha^{-1})[1]	SW (g)	NPP[1]	NSP	PH (cm)	LA (cm^2)[1]	DMS (g)[1]	SC (mmol m^{-2} s^{-1})[1]	Ψ_w (MPa)
Genotype	15	1068,64**	607,21*	7,73*	0,98**	2008,07**	673793,74^{ns}	47,23^{ns}	2170,72^{ns}	0,038*
GCA	3	1309,75**	2088,94**	3,60^{ns}	3,86**	7618,34**	434720,83^{ns}	49,95^{ns}	396,38^{ns}	0,037^{ns}
SCA	6	1433,16**	256,89^{ns}	10,23*	0,29^{ns}	321,94^{ns}	493137,22^{ns}	62,30*	3598,04*	0,036^{ns}
Reciprocal effect	6	583,57 *	216,66^{ns}	7,28^{ns}	0,22^{ns}	889,07^{ns}	973986,73^{ns}	30,79^{ns}	1630,56^{ns}	0,04^{ns}
Residual	30	235,80	235,00	3,14	0,19	415,16	425258,74	25,07	1316,13	0,015
Mean		802,3	229,40	6,94	3,86	147,72	1100,57	12,86	68,48	-0,94
CV (%)		9,89	7,13	11,77	12,17	14,61	37,55	19,63	12,75	14,06
Source of Variation	DF	Mean square – Full irrigation								
		GY (kg ha^{-1})[1]	SW (g)	NPP[1]	NSP	PH (cm)	LA (cm^2)[1]	DMS (g)[1]	SC (mmol m^{-2} s^{-1})[1]	Ψ_w (MPa)
Genotype	15	3608,87^{ns}	8170,16**	10,74^{ns}	0,41*	2200,26*	1956184,27*	121,99^{ns}	858,44**	0,042**
GCA	3	2102,29^{ns}	20076,41**	5,70^{ns}	1,00**	6428,97**	4104478,77**	167,51^{ns}	818,19^{ns}	0,048*
SCA	6	5414,24^{ns}	2722,25^{ns}	19,23^{ns}	0,34^{ns}	1411,62^{ns}	957653,17^{ns}	112,68^{ns}	833,79*	0,023^{ns}
Reciprocal effect	6	2556,80^{ns}	7664,94**	4,77^{ns}	0,17^{ns}	874,54^{ns}	1880568,13^{ns}	108,55^{ns}	903,22*	0,577**
Residual	30	2731,20	1673,76	9,49	0,17	859,09	828625,97	62,72	283,15	0,012
Mean		1704,9	266,62	11,02	4,79	149,45	2204,74	19,22	129,80	-0,58
CV (%)		15,27	7,91	13,15	9,18	20,61	21,87	21,90	14,66	20,01

[1]transformed data (√x+1). *significant at 5% level. **significant at 1% level. ^{ns} not significant.

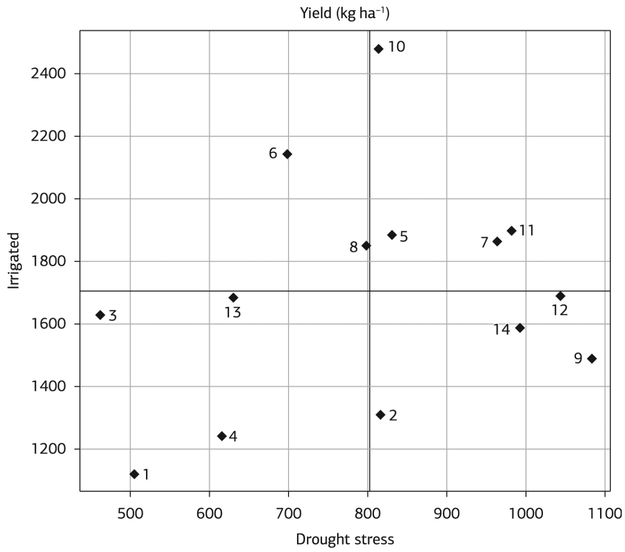

Figure 1. Performance of 10 progenies and the four respective parents of bean considering the two water contitions: 1 – Drought stress at pre-flowering stage (x-axis) and; 2 - Irrigated (y-axis).Genotypes: 1-BAT 477; 2-SEA 5; 3-IAC Alvorada; 4- IAC Carioca Tybatã; 5-BAT 477 × SEA 5; 6- BAT 477 × IAC Carioca Tybatã; 7-BAT 477 × IAC Alvorada; 8-SEA 5 × IAC Carioca Tybatã; 9- SEA 5 × IACAlvorada; 10-IAC Alvorada × BAT 477; 11-IAC Alvorada × SEA 5; 12-IAC Carioca Tybatã × IAC Alvorada; 13-IAC Carioca Tybatã × BAT 477 and 14-IAC Carioca Tybatã × SEA 5.

a significant reciprocal effect for cycle, plant height, first pod height, stem diameter and number of pods per plant. These authors concluded that there is a difference when a genotype is used as pollen donor or recipient, because of the cytoplasmic effect and nuclear gene effects of the female parent in the evaluated traits.

In both experiments, there was a prevalence of additivity effects in the inheritance of traits for the traits SW, NSP and PH, due to the significance given only by GCA. Additive genetic effects are fixed over successive generations and especially important for autogamous species (Carvalho & Ribeiro, 2002).

There was a predominance of dominance effects, under drought stress for traits NPP, DMS and SC, while in the irrigated condition , there was a predominance of dominance effect only for SC, because of the significance of SCA. The trait GY under water deficit showed a more complex inheritance, with effects of additivity and dominance, i.e. significance for both GCA and SCA.

Considering the estimates of the effects of general combining ability (g_i) for yield components and grain yield for the water deficit condition (Table 2), the cultivars SEA 5 and IAC Alvorada showed positive results for GY and SW, indicating increments of 93.7 and 18.3 kg ha^{-1} in GY and 10.69 and 4.93 g in SW, respectively, in crossings they participated for this group of genotypes. This is an important result because the common bean breeding programs have focused on grain quality, in addition to high yield and resistance to pests and diseases, in order to meet the consumer market, which has preferred larger grains with high one thousand seed weight (Carbonell et al., 2010).The cultivar SEA 5 also had a positive effect for NSP under water stress, which makes these cultivars promising alternatives for selection in drought conditions. When considering full irrigation, IAC Alvorada remains remarkable with high value of GCA for GY and SW.

According to Cruz et al. (2004), the GCA estimates provide information on the concentration of predominantly additive gene in its effects and are highly useful in identifying parents to be used in breeding programs. Thus, the higher the estimated of GCA, the higher the frequency of favorable alleles, and thus the greater the increase in traits with a particular behavior (Krause et al., 2012).

It was also possible to observe that parents with higher GCA values for GY contributed to reduce PH, due to negative values of GCA for this trait under water stress. Besides, under full irrigation, SEA 5 and IAC Alvorada also presented negative effects of gi for PH. Moraes et al. (2010) also verified a reduction in the height of bean plants grown under water stress. Molina et al. (2001) observed a negative correlation between grain yield and plant height in black bean cultivars.

The cultivars BAT 477 and IAC Carioca Tybatã had negative effects of gi for GY and SW under water stress, suggesting the reduction of traits. These same cultivars showed positive effects of gi for PH for the two water conditions, suggesting an increase in the trait. Krause et al. (2012) also found a positive effect of gi for plant height for IAC Carioca Tybatã under field conditions. Gonçalves-Vidigal et al. (2008) registered the occurrence of additive and non-additive effects under irrigated conditions for plant height, number of pods per plant, number of seeds per plant, number of seeds per pod, average weight of 50 seeds and grain yield, besides reaching similar results for the cultivar IAC Carioca Tybatã, which showed negative effects of $\hat{g}_i$ for yield and weight of seeds and positive effects of g_i for plant height.

To achieve a successful breeding program it is necessary to have clear and well defined objectives, and by means of the effects of g_i, one can make selection with greater assurance of success, since yield is one of the most important traits for all crops, especially dealing with selection of genotypes under adverse environmental conditions, but which exhibit satisfactory yield. Thus, it was observed that the cultivar SEA 5 showed positive effects of g_i for GY, SW and NSP and the cultivar IAC Alvorada had a positive effect of gi for GY and SW, and these may be indicated to compose breeding blocks aimed at increasing these trait sunder drought stress (Table 2).

Estimates of the effects of specific combining ability ($\hat{s}_{ij}$), listed in table 3, assist in the selection of the best combinations. The selection should prioritize the most favorable estimates of $\hat{s}_{ij}$ that involve at least one parent which has shown favorable effect of GCA (Cruz et al., 2004). For the trait GY, considering the water deficit experiment, the combinations that showed positive effects for $\hat{s}_{ij}$ were: 1×3 (BAT 477 × IAC Alvorada), 3×1 (IAC Alvorada × BAT 477), 4×1 (IAC Carioca Tybatã × BAT 477), 2×3 (SEA 5 × IAC Alvorada), 3×2 (IAC Alvorada × SEA 5) and 2×4 (SEA 5 × IAC Carioca Tybatã), and almost all crosses have participation of parents SEA 5 and IAC Alvorada, which showed the highest values for GCA. These results indicate that these specific combinations increased the GY. Combinations 1×2 (BAT 477 × SEA 5), 1×4 (BAT 477 × IAC Carioca Tybatã), 4×2 (IAC Carioca Tybatã × SEA 5) and 4×3 (IAC Carioca Tybatã × IAC Alvorada) had negative effects of $\hat{s}_{ij}$ and thus tend to reduce the trait.

The best combinations for GY, in the condition of water stress, involved the cultivar IAC Alvorada, either as father in the crossing with SEA 5 (2×3 crossing), either as mother in the combination with BAT 477 (3×1 crossing), as presented in table 3. The high yield given by SEA 5 × IAC Alvorada under drought conditions was due to high estimation of GCA presented by the two cultivars, namely, high concentration of favorable alleles that enabled the development of a hybrid combination with a high mean for this trait.

In relation to NPP, the combinations that showed positive effects of $\hat{s}_{ij}$ under water restriction were: 1×2 (BAT 477 × SEA 5), 1×3 (BAT 477 × IAC Alvorada), 4×1 (IAC Carioca Tybatã × BAT 477) and 2×3 (SEA 5 × IAC Alvorada). These combinations are promising as to drought tolerance, since positive effects for NPP, in dry conditions, tend to minimize the reduction in GY. The NPP is a production component severely affected by drought (Nuñes Barrios et al., 2005; Sousa & Lima, 2010).

The effects of $\hat{s}_{ij}$ for dry matter (Table 3) pointed out that combinations 1×2 (BAT 477 × SEA 5), 2×3 (SEA 5 × IAC Alvorada), 3×2 (IAC Alvorada × SEA 5) e 2×4

Table 2. Estimates of the effects of general combining ability ($\hat{g}_i$) evaluated in four bean cultivars under drought stressor full irrigation for grain yield (GY), one thousand grain weight (SW), number of seeds per pod (NSP) and plant height (PH)

Cultivars	GY (kg ha^{-1})	SW (g)	NSP	PH (cm)
Drought stress				
1- BAT 477	-78.1	-8.26	-0.263	20.06
2- SEA 5	93.7	10.69	0.588	-22.55
3- IAC Alvorada	18.3	4.93	-0.075	-3.12
4- IAC CariocaTybatã	-33.9	-7.37	-0.25	5.61
Full irrigation				
Cultivars	**GY (kg ha^{-1})**	**SW (g)**	**NSP**	**PH (cm)**
1- BAT 477	18.1	-31.74	0.19	10.63
2- SEA 5	-102.5	-4.86	-0.0063	-20.06
3- IAC Alvorada	119.3	38.41	-0.281	-6.33
4- IAC CariocaTybatã	-34.9	-1.81	0.094	15.76

Table 3. Estimates of the effects of specific combining ability ($\hat{s}_{ij}$) resulting from diallel crosses between four bean cultivars under drought stressor full irrigation for grain yield (GY), number of pods per plant (NPP), dry matter of shoots (DMS) and stomatal conductance (SC)

Drought stress								
Combinations	**GY**		**NPP**		**DMS**		**SC**	
Parents: (A) × (B)	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**
1 ×2	-16.80	–	0.67	–	3.10	–	3.68	–
1 × 3	15.84	75.00	1.62	-0.15	-0.88	-1.17	38.11	-34.50
1 × 4	-13.50	34.00	-0.52	1.20	-0.94	-2.75	-20.02	-2.34
2 × 3	131.00	50.50	0.81	-0.35	0.61	1.59	-33.60	2.50
2 × 4	45.70	-97.00	-0.48	-1.25	4.01	-0.39	13.11	4.17
3 × 4	–	-194.6	–	-0.55	–	-0.008	–	17.15
Full irrigation								
Combinations	**GY**		**NPP**		**DMS**		**SC**	
Parents: (A) × (B)	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**	**(A×B)**	**(B×A)**
1 × 2	110.00	–	-0.19	–	4.78	–	7.60	–
1 × 3	315.20	-307.50	1.99	1.20	-0.28	-3.92	-14.14	-5.08
1 × 4	212.80	229.00	2.18	1.00	3.76	-8.75	6.60	-18.83
2 × 3	-44.20	-202.50	-0.07	-0.85	3.63	-1.00	-7.24	0.67
2 × 4	137.00	132.50	-0.53	0.10	-1.99	0.34	1.41	-18.33
3 × 4	–	176.70	–	1.05	–	1.04	–	2.98

Parents: 1-BAT 477, 2-SEA 5, 3-IAC Alvorada and 4-IAC Carioca Tybatã.

(SEA 5 × IAC Carioca Tybatã) presented positive values for GCA under drought stress and have the cultivar SEA 5 as a parent. There was a 33% decrease in dry matter of plants subjected to water deficit, which is consistent with the results presented by Gomes et al. (2000), who found a reduction in the dry matter of leaves, stems and pods as well as in leaf area of plants under water deficit.

Considering the stomatal conductance (SC) assessed between 9 am. and 11am. on the abaxial surface of the leaf, in bean subjected to drought at pre-flowering (Table 3), the combinations 1×2 (BAT 477 × SEA 5), 1×3 (BAT 477 × IAC Alvorada), 3×2 (IAC Alvorada × SEA 5), 2×4 (SEA 5 × IAC Carioca Tybatã), 4×2 (IAC Carioca Tybatã × SEA 5) and 4×3 (IAC Carioca Tybatã × IAC Alvorada) showed a positive effect of $\hat{s}_{ij}$ and, with this, a larger stomatal aperture and a consequent greater water loss by transpiration to the atmosphere, however, there is an increased CO_2 assimilation. All other combinations presented negative values of $\hat{s}_{ij}$ for SC, suggesting the partial stomatal closure, which according Taiz & Zeiger (2009) is one way in which plants can adapt physiologically to drought conditions. Pimentel et al. (1999) also verified the existence of genotypic differences for the trait in beans subjected to water stress. For irrigated conditions, negative effects of $\hat{s}_{ij}$ were showed only by the combinations 1×3 (BAT 477 × IAC Alvorada), 3×1 (IAC Alvorada × BAT 477), 4×1 (IAC Carioca Tybatã × BAT 477), 2×3 (SEA 5 × IAC Alvorada) and 4×2 (IAC Carioca Tybatã × SEA 5), suggesting smaller stomatal aperture.

4. CONCLUSION

In both water conditions, the presence of additive and non-additive effects controlling the traits evaluated indicates that the four parents used in the study contributed differently in the crossings they participated in.

The parents SEA 5 and IAC Alvorada are recommended for breeding programs aimed at drought tolerance, due to its general combining ability, considering grain yield.

The crossing SEA 5 × IAC Alvorada, under drought stress, results in higher grain yield considering the specific combining ability.

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