Combining ability of tropical maize inbred lines under drought stress conditions

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ABSTRACT

Among the environmental stresses, drought is considered the main source of maize grain yield instability in tropical areas. Anthesis-silking interval (*ASI*) is used as an efficient phenotypic index for water stress tolerance and has also been used in breeding programs aiming to increase yield stability under water stress. This phenotypic index is also an important tool to be used in cultivar development, in relation to the emergence of silk hairs, since the ASI is totally independent from the differences in genotype cycles. The objective of this study was to evaluate the genetic potential of six maize inbred lines from the Embrapa Maize and Sorghum breeding program, selected for drought tolerance by using grain yield. The F_1*'s* and reciprocals from a diallel crosses, plus three hybrids checks, were evaluated under two irrigated systems: well-watered conditions during all growth stage and water-stressed conditions where irrigation was suppressed during the flowering period. The means over the checks were 15% and 5% higher than the means of all F_1*'s* hybrids in the experiments under non-stress and stress conditions, respectively. Under water-stressed conditions, yield means were 45.6% and 40.4% low for the checks and F_1*'s*, respectively, when compared to well-watered condition. The results for mean grain yield showed a great potential for the genetic material used in the ecological condition studied. Under well-watered conditions, the F1's L1147 x L10.1.1; L6.1.1 x L8.3.1 and L1147 x L13.1.2 and the reciprocal cross L13.1.2 x L1147 presented the highest specific combining ability effect values. For both conditions, general combining ability effects of the inbred line L6.1.1 showed the highest value and the inbred lines L10.1.1 and L1147 the lowest ones. Under water stress, the specific combining ability effects were not significant among F_1*'s* and reciprocals, indicating similar performances for crossing combinations among the evaluated lines. The grain yield means of the checks were similar to the means of the F_1*'s* in both environments. Among the hybrid checks, the single cross presented a higher grain yield than the three-way and double-crosses hybrids, in both well-watered and under water-stress conditions.

KEY WORDS: *Zea mays* L., hybrids, water stress, tolerance, grain yield, general combining ability and specific combining ability effects.

INTRODUCTION

Genotypic selection for adaptation to differentiated water regimes is an important strategy in a breeding program. Thus, in an abiotic stress condition, drought for example, it is desirable to search for genotype evaluation and selection with better adaptation and tolerance to water constrains, as well as with high and stable productivity.

Among the abiotic stresses, drought is one of the major sources of grain yield instability of maize in tropical regions. DuPlessis and Dijkhuis (1967), Hall et al. (1982), Bolaños and Edmeades (1993), Durães et al. (1993, 1994, 1997, 1999, 2000a, 2000b) showed that when the drought stress occurs during flowering, the losses in grain yield can be higher than 50%. These losses may be a consequence of the reduction in the number of seeds set per plant due to flowering inhibition, failure in the fertilization and abortion of embryos (Westgate, 1986).

The stage between the emergence of silk hairs and the anther extrusion with pollen grain release, or days to silking and pollen shed, is known as the anthesis-silking interval (ASI). In maize, ASI is considered an efficient phenotypic index to evaluate the tolerance to drought stress, and has been widely used in the breeding programs aiming to increase the stability of grain yield under drought stress conditions (Durães et al., 1997; Labory et al. 1997). Low values of ASI are an indication of synchronism in the flowering time, which means an adaptation for better yield under drought condition, as a partial consequence of a high water potential during the flowering time. So, ASI may be a powerful tool to be used on the development of maize cultivars that are more adapted to drought stress, once it is independent on the mature differences between the genotypes (Bolaños and Edmeades 1993).

The diallel cross methodology gives the opportunity to calculate general and specific combining ability effects (Sprague and Tatum, 1942). According to Yordanov (1983), it is applicable in an advanced breeding stage when a small number of selected lines will remain to be tested. The diallel crosses, corresponding to all possible crosses among lines or other broad genetic base materials, have been largely utilized by plant breeders in order to better understand the nature of genes action in the control of traits of agricultural importance, and in the evolution (Kempthorne, 1961). Also is utilized by breeders in decisions related to the selection of characteristics of promising materials (Gardner and Eberhart, 1966), and in the comparison of relative magnitudes to the general combining ability of a lines group (Hayes and Johnson, 1939).

The aim of this study was to evaluate the genetic potential for grain yield of six maize inbred lines derived from a flint variety BR 105 from the Embrapa Maize and Sorghum drought tolerance breeding program, by comparing the F1's and reciprocal effects, produced from a diallel set of crosses under water stress condition.

MATERIAL AND METHODS

Field conditions: Field trials were conducted during the normal growing season (November- March) of 1999/2000, in a dark-red, alic latossoil, at the Embrapa Maize and Sorghum Research Center, in Sete Lagoas, MG, Brazil, located at 19°28' S, 44°15'08" E, at an elevation of 732 m, and in a savanna climate, type AW according to the Köeppen classification. The drought stress was imposed by a "veranico" period occurring during the summer months (January –February) in the early flowering time.

Genetic materials: Since the middle of 1990, maize breeders at the Embrapa Maize and Sorghum Research Center have started a drought tolerance breeding program using adequated source populations like BR 105 as a tropical, early cycle and flint type maize variety. Hundreds of selfed progenies were evaluate each winter for drought tolerance; selection was mainly based on an efficient phenotypic index, the anthesis-silking interval (ASI), for water stress tolerance. After several cycles of inbreeding selections and evaluations using the ASI parameter, two groups of lines were selected with no tolerance and tolerance to water stress conditions. For this study, six maize inbred lines were chosen to represent a group of tolerant and non-tolerant lines to drought stress (Durães et al., 1999, 2000a, 2000b). Fifteen single-cross hybrids and the reciprocals produced from a diallel set of crosses among these six inbreds, and three commercial hybrids, were used in this study (Table 1). Analysis for genotype performance was done using a water stress index based on yield under drought condition to identify the most tolerant progenies to the moisture stress imposed in the experiments. The water stress index (WSI) was calculated by the equation:

$WSI = \left(Y_W - Y_D\right)/\left(\bar{Y}_W - \bar{Y}_D\right)$, where Y_W and Y_D are genotype productions in well-watered and water-stress environments, and $\bar{Y}_W$ and $\bar{Y}_D$ are mean productions considered all genotypes in well-watered and water-stress environments, respectively. Thus, the best genotype would be the one with productivity above the general mean in stress condition and with WSI value less than one (WSI<1.0).

Experimental design: Two experiments were performed simultaneously in the field where the treatments were arranged in a complete randomized block design with two replications, and plots consisted of four rows, 4.0 m long and spaced by 0.9 m apart. The data were collected from the two center rows of 3.0 m each. The recommended amount of fertilizers ($8N{:}28P_2O_5{:}16K_2O$, 200 kg ha^{-1}) were applied (Embrapa, 1987). The two sets of experiments were differentiated by the irrigation system, where in one experiment the water was supplied during the whole culture cycle (I) and in the other the water was suppressed 10 days before and after the flowering time (II).

Biomass and grain yield: The vegetative and grain filling periods of each plot were evaluated before and after-anthesis stages, respectively (data not shown for flowering and other morphological and physiological evaluations). Grain yield data for all hybrids were collected from the subplots (each measuring 5.4 m^2) and the grain moisture was corrected for 13%.

Statistical analysis: General and Specific combining ability effects for grain yield were estimated using Method 3, Model I, of Griffing (1956a, 1956b), with the inbred lines treated as fixed effects. The data for the three check hybrids were computed separately from the diallel analysis. The Genes software (Cruz, 1997) was used to obtain the estimates.

RESULTS AND DISCUSSION

Mean grain yield (kg ha^{-1}) for the $F_{1's}$ and the hybrid checks evaluated in two environments with and without water stress are shown in Table 2. The coefficient of variation found for the experiment without stress was low, and the water-stressed coefficient was acceptable for grain yield. The mean of the check hybrids was high (12.5%) compared to the mean yield of the F1's. This can be explained by the low heterosis among the tolerant and non-tolerant lines compared with the superior yielding materials used as checks. However, some of the single crosses were as productive as the check hybrids in the stress environment, which indicates the good potential of the selected lines for hybrid development. The best yielding cross in the stress environment was between a low ASI L6.1.1 with a high ASI L1170 line.

Therefore, the F_1 L8.1.1 x L6.1.1. presented homeostasis effects with high yields in both environments. In the non-stress environment, the F1's hybrids presented grain yield means ranging from 5105 kg ha^{-1} (L6 x L4) to 3109 kg ha^{-1} (L3 x L5). Among the check hybrids, the mean varied from 5296 kg ha^{-1} (HS 93H) to 4147 kg ha^{-1} (BRS 2114). In the stress environment, mean grain yield among the F1´s hybrids vary from 3459 kg/ha (L1xL4) to 1487 kg/ha (L2xL1), and from 2899 kg/ha (HS 93H) to 2004 kg/ha (BRS 3060) for the check hybrids.

Variance analyses related to grain yield for the two experiments using different irrigation systems (with and without water suppression during flowering) are presented in Table 2. In the experiment carried out with sprinkler irrigation, the partitioning of the F1 hybrid mean squares showed highly significant effects ($P < 0.01$) for the general (GCA) and specific (SCA) combining ability. The significance of GCA means that at least one of the lines is different in relation to

Table 1. Characteristics of the inbred lines and check hybrids of maize. Sete Lagoas, MG, Brazil. September/2001.

Genotype		*Background*		Characteristics
Sigla	Name	Inbreeding/Cycle	Genetics	
		(Parental lines/ F1's e reciprocals)		
L1	L 1170	S8	Line	High ASI[1/]
L2	L 1147	S8	Line	High ASI
L3	L 13.1.2	S8	Line	Low ASI
L4	L 6.1.1	S8	Line	Low ASI
L5	L 10.1.1	S8	Line	Low ASI
L6	L 8.3.1	S8	Line	Low ASI
		(Hybrid checks)		
C1	HS 93H	Early maturity	SC	Experimental SC
C2	BRS 3060	Early	TWC	Commercial TWC
C3	BRS 2114	Early	DC	Commercial DC

[1/] ASI (Anthesis-silking interval)

Table 2. Variance component for grain yield (kg/ha) for F1's and reciprocals of 6 maize lines and 3 hybrids checks, tested over stress and non-stress water conditions. Sete Lagoas, MG, Brazil. September/2001.

SOURCE	GL	MEAN SQUARE	
		WELL WATERED	WATER STRESSED
Block	2		
Treatment	32	952718.6 [2/]	757111.8 [2/]
Among F1's	29	873796.9 [2/]	779476.6 [2/]
GCA	5	3195047.5 [2/]	2781714.7 [2/]
SCA	9	735009.3 [2/]	402261.4 ns
Reciprocal Effect	15	183319.5 ns	338393.0 ns
Among checks	2	995339.1 [1/]	752655.9
Check Vs. F1's	1	3156205.1 [2/]	117444.0 ns
Error	64	231161.6	279037.3

[1/] Significant at 0.05 and 0.01 levels of probability; respectively. NS (non significant).

the favorable gene concentration for grain yield, regardless the type of dominance of these genes or alleles (Vencovsky and Barriga, 1992). Significant differences among hybrids were detected, but not for the reciprocals (no maternal effect). Among the check hybrids, the interaction checks x F_1's ($P < 0.01$) and for the check hybrids ($P< 0.05$) were detected, but not for the reciprocals (no maternal effect). The significance of the mean squares associated to the effects of hybrids and SCA evidenced that the lines did not constitute a homogeneous group and that there is a manifestation of heterosis The environment index, or water stress index (WSI) is show in Figure 1. According to the yield under water stress and the environment index the crosses can be located into four groups. As shown in this figure, the third quadrant, characterized by highs WSI value and yield, was composed of 5 F1's and 1 check, and were classified as high yieldings and responsive to drought.

Experiment 1 – With full irrigation during all cycle of the plant

The inbred L6.1.1 had a high GCA effect (602.8), while the inbreds L10.1.1 (-457.26) and L1147 (-228.10) had negative GCA effects (Table 3).

Thus, line L 6.1.1 selected for low ASI, an indication for tolerance to drought, was found to contribute to the increase in the production of grain yield in its crosses. On the other hand, line L1147, with a high ASI - an indication for non-tolerance to drought - contributed to the reduction in grain yield in its hybrids. The best hybrids combinations with high SCA effects were L1147 x L10.1.1 (492.04), L6.1.1 x L8.3.1 (349.66) and L1147 x L13.1.2 (305.03), and L1170 x L1147 (-334.80) with the lowest and negative SCA effects. Knowledgment on SCA is very important for hybrid development and interpretation, and use of the inbred lines. Normally, breeders are most interested in hybrid combinations with SCA effects more favorable to the evolvement of at least one of the two parents with high GCA effects (Cruz and Regazzi, 1994). Thus, for this study the $F_{1's}$ L 6.1.1 x L 8.3.1, L 6.1.1 x L 10.1.1 and L 1147 x L 13.1.2 would be the most favorable crosses.

Experiment 2 – With water stress during flowering time

With drought stress during the flowering time, the statistic analysis (Table 2) showed significant effects ($P< 0.01$) for treatments, hybrids, and check hybrids ($P< 0.05$). However, there were no significant difference among the reciprocals, meaning a non maternal effect for this set of lines use in this study. GCA effects showed to be highly significant ($P< 0.01$), while SCA effects were not significant, indicating a similar performance to lines in hybrid combinations. In this water stress environment, these lines did not present a high degree of complementation among them in relation to allele frequency in the locus with some degree of dominance. (Vencovsky and Barriga, 1994).

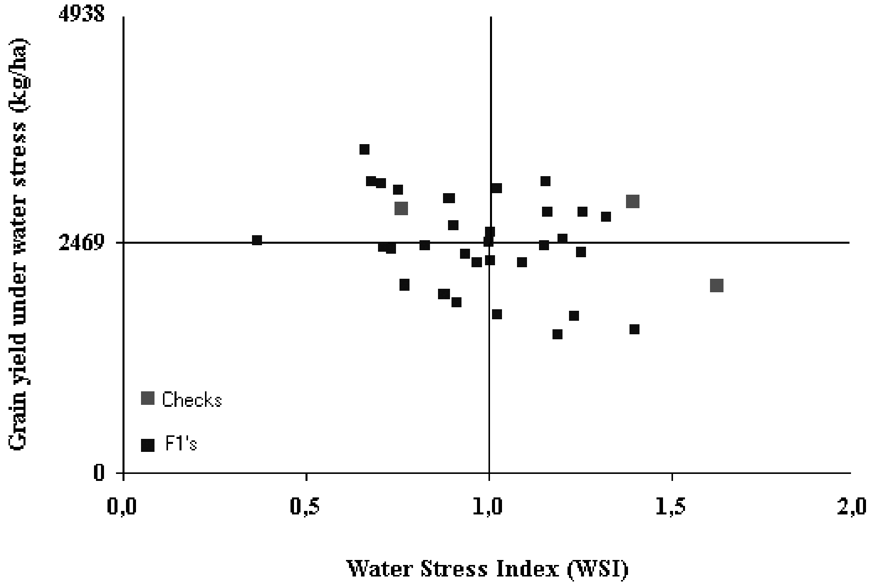

Figure 1. Grain yield (kg/ha, at 13% moisture) as a function of environment index (or, *Water Stress Index – WSI*) of maize checks and F1's, evaluated in two experiments with and without water stress. Sete Lagoas, MG, Brazil. September/2001.

Estimates of the GCA effects for grain yield are presented in Table 4. Inbred line L6.1.1 had a high GCA (551.5) effect, while lines L10.1.1 (-381.75) and L1147 (-293.43) presented the lowest and more negative values, contributing to the increase and reduction, respectively, in the yield of its hybrids. As the calculated mean square for SCA was not significant, there is no need to discuss the estimated parameters for specific combining ability effects for the lines.

Experiments 1 and 2:

GCA effects differed according to the stress and non-stress conditions. Inbred line L1 had high GCA effects in a water stress environment, but not (negative GCA value) in a non-stress environment. Therefore, inbred L4 had high GCA effects while inbreds L2 and L5 had low GCA effects at both environments.

SCA effects also differed according to the stress and non-stress environments. The hybrid combination L3 x L5 had a high SCA effect in a stress environment but not (negative SCA value) in a non-stress environment. However, the cross L1 x L2 had low and negative SCA effects at both environments.

For the three check hybrids the double cross hybrid (BRS 2114) presented less drought effect on yield than the three-way cross (BRS 3060) when grown at the two environments.

Yield trait on maize related to water stress is under genetic control and these inbred lines differ in this trait.

The magnitude of the GCA mean squares were much larger than the SCA effects, indicating that additive effects were more important than dominance effects.

For grain yield the means over all checks were 83% and 63% higher than the means of the F_1's hybrids in the experiments under well watered and with water stressed conditions, respectively. The yield means with water stress were 45.6% and 40.4% reduced for the checks and for the F_1's, respectively, when compared to non-water stress.

CONCLUSIONS

Some of the single crosses were as productive as the check hybrids in the stress environment indicating the high potential of the selected lines for hybrid development.

The CGA effects were more important than SCA effects for this set of lines.

The highest GCA estimates effects were related to line L6.1.1, while lines L1147 and L10.1.1 had low GCA effects for grain yield in both experiments.

SCA mean square showed no significance for the

Table 3. Estimates of GCA effects (diagonal) and SCA effects (above diagonal) of 6 lines of maize and its reciprocals (below diagonal) for grain yield (kg/ha) evaluated over non-stress water condition. Sete Lagoas. MG. Brazil. September/2001.

Fem.\Male.	L1	L2	L3	L4	L5	L6
L1- L1170	**(-79.92)**	-334.80	213.35	-197.51	141.21	177.75
L2- L1147	-44.70	**(-228.10)**	305.03	-206.69	492.04	-255.57
L3- L13.1.2	110.35	397.15	**(185.10)**	-28.94	-467.16	-22.27
L4- L6.1.1	141.50	2.15	-75.50	**(602.82)**	83.48	349.66
L5- L10.1.1	82.85	-15.20	-276.20	-162.85	**(-457.26)**	-249.56
L6- L8.3.1	-268.30	228.50	-141.70	-50.65	62.65	**(-22.65)**

Table 4. Estimates of GCA effects (diagonal) and SCA effects (above diagonal) of 6 lines of maize and its reciprocals (below diagonal), for grain yield (kg/ha), evaluated over stress water condition. Sete Lagoas. MG. Brazil. September/2001.

Fem.\Male.	L1	L2	L3	L4	L5	L6
L1- L1170	**(40.21)**	-495.33	89.06	228.25	-58.30	236.32
L2- L1147	221.85	**(-293.43)**	185.20	130.39	121.29	58.46
L3- L13.1.2	-269.65	262.15	**(180.39)**	-261.43	181.32	-194.15
L4- L6.1.1	181.65	-274.85	126.85	**(551.50)**	-120.44	23.24
L5- L10.1.1	-365.15	355.50	41.65	138.70	**(-381.75)**	-123.86
L6- L8.3.1	-304.00	298.50	-90.00	-192.20	-153.15	**(-96.93)**

hybrids in the experiment with stress.

Hybrids L1147 x L10.1.1 and L1147 x L13.1.2 presented the highest SCA effects in the non-stress environment.

The check grain yield means were greater than the means of the hybrids in both environments.

RESUMO

CAPACIDADE DE COMBINAÇÃO DE LINHAGENS DE MILHO TROPICAL SOB CONDIÇÕES DE ESTRESSE HÍDRICO

Dentre os estresses ambientais, seca é a maior fonte de instabilidade de rendimento de grãos de milho em áreas tropicais. Para milho, IFMF (intervalo entre florescimentos masculino e feminino, em dias) é considerado um eficaz indicador fenotípico de tolerância ao déficit hídrico, e vem sendo utilizado em programas de melhoramento que tem como objetivo aumentar a estabilidade na produção sobre condições de déficit hídrico. Neste contexto, o IFMF torna-se uma potente ferramenta de diagnóstico no desenvolvimento de cultivar, em relação à emissão de estilo-estigma em si, uma vez que o IFMF é totalmente independente das diferenças de maturação entre os genótipos. O objetivo desse trabalho foi o de avaliar o potencial genético para rendimento de grãos de seis linhagens de milho com alto grau de endogamia, oriundas do programa de melhoramento visando tolerância à seca, da Embrapa Milho e Sorgo, e comparar seus F1's e recíprocos com outros três genótipos-testemunhas melhorados, em dois sistemas irrigados (com irrigação plena durante o ciclo e com supressão de irrigação durante o florescimento). No experimento com irrigação plena, o rendimento médio entre os genótipos-testemunhas foi 15,0% superior ao rendimento médio dos híbridos F1's, e de 5,0% superior, no experimento com supressão de água no florescimento. Em média, no experimento com supressão de água no florescimento, o rendimento de grãos foi reduzido de 45,52% e de 40,41%, para genótipos-testemunhas e híbridos F1's, respectivamente, em relação ao experimento com irrigação plena. Os dados médios do caráter rendimento de grãos revelam um potencial do material genético em teste nas condições ecológicas estudadas. Em irrigação plena, o efeito da capacidade específica de combinação de linhagens, resultou nas melhores combinações para F1's (L1147xL10.1.1; L6.1.1xL8.3.1; L1147xL13.1.2 e o recíproco L13.1.2xL1147). O efeito da CGC, para o caráter produção de grãos, mostrou que a linhagem L6.1.1 apresentou maior valor de CGC, em ambos os experimentos (com irrigação plena e com supressão de irrigação no florescimento), e as linhagens L10.1.1 e L1147, baixos valores de CGC. Sob estresse hídrico imposto no florescimento, a não significância do efeito de CEC entre F1's e também para efeito de recíprocos, mostrou performance similares de combinação entre as linhagens estudadas. A média de rendimento de grãos dos genótipos-testemunhas foi pouco superior à média dos F1's, nos dois ambientes.

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