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Original scientific paper

MORPHO-PHYSIOLOGICAL COMBINING ABILITY AMONG TROPICAL AND TEMPERATE MAIZE GERMPLASM FOR DROUGHT TOLERANCE

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Erdal S., M. Pamukcu, A. Ozturk, K. Aydinsakir, O.Yilmaz Dogu (2016): *Morpho-physiological combining ability among tropical and temperate maize germplasm for drought tolerance.*- Genetika, vol 48, no. 3, 1053 – 1066.
In this study, seven maize inbred lines representing different tropical, drought tolerant populations and two adapted temperate maize inbred lines were crossed in a half-diallel mating design to determine combining abilities. The genotypes were tested in well-watered (WW) and managed water stressed (WS) conditions in 2013 and 2014. General combining ability (GCA) and specific combining ability (SCA) mean squares were significant for all investigated traits and demonstrated both additive and non-additive genetic effects in both conditions. Higher desired leaf rolling, leaf senescence, stomatal conductance and leaf chlorophyll content GCA effects of tropical inbreds under WS conditions showed the presence of the valuable allels related to drought stress. SCA analysis revealed that the best hybrids for water use efficiency and irrigation water use efficiency were tropical x temperate crosses. Stress tolerance index and drought resistance index identified G5 x G9, a tropical x temperate hybrid, as the most tolerant hybrid to drought. Our study suggests that tropical drought tolerant germplasm has the potential to contribute useful genetic diversity to temperate maize breeding programs.
Keywords: diallel analysis, drought tolerance, maize, temperate, tropical

INTRODUCTION

Water stressed environments are projected to worsen in the future because of climate change (IPCC, 2007). Global warming is expected to account for about 20 percent of the global increase in water scarcity this century. It is predicted that global warming will alter precipitation patterns around the world, melt mountain glaciers, and worsen the extremes of droughts and floods (ANONYMOUS, 2015).

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Drought stress effects negatively maize grain and silage quality and quantity worldwide. Developing drought tolerant or water use efficient maize hybrids has been an effective approach for coping with drought stress (BÄNZIGER *et al*., 2000; ASHRAF *et al*., 2010).

Drought stress can be severe in tropics, and hence several populations have been developed by The International Maize and Wheat Improvement Center (CIMMYT) to improve drought tolerance in tropical maize germplasm. (FISCHER *et al*., 1989; BOLANOS and EDMEADES, 1993; BYRNE *et al*., 1995; EDMEADES *et al*., 1999). Studies showed that inbred lines derived from drought tolerant recurrent selection populations were better performing in water stressed environments than conventional tropical maize populations (EDMEADES *et al*., 1996; BECK *et al*., 1996).

Drought stress in areas where temperate maize is grown is getting becoming more frequent and is intensifying. Improved drought tolerance of high yielding maize hybrids will help to stabilize and sustain maize productivity. Drought tolerant tropical maize germplasm developed by CIMMYT may be a good source of diversity for drought stress tolerance in temperate areas. Also, tropical germplasm may broaden the genetic base of temperate maize germplasm for other traits (ALBRECHT and DUDLEY, 1987; FAN *et al*., 2010; TALLURY and GOODMAN, 1999; NELSON and GOODMAN, 2008; GOODMAN, 1999; GOODMAN, 2004).

Information on combining ability based on morpho-physiological parameters between tropical and adapted temperate maize germplasm may be useful to identify genetic diversity in exotic tropical germplasm for use in temperate maize breeding.

The objectives of this study were to: i) Analyze combining ability among exotic tropical germplasm and adapted temperate Turkish maize inbreds under water stress and non-stress conditions for morpho-physiological parameters, ii) determine suitable parents for further breeding research and applied breeding, iii) identify hybrids that are tolerance to drought based on the investigated traits.

MATERIALS AND METHODS

Germplasm

Seven tropical drought tolerant maize inbred lines and two adapted temperate lines were used in the study. The tropical inbred lines were obtained from CIMMYT, and were derived from the Drought Tolerant-Yellow (DTP-Y) population (lines G1, G2, G4, G6 and G7), the Drought Tolerant-White (DTP-W) (line G3) and La Posta Sequia (LPS) (line G5) recurrent selection populations. Two well-adapted, commercial, temperate inbreds from Stiff-Stalk (TK56) and Lancaster (TK72) backgrounds were used in the study. The nine inbred lines were crossed in a half- diallel design in 2011/12 to obtain 36 crosses excluding reciprocal crosses. Two popular high yielding commercial hybrids, P31A34 and DKC6589 were used as checks in the experiments.

Experiments

The study was conducted at Bati Akdeniz Agricultural Research Institute’s Field Crops Department, Antalya (36052’N, 30045’E), Turkey over two years (2013 and 2014). The climate of the region is typically Mediterranean, i.e. mild and rainy in winter and dry and hot in summer. Temperature and precipitation data during the period of the study was shown in Figure 1. During the reproductive stage of the crop (June to August), negligible precipitation was recorded in both years of experimentation resulting in highly favorable conditions in which to screen under drought stress. The soil of the research station is clay–loam in texture, unsalted and rich in calcium carbonate and alkali.

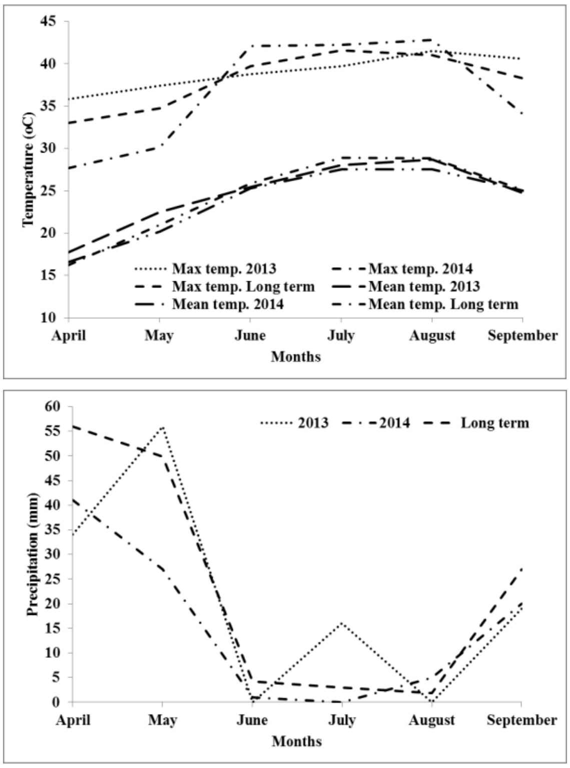

Figure 1. Temperature and precipitation data during the period of the study

A total of 47 entries (36 single crosses, 2 commercial checks and 9 inbred lines were evaluated under water stressed (WS) and well-watered (WW) conditions in adjacent experiments. Reproductive stage drought stress was induced in the WS experiments by withdrawing irrigation approximately 2-3 weeks before flowering until harvest as suggested by BÄNZIGER *et al*. (2000) and BRUCE *et al*. (2002). Soil water content in both WS and WW experiments was monitored using a gravimetric method (BLACK, 1965). The moisture changes in the 0-90 cm soil depth of the experiments in 2013 and 2014 are shown in Figure 2. Efforts were made to maintain field water holding capacity in the WW experiments through irrigation.

Experiments were designed as Randomized Complete Blocks with three replications. Plots consisted of two rows, 5 meters long with row spacing of 0.7 meters. Border rows were included to eliminate border effects. After emergence, plants were thinned to approximately 0.2 m interplant density. Fertilization and plant protection measures were undertaken according to local recommendations.

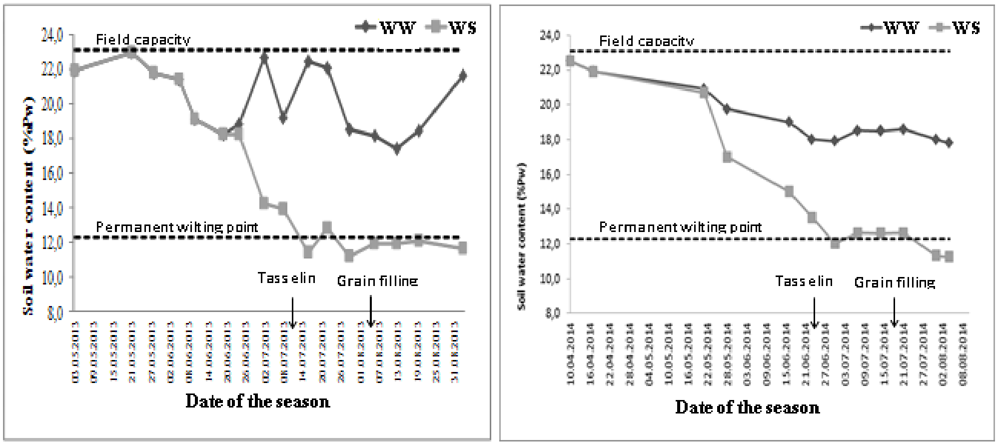

Figure 2. Change in soil moisture content prior to irrigation in WW and WS experiments obtained in 2013(left) and 2014 (right).

Data Analysis

The traits evaluated in the research were measured according to BÄNZIGER *et al.* (2000) and UPOV (2009). Plots were scored on a scale from 1 to 5 for leaf rolling (LR): where 1 = unrolled, turgid; 2 = Leaf rim starts to roll; 3 = leaf has the shape of a "V"; 4 = rolled leaf rim covers part of leaf blade; and 5 leaf is rolled tightly like an onion. Leaf senescence (LS) was determined based on a scale from 1 to 10, dividing the percentage of the estimated total leaf area that is dead by 10. The LS scores were 1) 10% dead leaf area 2) 20% dead leaf area 3) 30% dead leaf area 4) 40% dead leaf area 5) 50% dead leaf area 6) 60% dead leaf area 7) 70% dead leaf area 8) 80% dead leaf area 9) 90% dead leaf area 10) 100% dead leaf area. A portable leaf porometer (Decagon devices, Inc, SC-1) was used to measure stomatal conductance (SC). SC readings were performed on fully matured youngest leaves of the five representative plants per plot. Leaf chlorophyll content (LC) was measured with a portable Chlorophyll Meter (SPAD 502 Plus). Water use efficiency (WUE) is defined as grain yield (Y, kg ha^{-1}) divided by the water use (WU, mm) during the growing season while irrigation water use efficiency (IWUE) is defined as the ratio of yield (Y, kg ha^{-1}) to the amount of irrigation water (I, mm) applied throughout the season:

$WUE = Y/WU$

$IWUE = Y/I$

Analysis of variance was performed on data from 2013 and 2014 for morpho-physiological traits in WW and WS experiments. Years were considered as environments in the analyses and checks were excluded from the diallel analysis. A SAS program developed by ZHANG *et al.* (2005) was used for Griffing's diallel method 2 model 1 (GRIFFING, 1956) analysis. In the model, parents which were treated as fixed effect and their half-diallels (reciprocal crosses excluded) were used.

Drought Resistance Index (DI) (LAN, 1998) and Stress Tolerance Index (STI) (FERNANDEZ, 1992) indices were computed using Excel files.

$STI = (Ys \times Yp)/(\bar{Y}p^2)$

$DI = (Ys \times (Ys/Yp))/\bar{Y}s$

In the above formulas, Y_s, Y_p, $\overline{Y}s$ *and* $\overline{Y}p$ represent the trait under stress (WS), trait under well watered (WW) for each genotype and experiment trait means in WS and WW conditions for all genotypes respectively.

RESULTS AND DISCUSSION

Results of the combined analysis of variance for leaf rolling (LR), leaf senescence (LS), stomatal conductance (SC) leaf chlorophyll content (LC), water use efficiency (WUE) and irrigation water use efficiency (IWUE) obtained from WW and WS experiments were shown in Table 1. According to the analysis, highly significant differences (P<0.01) were determined amongst genotypes for all investigated traits in both condition's. The analysis revealed that environments (years) were significant for both experiments except for LR in the WS experiments and LC in WW experiments. Genotype by environment interaction was significant in both WW and WS experiments. General combining ability (GCA) effects of the inbreds and specific combining ability (SCA) of the hybrids were found to be highly significant (P<0.01) for all traits in both experiments and demonstrated the presence of both additive and non-additive effects. The magnitude of the GCA mean square and SCA mean square revealed the direction of gene action for the investigated traits. According to the ratio of the GCA/SCA mean square results, larger additive effects were determined for LS and to an extend LR compared to other traits. The especially large GCA/SCA mean square of LS under drought conditions points out high levels of heritability. LS is an easy, fast and cost efficient trait for a breeder to identify genotypes to drought. It was reported that there is a relationship between LS and grain yield under grain-filling stress (BÄNZIGER *et al.*, 2000). Therefore selection for delayed leaf senescence (stay-green) could be useful for drought tolerance. Secondly, the GCA/SCA mean square of LR was 2.17 and 5.03 in WW and WS experiments respectively, suggesting additive gene action for this trait as well. Non-additive gene action was detected for WUE (0.82) and IWUE (0.79) in WS experiment (Table 1).

Table 1. Analysis of variance for leaf rolling, leaf senescence, stomatal conductance, Leaf chloropyll content, water use efficiency and irrigation water use efficiency obtained from WW and WS conditions

Source	**Leaf rolling (1-5)**		**Leaf senescence (1-10)**		**Stomatal conductance (umolH2O $m^{-2}s^{-1}$)**		**Leaf chloropyll content (SPAD)**		**Water use efficiency (mm/kg/ha)**		**Irrigation water use efficiency (mm/kg/ha)**	
	WW	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
Genotype (Gen)	1.17**	1.42**	6.61**	20.22**	10000.57**	6020.71**	58.27**	44.56**	167.80**	61.57**	266.40**	415.14**
Environment (Env)	1.48**	0.37	46.46**	182.53**	7151.80**	1351.62**	5.15	352.04**	21.34*	2058.30**	124.71**	16937.40**
Gen x Env	0.36**	0.61**	2.79**	1.47**	11200.38**	6915.04**	20.35**	25.78**	7.64**	15.62**	9.77**	125.90**
GCA	2.08**	4.13**	26.60**	92.60**	25875.35**	11784.38**	149.87**	57.52**	248.62**	52.43**	376.57**	341.91**
GCA x Env	2.95**	1.18**	5.55**	2.22*	24232.81**	5122.07**	15.73	18.10	16.83**	10.14**	19.32**	75.82**
SCA	0.96**	0.82**	2.17**	4.14**	6476.50**	4739.89**	37.92**	41.68**	149.84**	63.60**	241.92**	431.41**
SCA x Env	0.34**	0.48**	2.18**	1.30*	8304.28**	7313.48**	21.38**	27.49**	1.58*	16.84**	7.65	137.06
GCA / SCA	2.17	5.03	12.25	22.36	4.0	2.49	3.95	1.38	1.66	0.82	1.56	0.79
CV (%)	28.70	18.85	18.97	14.11	5.86	8.77	6.21	7.90	15.76	20.97	15.59	21.40
Mean	1.36	2.41	2.27	6.56	241.90	116.07	53.31	41.80	11.94	5.09	15.05	13.36

*.**: statistically significant at 0.05 and 0.01 level respectively

The 2013, 2014 and mean GCA results of the nine inbreds are presented in Table 2, Table 3 and Table 4. According to the mean leaf rolling GCA effects, two tropical inbred lines (G7 and G5) and a temperate line G9 showed negative and significant GCA effects under WW conditions. On the other hand, G5, G1, G2 and G9 gave desired negative GCA effects in WS experiment. In particular, G5 and G9 showed good performance in both conditions. Leaf senescence (LS) GCA effects revealed that tropical inbred lines performed better compared to temperate inbred lines under drought stressed conditions, especially the G2, G3, G4, G5 and G6 genotypes. It was reported by previous researchers that LS trait has positive relationships with grain yield under drought stress (BÄNZIGER *et al*., 2000; ARAUS *et al*., 2012; EDMEADES, 2013). Therefore, GCA results of the LS indicated that tropical drought tolerant germplasm may carry unique alleles for drought tolerance.

Table 2. GCA effects for leaf rolling and leaf senescence obtained from WW and WS conditions

	Leaf rolling (1-5)						Leaf senescence (1-10)					
	2013		2014		Mean		2013		2014		Mean	
Inbred	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
G1	-0,01	-0,25**	-0,15	-0,16*	-0.08	-0.21**	-0,01	1,02**	0,47**	0,45**	0.23*	0.74**
G2	-0,07	-0,19*	0,09	-0,11	0.01	-0.15*	-0,56**	-0,43**	0,07	-0,36*	-0.24*	-0.40*
G3	0,17**	0,35**	0,49**	0.44**	0.33**	0.40**	0,11	-0,92**	0,04	-0,91**	0.08	-0.91**
G4	0,26**	0,11	0,12	0.20**	0.19**	0.15*	-0,59**	-1,80**	-0,38**	-1,52**	-0.48**	-1.66**
G5	-0,10**	-0,29**	-0,12	-0.17*	-0.11*	-0.23**	-0,56**	-0,62**	-0,28**	-1,18**	-0.42**	-0.90**
G6	0,08*	-0,01	-0,08	-0.26**	-0.005	-0.13*	-0,62**	-0,56**	-0,38**	-0,70**	-0.50**	-0.63**
G7	-0,26**	-0,31**	-0,21*	0.16*	-0.23**	-0.07	-0,68**	0,35*	-0,56**	0,58**	-0.62**	0.46**
G8	0,14**	0,59**	0,01	0.20**	0.07**	0.40**	1,59**	1,63**	0,86**	2,12**	1.22**	1.87**
G9	-0,20**	-0,01	-0,15	-0.29**	-0.17**	-0.15*	1,32**	1,32**	0,16*	1,52**	0.74**	1.42**

*.**: statistically significant at 0.05 and 0.01 level respectively

Table 3. GCA effects for stomatal conductance and leaf chlorophyll content obtained from WW and WS conditions

	Stomatal conductance (umolH2O $m^{-2}s^{-1}$)						Leaf clorophyll content (SPAD)					
	2013		2014		Mean		2013		2014		Mean	
Inbred	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS	WW	WS
G1	11,28**	-2,54	-16,8**	-11,11**	-2.76	-6.82	1,04	1,55*	1,94**	-0,41	1.49**	0.57
G2	0,96**	-3,14	-26,05**	10,12**	-12.54*	3.49	-3,14**	-0,99	-3,01**	-1,56**	-3.08**	-1.28**
G3	9,77**	16,67**	-11,17**	9,16**	-0.70	12.92**	0,27	0,91	-0,08	1,60**	0.09	1.25*
G4	-74,02**	-17,62**	16,93**	4,21**	-28.55**	-6.70	-1,56*	0,28	-0,20	0,43	-0.88*	0.35
G5	29,19**	32,40**	9,62**	11,94**	19.40**	22.17**	-0,04	-0,54	-1,33**	-0,54	-0.68	-0.54
G6	-20,86**	18,32**	-30,86**	7,20**	-25.86**	12.76**	-0,92	0,26	-0,27	-0,61	-0.60	-0.17
G7	26,59**	-17,88**	30,05**	1,01 ns	28.32**	-8.44	0,89	1,03	1,45**	1,52**	1.17**	1.27*
G8	14,46**	-2,53	-1,89	-25,46**	6.28	-13.99**	1,03	-1,19	0,57	0,53	0.80	-0.33
G9	2,64**	-23,68**	30,17**	-7,07**	16.41**	-15.37**	2,44**	-1,30*	0,94**	-0,95	1.69**	-1.13*

*.**: statistically significant at 0.05 and 0.01 level respectively

Stomatal conductance (SC), is the measure of the rate of passage of carbon dioxide (CO_2) or water vapor through the stomata of the leaf (ANONYMOUS, 2010). Plants under drought stress tend to close their stomata to decrease water lose (CHAVES *et al*., 2009; ARVE *et al*., 2011). However, for an effective photosynthesis there must be CO_2 pass through the stomata and therefore stomata must be open under drought stress. BENESOVA *et al.* (2012) showed that tolerant maize genotypes had higher SC values than sensitive genotypes. According to SC GCA results, tropical germplasm had generally higher positive and significant GCA effects than temperate inbred lines (Table 3), especially the G3 and G6 genotypes under drought stress and G5 in both conditions. These three inbred lines, especially G5 which represents La Posta Sequia (LPS) could be good donors for temperate maize breeding to drought.

Leaf chlorophyll content (SPAD) GCA effects were given in Table 3. According to the results G1 and G9 inbred lines had positive and significant values in WW conditions, while G3 had positive and significant (mean values) values in WS. Besides, G7 had positive and significant GCA effects in both conditions. Since higher SPAD values, is thought to be a good secondary trait for drought tolerance (KAMARA *et al*., 2002; ARAUS *et al*., 2012; GEKAS *et al*., 2013) it can be said that G7 and G3 tropical inbred lines can be selected for improving temperate maize tolerance level to drought.

Table 4. GCA effects for water use efficiency and irrigation water use efficiency obtained from WW and WS conditions

	Water use efficiency (mm/kg/ha)						**Irrigation water use efficiency (mm/kg/ha)**					
	2013		**2014**		**Mean**		**2013**		**2014**		**Mean**	
Inbred	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
G1	1,99**	0,70**	1,57**	0,69**	1.78**	0.70	2,34**	1,62**	2,22**	1,88**	2.28**	1.75
G2	-1,15**	-,042**	-1,34**	0,22	-1.24**	-0.09	-1,35**	-0,97**	-1,69**	0,59	-1.52**	-0.19
G3	-2,21**	-0,65**	-1,38**	-0,25	-1.80**	-0.45	-2,60**	-1,52**	-1,75**	-0,67	-2.18**	-1.09
G4	-3,03**	-0,63**	-2,71**	-1,37**	-2.87**	-1.00*	-3,57**	-1,46**	-3,58**	-3,72**	-3.58**	-2.59*
G5	1,17**	0,10	0,02	1,42**	0.60*	0.76	1,38**	0,23	0,09	3,84**	0.74*	2.04
G6	-2,12**	-0,78**	-0,60*	-1,86**	-1.36**	-1.32**	-2,50**	-1,81**	-0,87*	-5,04**	-1.68**	-3.43**
G7	-0,53	-0,61**	0,64*	-0,47*	0.06	-0.54	-0,62	-1,43**	0,77*	-1,28*	0.08	-1.35
G8	3,03**	1,18**	1,99**	0,28	2.51**	0.73	3,56**	2,75**	2,55**	0,77	3.06**	1.76
G9	2,86**	1,11**	1,81**	1,34**	2.33**	1.22**	3,35**	2,58**	2,25**	3,62**	2.80**	3.10*

*.**: statistically significant at 0.05 and 0.01 level respectively

According to water use efficiency (WUE) and irrigation water use efficiency (IWUE) GCA results G8 and G9 adapted temperate maize inbred lines and G1 and G5 tropical inbreds gave higher GCA effects (Table 4). Especially temperate inbreds showed good performance due to the adaptation and higher grain yield potential as WUE and IWUE calculated based on grain yield.

Specific combining ability (SCA) of the best five combinations in WW and WS conditions obtained in 2013, 2014 and combined years were presented in Table 5 and 6. Hybrid combinations that gave desired SCA effects in both years were underlined. According to the LR results, G3xG6 (tropical x tropical) hybrid combination had the highest mean SCA effect in WW conditions.

Table 5. SCA effects for leaf rolling (LR), leaf senescence (LS) and stomatal conductance (SC) of the best five hybrid combinations

	LR		LS		SC	
Years	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
2013	G3xG4 (-0.71**)	G2xG7 (-0.87**)	G8xG9 (-1.92**)	G2xG6 (-1.72**)	G5xG8 (52.4**)	G3xG5 (90.1**)
	G4xG8 (-0.68**)	G4xG9 (-0.81**)	G1xG5 (-1.11**)	G2xG7 (-1.30**)	G1xG9 (51.3**)	G6xG8 (71.8**)
	G3xG6 (-0.53**)	G5xG7 (-0.81**)	G7xG8 (-0.55**)	G1xG4 (-1.26**)	G3xG9 (50.6**)	G1xG6 (57.1**)
	G6xG8 (-0.50**)	G4xG8 (-0.78**)	G2xG3 (-0.56**)	G5xG6 (-1.20**)	G2xG7 (41.1**)	G3xG8 (51.2**)
	G2xG4 (-0.47**)	G3xG8 (-0.66*)	G2xG4 (-0.53*)	G2xG5 (-0.99*)	G1xG5 (34.4**)	G5xG6 (48.5**)
2014	G3xG6 (-0.83**)	G2xG4 (-0.54*)	G4xG8 (-1.33**)	G1xG6 (-1.49**)	G4xG9 (110.05**)	G1xG7 (64.6**)
	G1xG3 (-0.44)	G4xG5 (-0.48*)	G6xG8 (-1.00**)	G5xG7 (-1.46**)	G2xG9 (103.09**)	G1xG8 (64.6**)
	G2xG6 (0.44)	G1xG7 (-0.45**)	G7xG3 (-0.81**)	G4xG7 (-1.12*)	G6xG9 (102.08**)	G3xG9 (47.90**)
	G3xG9 (0.43)	G1xG8 (-0.39)	G2xG9 (-0.76**)	G5xG9 (-1.06*)	G6xG8 (77.5**)	G2xG8 (46.03**)
	G4xG5 (0.43)	G3xG7 (-0.38)	G3xG9 (-0.73**)	G1xG4 (-1.00)	G5xG8 (52.03**)	G1xG6 (42.6**)
Mean	G3xG6 (-0.68**)	G4xG8 (-0.63**)	G1xG5 (-0.74*)	G1xG4 (-1.14*)	G4xG9 (64.47**)	G1xG6 (49.86**)
	G4xG5 (-0.44*)	G2xG7 (-0.52*)	G7xG8 (-0.71*)	G5xG7 (-1.12*)	G5xG8 (52.23**)	G1xG8 (41.37**)
	G2xG4 (-0.39*)	G5xG7 (-0.45*)	G2xG9 (-0.60)	G2xG6 (-1.03*)	G6xG8 (50.24**)	G3xG9 (36.35**)
	G3xG4 (-0.38*)	G4xG9 (-0.42*)	G2xG3 (-0.60)	G4xG7 (-1.03*)	G6xG9 (39.20*)	G5xG6 (34.1*)
	G2xG6 (-0.36*)	G3xG8 (-0.37)	G8xG9 (-0.57)	G1xG6 (-1.0*)	G2xG9 (33.89)	G3xG5 (29.77*)

*.**: statistically significant at 0.05 and 0.01 level respectively

As seen in Table 5, tropical inbred lines combined well when tested under WW conditions compared to semi tropical or temperate hybrids. G4xG8 is a semi tropical hybrid had the highest SCA effect under WS conditions for LR. Although, there were a few good semi tropical combined hybrids under WS, tropical hybrids were more successful for LR (Table 5). Leaf senescence (LS) SCA results showed that tropical hybrids combined well under WS conditions when compared to semi tropical or temperate germplasm (Table 5). The 5 best combinations were tropical hybrids, except G5xG9 in 2014. Stomatal conductance SCA effects showed that tropical inbred lines combined well with temperate inbreds in WW conditions. G1xG6 a tropical hybrid combination was the best hybrid with highest positive and significant SCA effect in WS conditions. Also G1xG8 and G3xG9 semi tropical hybrids showed good SCA performance under drought stress conditions. When leaf chlorophyll content (SPAD) SCA effects were observed, positive results were obtained in both conditions (Table 6). Generally both tropical and semi tropical hybrids gave highest SCA values, indicated that tropical germplasm has potential for improving temperate germplasm for drought tolerance (Table 6). Grain yield water use efficiency (WUE) and irrigation water use efficiency (IWUE) SCA effect results showed that tropical and temperate inbreds combined well for drought tolerance. Especially, G5xG9, G4xG8 and G3xG9 were the best hybrids both for WUE and IWUE.

Table 6. SCA effects for leaf chloropyll content (SPAD) water use efficiency (WUE) and irrigation water use efficiency (IWUE) of the best five hybrid combinations

	SPAD		WUE		IWUE	
Years	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
2013	G6xG9 (6.38**)	G3xG8 (6.46**)	G5xG9 (7.96**)	G5xG9 (4.67**)	G5xG9 (9.39**)	G5xG9 (10.9**)
	G1xG5 (5.67*)	G2xG6 (4.87*)	G4xG8 (7.42**)	G4xG8 (3.18**)	G4xG8 (8.77**)	G4xG8 (7.40**)
	G4xG8 (4.46)	G4xG9 (3.75*)	G1xG4 (6.86**)	G1xG5 (2.31**)	G1xG4 (8.05**)	G1xG5 (5.37**)
	G4xG6 (4.14)	G6xG9 (3.75)	G4xG9 (5.26**)	G3xG8 (2.15**)	G6xG8 (6.20**)	G3xG8 (5.01**)
	G2xG7 (3.48)	G5xG6 (3.75)	G6xG8 (5.24**)	G6xG8 (1.96**)	G4xG9 (6.17**)	G6xG8 (4.57**)
2014	G1xG8 (5.34**)	G2xG8 (5.56**)	G4xG8 (6.13**)	G5xG9 (9.51**)	G4xG8 (8.53**)	G5xG9 (25.73**)
	G6xG8 (4.65**)	G1xG7 (4.49**)	G1xG3 (4.93**)	G3xG9 (6.51**)	G3xG9 (6.74**)	G3xG9 (17.61**)
	G7xG9 (4.13**)	G2xG3 (3.83**)	G1xG4 (4.79**)	G4xG8 (5.82**)	G1xG3 (6.66**)	G4xG8 (15.76**)
	G2xG6 (3.38**)	G1xG8 (3.74**)	G3xG9 (4.75**)	G4xG7 (5.43**)	G5xG9 (6.56**)	G4xG7 (14.70**)
	G2xG9 (3.35**)	G1xG5 (3.54**)	G6xG9 (4.70**)	G1xG2 (4.86**)	G1xG4 (6.49**)	G1xG2 (13.15**)
Mean	G1xG8 (3.96**)	G3xG8 (4.42**)	G4xG8 (6.77**)	G5xG9 (7.08**)	G4xG8 (8.64**)	G5xG9 (18.30**)
	G6xG9 (3.12*)	G1xG7 (4.28**)	G5xG9 (6.27**)	G4xG8 (4.50**)	G5xG9 (7.98**)	G4xG8 (11.58**)
	G2xG7 (3.11*)	G2xG6 (4.19**)	G1xG4 (5.83**)	G3xG9 (3.53*)	G1xG4 (7.27**)	G3xG9 (9.45*)
	G6xG8 (2.54)	G2xG8 (2.70)	G3xG9 (4.68**)	G1xG2 (3.36*)	G3xG9 (6.09**)	G1xG2 (8.74*)
	G4xG7 (2.47)	G1xG4 (2.53)	G6xG8 (4.65**)	G6xG8 (2.98*)	G6xG8 (5.89**)	G4xG7 (7.70*)

.: statistically significant at 0.05 and 0.01 level respectively*

Due to the complexity of drought tolerance various selection indices have been developed incorporating various secondary traits (HAO *et al*., 2011). These include the Drought Resistance Index (DI) (LAN, 1998) and Stress Tolerance Index (STI) (FERNANDEZ, 1992). These two indices are used to identify tolerance genotypes. Two high yielding, commercial, single cross hybrids, P31A34 and DKC6589, were also used as checks against the half diallel hybrids in order to assess their performance relative to widely cultivated varieties in Turkey. According to the STI results, SPAD index values of the genotypes were not big enough to differentiate genotypes. However, other parameters showed genotypic differences among the genotypes. A tropical x temperate hybrid (G5xG9) determined as the most tolerant genotype to drought in terms of WUE and IWUE STI values. Besides, this special hybrid was very successful for other traits such as SC, LR and LS (Figure 3). On the other hand, commercial checks were also showed good performance in terms of WUE and IWUE and ranked second and third after G5 x G9 hybrid combination. It is likely that adaptation to local conditions in Turkey played an important role. Several researchers (DUVICK, 1977, 1992; HALLAUER *et al.*, 1988; RUSSEL, 1991; CARENA and CROSS, 2003; TOLLENAR and WU, 1999; TOLLENAR, 2000) have also attributed increased stress tolerance in modern temperate maize germplasm to indirect selection through planting at high plant densities. Moreover, tropical x temperate crosses seemed to be more tolerant than tropical hybrids with high WUE and IWUE STI values. However, last ten tropical hybrids were good in terms of LS, LR and SC. Obviously, tropical drought tolerant inbred lines have the potential to improve temperate germplasm tolerance to drought. When DI index results investigated, similar results to STI index were obtained (Figure 3). However, genotypic differences were sharper in DI index (Figure 4). A commercial temperate hybrid, DKC 6589 seemed to be sensitive hybrid in terms of leaf senescence scores. Also another commercial hybrid, P31A34 seemed to be sensitive in terms of leaf rolling index values. High stomatal conductance index scores were determined in tropical hybrids (G3x G5, G1xG6, G5 xG6) indicated tolerance potential of the tropical germplasm. STI and DI index results showed that, tropical x temperate hybrids were more tolerant to drought in terms of WUE and IWUE index values. LR, LS and SC parameters showed that tropical germplasm carries unique alleles and can be used as donor.

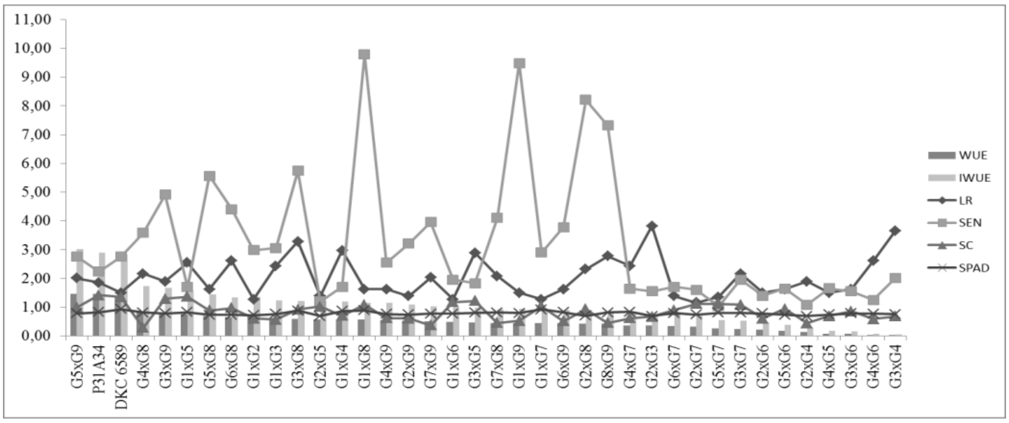

Figure 3. Stres tolerance index (STI) of the hybrids and checks for LR, LS, SC, SPAD, WUE and IWUE

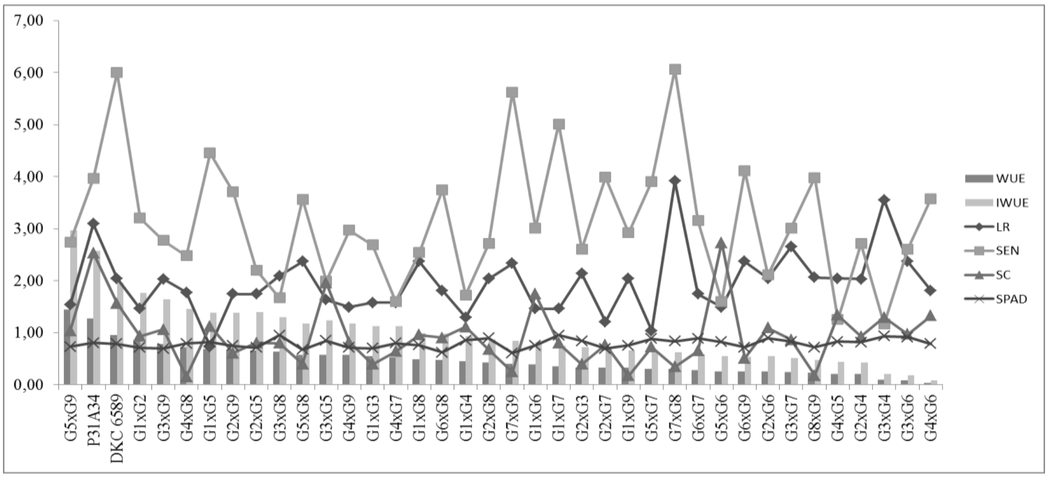

Figure 4. Drought resistance index (DI) of the hybrids and checks for LR, LS, SC, SPAD, WUE and IWUE

In conclusion, general combining ability (GCA) and specific combining ability (SCA) mean squares were significant for all investigated traits and demonstrated both additive and non-additive genetic effects in both conditions. Higher desired leaf rolling, leaf senescence, stomatal conductance and leaf chlorophyll content GCA effects of tropical inbreds showed the presence of the valuable alleles related to drought. G1 and G5 tropical inbreds were comparable to temperate inbreds for water use efficiency and irrigation water use efficiency. The successful SCA effects of tropical or semi tropical hybrid combinations for LR, LS, SC and SPAD showed that tropical germplasm was a good source germplasm for drought tolerance for improving temperate germplasm. On the other hand, high WUE and IWUE SCA values in tropical x temperate combinations suggested that semi tropical combinations can be useful in addressing severe reproductive stage drought stress. Stress tolerance index and drought resistance index identified G5 x G9 hybrid as the most tolerant hybrid to drought and revealed that tropical drought tolerant sources has the potential to contribute useful and unique alleles to temperate maize breeding programs.

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MORFO-FIZIOLOŠKA KOMBINACIONA SPOSOBNOST MEĐU GERMPLAZMAMA TROPSKOG I KUKURUZA UMERENOG POJASA U OPLEMENJIVANJU NA TOLERANTNOST NA SUŠU

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Izvod

Sedam inbred linija koje pretstavljaju tropske populacije tolerantne na sušu i dve adaptirane linije su ukrštene u half-dialel eksperimentu u cilju određivanja kombinacione sposobnosti. Genotipovi su testirani u dobro navodnjenim (WW) i uslovima stvorenim za sušu (WS) u toku 2013. i 2014. godine. Srednje vrednosti kvadrata opšte kombinacione sposobnosti i specifične kombinacione sposobnosti su bile značajne za sve ispitivane osobine i pokazale aditivne i neaditivne genetičke efekte u ispitivanim uslovima. Opšte kombinacione sposobnosti za veće uvijanje listova, starenje listova, aktivnost spora i sadržaj hlorofila tropskih inbred linija u uslovima suše su pokazale prisustvo značajnih alela vezanih za stres suše. Posebne kombinacione spososbnosti su potvrdile da su najbolji hibridi za efikasnost korišćenje vode i navodnjavanja bili iz ukrštanja tropskih x adaptiranih linija. Indeks toleratnosti na stres i indeks rezistentnosti na sušu identifikovali su G5 x G9, tropski x umereni hibrid, kao najtoleratniji na sušu. Naši rezultati pokazuju da tropska germplazma toleratna na sušu ima potencijal da doprinese korišćenju genetičke raznovrsnosti programima oplemenjivnaja kukuruza umerenog pojasa.

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