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Water Stress Effects on Combining Ability and Gene Action of Yield and Genetic Properties of Drought Tolerance Indices in Maize

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Abstract: This study was carried out, in order to investigate the genetic structure of the 36 maize hybrids established from eighteen female lines and two male testers according to line×tester method under non water stress and water stress conditions. So, 36 generated hybrids were planted in two experiments with normal irrigation and water stress at grain filling stage in Iran in 2008, using a RBCD design with three replications. The results showed that the effect of gene action could be both non additive and additive in the expression of grain yield under both conditions. However, GCA/SCA variance ratio revealed that non additive genetic variance was more important for grain yield than additive variance. Grain yield recorded high genetic variance value under non water stress condition compared to those under water stress condition. Also, narrow and broad sense heritability estimates in non water stress condition were higher than water stress condition. The lines L8, L11 and L17 in non stress condition and the lines L15, L16 and L17 in stress condition showed better general combining abilities for grain yield. The crosses such as L1×T1, L4×T1 and L8×T1 in non stress condition and L9×T2 in stress condition showed better specific combining abilities for grain yield. For choosing high efficient drought tolerance indices (SSI, TOL, MP and STI), broad sense heritability, narrow sense heritability and correlation of these indices were estimated. The results showed that STI was a successful index to select high yield and tolerant genotypes in comparison to SSI and TOL indices. Based on yield in both conditions and STI, the crosses L1×T1, L4×T1, L8×T1 and L17×T1 had the best tolerance to water stress at grain filling stage.

Key words: Maize, water stress, GCA, SCA, additive, dominance, line×tester

INTRODUCTION

Maize (*Zea mays* L.) is one of the important cereal crops of Iran and the world after wheat and rice. Recent projections by the International Food Policy Research Institute indicate that by 2020 the demand for maize in all developing countries will overtake for wheat and rice (Gerpacio and Pingali, 2007). In Iran, the average grain yield ha^{-1} in 2007 was 7.6 tons, whereas the soil and climatic condition of Iran are suitable for maize production but the yield is low compared to the United States of America with 9.5 t ha^{-1} in 2007. Thus, it is prerequisite to select promising hybrids for different conditions in order to speed up economical crop production.

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Maize breeders have successfully exploited heterosis for grain yield by crossing inbred lines to develop desirable hybrids. However, the nature of gene action involved in expression of heterosis for the grain yield of elite maize hybrids remains unresolved.

General Combining Ability (GCA) and Specific Combining Ability (SCA) are the most important indicators for expressing the potential value of lines. The non additive gene effect is distinguished by specific combining ability but additive gene effect is distinguished by general combining ability (Nevado and Cross, 1990; Choukan, 2008).

The choice of efficient breeding program depends on a large knowledge of type gene action involved in expression of the character. Dominance gene action would favor the production of hybrids, whereas additive gene action indicates that standard selection procedures would be effective in breeding about changing in character (Edwards *et al.*, 1976).

Earlier studies have shown that both additive and non additive gene effects were important for controlling grain yield (Malvar *et al.*, 1996; Iqbal *et al.*, 2007). However, Abdel-Moneam *et al.* (2008) have shown that grain yield is governed by genes acting non additively.

Drought is one of the most important abiotic stress factors, which affects almost every aspect of plant growth.

Different type of gene action under drought and low nitrogen conditions were reported by Betran *et al.* (2003). They concluded that additive effects were more important under drought condition and dominance effects were more important under low nitrogen condition.

Several indices have been utilized to evaluate genotypes for drought tolerance based on grain yield such as mean production (Rosielle and Hamblin, 1981), stress susceptibility index (Fischer and Maurer, 1978), stress tolerance index (Fernandez, 1993) and tolerance (Rosielle and Hamblin, 1981). These indices have been compared by some researchers (Fernandez, 1993; Shiri, 2005; Sanjari-Pirevatlou and Yazdansepas, 2008), but there were a few studies on genetic properties of these indices.

Based on the results obtained in previous studies, it seemed that STI and MP were useful yield-based drought tolerance indices to select high yielding genotypes in both non water stress and water stress conditions. On the other hand, SSI and TOL were not useful indices to select for drought tolerant genotypes (Fernandez, 1993; Shiri, 2005; Sanjari-Pirevatlou and Yazdansepas, 2008).

The objectives of this study were; (1) to estimate the general combining ability of lines and testers and specific combining ability of crosses for grain yield under water stress and non water stress conditions, (2) to estimate the gene action governing under non water stress and its changes under water stress condition, (3) to calculate the genetic parameters and especially the narrow sense heritability of the important yield-based drought tolerance indices by using line×tester analysis and (4) to select the efficient drought tolerance indices.

MATERIALS AND METHODS

The seeds of twenty maize inbred lines were obtained from Seed and Plant Improvement Institute of Iran. In line × tester fashion, eighteen female inbreds and two male testers (K3653/2 and K3615/1) were crossed through controlled pollination to produce thirty six hybrid progenies in field of Agricultural and Natural Resources Research Center of Ardebil Province (Moghan) in 2007. The parents were:

- KLM77008/1-3-3-1-2-2-1 (L1)
- KLM77012/4-1-1-4-1-2-1 (L2)
- KLM77021/4-1-2-1-2-1-2 (L3)
- KLM77029/8-1-1-1-2-1-5 (L4)
- KLM77029/8-1-1-1-2-2-2 (L5)
- KLM76004/3-5-1-2-2-1-1-1 (L6)
- KLM76012/1-3-1-1-1-2-1-1 (L7)
- K74/2-2-1-3-1-1-1-1 (L8)
- K74/2-2-1-4-4-1-1-1 (L9)
- K74/2-2-1-19-1-1-1-1 (L10)
- K74/2-2-1-21-2-1-1-1 (L11)
- K74/2-2-1-21-3-1-1-1 (L12)
- K74/1 (L13)
- K3545/7 (L14)
- K3544/4 (L15)
- K3640/6 (L16)
- KLM75010/4-4-1-2-1-1-1 (L17)
- KLM76010/1-13-1-2-1-1 (L18)
- K3653/2 (T1)
- K3615/1 (T2)

Thirty six generated maize hybrids were planted in two experiments with non water stress and water stress at grain filling stage in Pars Abad-e-Moghan (39° 41' N 47° 32' E, with 281.3 mm annual precipitation), Ardebil, Iran in 2008, using a RBCD design with three replications. The plot was made of four rows of 5 m length with the distance between rows and hills of 75 and 18 cm, respectively. Sowing was performed by three seeds per hill and thinning eighteen days after planting reduced the stand at one plant per hill. Thus, a planting density of 75000 plant ha^{-1} was achieved.

In non water stress condition, the irrigation was performed nine times based on crop water requirements during growth periods, but in water stress at grain filling stage condition, the irrigation was done five times from planting time till the end of flowering period and then, in order to apply water stress, irrigation was withheld completely from the end of flowering till crop maturity (grain filling stage). The environmental severity degree is estimated with SI (stress intensity) and maximal rate of SI is one (Fischer and Maurer, 1978). In this study, SI was 0.31, so stress intensity was moderate. Grain yield were determined under both non water stress and water stress experiments and used as Yp and Ys, respectively.

For every genotype, the four drought tolerance indices were calculated based on their grain yield in non water stress and water stress conditions.

The drought tolerance indices were calculated as follows:

Stress Susceptibility Index (Fischer and Maurer, 1978): $$SSI = \left[1 - \left(Y_S / Y_P\right)\right] / SI$$

Where:

$$SI = 1 - (\bar{Y}_S / \bar{Y}_P)$$

Mean Productivity (Rosielle and Hamblin, 1981): $MP = \frac{Y_P + Y_S}{2}$

Tolerance (Rosielle and Hamblin, 1981): $TOL = Y_P - Y_S$

Stress Tolerance Index (Fernandez, 1992): $STI = (Y_P).(Y_S)/(\overline{YP})^2$

Where:
Y_P = Yield of a genotype in non water stress condition
Y_S = Yield of a genotype in water stress condition
$\overline{Y_P}$ = Mean yield in non water stress condition
$\overline{Y_S}$ = Mean yield in water stress condition

The recorded data were subjected to analysis of variance according to Steel and Torrie (1980) to determine significant differences among crosses. The significant differences among crosses were further partitioned by using line×tester analysis (Kempthorne, 1957). The estimation of General Combining Ability (GCA) for lines, testers, Specific Combining Ability (SCA) for crosses, dominance and additive variance were also estimated following function of Kempthorne (1957). For testing of general combining ability for lines, testers and specific combining ability for crosses were used T test method (Steel and Torrie, 1980). The data were statistically analyzed by MSTATC, STATISTICA and EXCEL computer programs.

RESULTS AND DISCUSSION

The analysis of variance (Table 1) showed that mean square due to crosses for grain yield was significant in both water stress and non water stress conditions, indicate the existence of variability among the cross combinations for grain yield. The analysis of variance according to line×tester method revealed significant difference among lines, testers and line×tester interaction for grain yield in both conditions and for all of indices. This indicated that both additive and non additive (dominance) gene effects were important in genetic expression of all of indices and grain yield in both water stress and non water stress conditions. The GCA/SCA ratio was less than unity for all of indices and grain yield in both conditions; this means that these characters were governed predominantly by non additive component. Also narrow sense heritability estimates were generally lower than broad sense heritability, indicating the presence of non additive gene action. These components can be exploited by hetreotic breeding programme. The similar results have been reported in maize under normal and high plant densities by Choukan (1999). It has been frequently reported that grain yield is controlled by both additive and non additive gene action in normal condition (Malvar *et al.*, 1996; Iqbal *et al.*, 2007).

Grain yield recorded high genetic variance value under non water stress condition compared to those under water stress condition. Also narrow and broad sense heritability estimates in non water stress condition were higher than water stress condition (Table 1).

The low heritability in non water stress condition was related to remarkable decrease in genetic variance than environmental variance. Ngaboyisonga *et al.* (2009) concluded that the reduction in genetic variance was the effect of drought on genetic variation of grain yield. Also, Hefny (2007) stated that heritability and genetic variance component estimates were high at optimal N fertilizer (normal environment) compared with low N fertilizer (stress environment).

Table 1: Mean square and variance components for grain yield and drought tolerance indices under non water stress and water stress conditions according to line×tester analysis

SOV	df	YP	YS	TOL	SSI	MP	STI
Rep	2	0.236	3.231	1.774	0.003	1.3	0.036
Crosses	35	3.156**	0.768**	3.041**	0.267**	1.202**	0.043**
Lines	17	3.189**	0.808**	3.319**	0.299**	1.122**	0.038**
Testers	1	17.642**	0.965**	7.202**	0.325**	8.173**	0.3**
Line×tester	17	2.271**	0.717**	2.518**	0.232**	0.872**	0.033**
Error	70	0.363	0.227	0.493	0.057	0.172	0.007
σ^2_A	-	0.0221	0.0011	0.013	0.0009	0.008	0.0003
σ^2_D	-	0.636	0.169	0.675	0.0583	0.2333	0.0087
$\sigma^2_{gca}/\sigma^2_{sca}$	-	0.0173	0.002	0.009	0.007	0.018	0.014
σ^2_g	-	1.052	0.256	1.01	0.089	0.4	0.0143
σ^2_P	-	1.173	0.33	1.17	0.108	0.457	0.016
h^2_B	-	0.897	0.776	0.863	0.82	0.875	0.894
h^2_N	-	0.019	0.003	0.011	0.008	0.017	0.19

**:Significant at 1% level of probability YP: Grain yield under non water stress condition, YS: Grain yield under water stress condition, TOL: Tolerance, SSI: Stress susceptibility index, MP: Mean productivity, STI: Stress tolerance index, σ^2_A: Additive variance, σ^2_D: Dominance variance, $\sigma^2_{gca}/\sigma^2_{sca}$: The ratio of general combining ability variance and specific combining ability variance, σ^2_g: Genotypic variance, σ^2_P: Phenotypic variance, h^2_B: Broad sense heritability, h^2_N: Narrow sense heritability

Analysis of General Combining Ability (GCA) indicated that the variation of combining ability of lines in non water stress condition was higher than water stress condition. The reactions of GCA of lines in both conditions were not similar. For example, the line 8 (L8) had significantly positive GCA effect in non water stress condition, whereas, this line had negative GCA effect in water stress condition. Conversely, in line 16 (L16), it had significantly negative and positive GCA effect in non water stress and water stress conditions, respectively. The Line 17 (L17) had significantly positive GCA effect in both non water stress and water stress conditions. Overall, the lines L8, L11 and L17 in non stress condition and the lines L15, L16 and L17 in stress condition showed better general combining abilities for grain yield (Table 2).

The Specific Combining Ability (SCA) effects of 36 crosses were shown in Table 3. The crosses L1×T1, L4×T1 and L8×T1 showed significant and positive SCA effects in non water stress condition, whereas, the cross L9×T2 had highest value of SCA effects in water stress condition. The lines GCAs, both in direction and in magnitude changed with the change of conditions (Table 3).

Variation of specific combining ability of crosses in non water stress condition was higher than water stress condition. It means that the number of crosses with positive and significant SCA effects were more in non water stress condition than water stress condition (Table 3).

The results of heritability of indices showed that the STI index with 0.894 had the highest rate of broad sense heritability among indices. In this experiment SSI exhibited negligible narrow sense heritability and STI was more heritable than MP and TOL, as determined by narrow sense heritability estimates (Table 1). Genetic advances are directly related to the magnitude of narrow sense heritability (Choukan, 2008). Thus, it seems that selection for drought tolerance based on STI will be useful than based on SSI and TOL. These results were in agreement with those of Saba *et al*. (2001).

To determine the most desirable drought tolerance index, the correlation coefficient among Y_P (grain yield in non water stress), Y_S (grain yield in water stress) and other quantitative indices of drought tolerance were calculated (Table 4). The most desirable

Table 2: General Combining Ability (GCA) of lines and testers for grain yield under non water stress and water stress conditions

	Conditions	
GCA of lines	Non water stress	Water stress
g_{L1}	0.59*	0.35^{ns}
g_{L2}	-0.73**	0.22^{ns}
g_{L3}	-1.35**	-0.67**
g_{L4}	-0.74**	0.05^{ns}
g_{L5}	0.34^{ns}	-0.41*
g_{L6}	-0.16^{ns}	-0.38^{ns}
g_{L7}	-0.15^{ns}	-0.16^{ns}
g_{L8}	1.34**	-0.20^{ns}
g_{L9}	-0.18^{ns}	-0.08^{ns}
g_{L10}	0.30^{ns}	-0.21^{ns}
g_{L11}	0.78**	-0.15^{ns}
g_{L12}	0.46^{ns}	0.11^{ns}
g_{L13}	-0.49*	-0.04^{ns}
g_{L14}	-0.60*	-0.22^{ns}
g_{L15}	0.07^{ns}	0.51**
g_{L16}	-1.02**	0.50**
g_{L17}	0.97**	0.58**
g_{L18}	0.55*	0.21^{ns}
SE (g_i)	0.25	0.19
SE (g_i-g_j)	0.35	0.27
GCA of Testers		
g_{T1}	0.40**	0.09^{ns}
g_{T2}	-0.40**	-0.09^{ns}
SE (g_i)	0.08	0.06
SE (g_i-g_j)	0.12	0.09

ns: Non significant, *, **: Significant at 5 and 1% levels of probability, respectively

Table 3: Specific Combining Ability (SCA) of crosses for grain yield under non water stress and water stress conditions

	Conditions			
	Non water stress		Water stress	
Lines	T1	T2	T1	T2
L1	1.05**	-1.05**	-0.14^{ns}	0.14^{ns}
L2	0.28^{ns}	-0.28^{ns}	-0.24^{ns}	0.24^{ns}
L3	-0.14^{ns}	0.14^{ns}	-0.38^{ns}	0.38^{ns}
L4	0.98**	-0.98**	0.37^{ns}	-0.37^{ns}
L5	0.27^{ns}	-0.27^{ns}	0.40^{ns}	-0.40^{ns}
L6	-0.79*	0.79*	-0.05^{ns}	0.05^{ns}
L7	-0.31^{ns}	0.31^{ns}	0.38^{ns}	-0.38^{ns}
L8	1.23**	-1.23**	0.52^{ns}	-0.52^{ns}
L9	0.22^{ns}	-0.22^{ns}	-0.68*	0.68*
L10	0.40^{ns}	-0.40^{ns}	-0.52^{ns}	0.52^{ns}
L11	-0.52^{ns}	0.52^{ns}	0.05^{ns}	-0.05^{ns}
L12	-0.43^{ns}	0.43^{ns}	0.09^{ns}	-0.09^{ns}
L13	-0.28^{ns}	0.28^{ns}	0.00^{ns}	0.00^{ns}
L14	0.21^{ns}	-0.21^{ns}	0.37^{ns}	-0.37^{ns}
L15	-0.60^{ns}	0.60^{ns}	-0.27^{ns}	0.27^{ns}
L16	-0.62^{ns}	0.62^{ns}	-0.31^{ns}	0.31^{ns}
L17	-0.47^{ns}	0.47^{ns}	0.25^{ns}	-0.25^{ns}
L18	-0.47^{ns}	0.47^{ns}	0.18^{ns}	-0.18^{ns}
SE (SCA)	0.35		0.28	

ns: Non Significant.*, ** Significant at 5 and 1% levels of probability, respectively

drought tolerance index is the one which has significant and the same sign correlation with both Y_P and Y_S. The correlation coefficient of Stress Susceptibility Index (SSI) with Y_S and Y_P were -0.42 and 0.74, respectively. Therefore, selection for SSI should give a positive yield

Table 4: The correlation coefficients among grain yield under non water stress (YP), grain yield under water stress (YS) and drought tolerance indices

	YP	YS	TOL	SSI	MP	STI
YP	1.00	0.28^{ns}	0.88**	0.74**	0.92**	0.87**
YS		1.00	-0.21^{ns}	-0.42**	0.63**	0.71**
TOL			1.00	0.96**	0.62**	0.53**
SSI				1.00	0.43**	0.32^{ns}
MP					1.00	0.99
STI						1.00

ns: Non significant. **: Significant at 1% level of probability. YP: Grain yield under non water stress condition, YS: Grain yield under water stress condition, TOL: Tolerance, SSI: Stress susceptibility index, MP: Mean productivity, STI: Stress tolerance index

response under water stress condition. The correlation coefficient of Stress Tolerance Index (STI) with Y_P and Y_S were 0.87 and 0.71, respectively. Thus, selection for STI should give positive responses in both conditions. On the other hand, MP and STI were highly correlated with each other as well as with Y_S and Y_P. Thus, through these indices, it is possible to distinguish high yielding genotypes in either condition. The non significant correlation between SSI and STI (r = 0.32) would indicate that the combination of high STI with a low to moderate SSI is biologically attainable in maize.

The observed relationship between Y_P and (MP and STI) and Y_S and (MP and STI) were in consistence with those reported by Fernandez (1993), Shiri (2005) and Sanjari-Pirevatlou and Yazdansepas (2008).

Furthermore, A good drought tolerance index should be able to identify superior genotypes both in non water stress and water stress conditions from the genotypes that are favorable only in one condition.

According to Fernandez (1993), genotypes can be categorized into four groups based on their performance in stress and non stress environments: genotypes express uniform superiority in both environments (Group A); genotypes perform favorably only in non stress environments (Group B); genotypes yield relatively higher only in stress environments (Group C); and genotypes perform poorly in both environments (Group D).

The grain yield ranged from 6.09 to 11.2 tons per hectare in non water stress condition and from 4.7 to 6.6 tons per hectare in water stress condition (Table 5).

Based on grain yield in water stress and non water stress conditions, the studied crosses were divided into four groups as following: L1×T1, L4×T1, L5×T1, L8×T1, L11×T1, L12×T1, L14×T1, L17×T1, L18×T1, L15×T2 and L17×T2 crosses placed in group A. L9×T1, L10×T1, L6×T2, L11×T2, L12×T2 and L18×T2 crosses included in group B. L2×T1, L7×T1, L13×T1, L15×T1, L16×T1, L1×T2, L2×T2, L9×T2, L10×T2 and L16×T2 crosses were in group C and finally L3×T1, L6×T1, L3×T2, L4×T2, L5×T2, L7×T2, L8×T2, L13×T2 and L14×T2 crosses located in group D (Table 5, Fig. 1). Fernandez (1993) stated that an optimal selection criterion should be able to distinguish group A from the other three groups.

Genotypes with high values of TOL and SSI are sensitive to water stress and therefore, selection must be done based on low rates of these indices. Based on TOL and SSI indices, the crosses L16×T1, L2×T2, L4×T2 and L16×T2 had the highest yield stability among the studied crosses. These crosses had low grain yield under both stress and non water stress conditions and located in group C and D (Table 5). Therefore, the use of TOL and SSI indices lead the selection toward tolerant and low yielding genotypes. It is better to use these indices for the omission of susceptible genotypes, but not for the selection of both stress tolerant and high yielding genotypes. Moghaddam and Hadizadeh (2001) have got similar results on this subject.

Table 5: Estimation of drought tolerance indices based on grain yield of maize crosses under water stress and non water conditions (SI = 0.31)

Entry	Crosses	YP	YP	YS	YS	TOL	SSI	MP	STI	Group
1	L1×T1	10.25	AB+	6.00	A-E+	4.25	1.33	8.13	0.91	A++
4	L4×T1	8.86	C-G	6.21	ABC	2.65	0.96	7.53	0.82	A
5	L5×T1	9.23	BCD	5.79	A-G	3.44	1.19	7.51	0.79	A
8	L8×T1	11.2	A	6.11	A-D	5.1	1.46	8.6	1.01	A
11	L11×T1	8.87	C-F	5.69	A-H	3.18	1.15	7.28	0.75	A
12	L12×T1	8.65	C-H	6.00	A-E	2.65	0.98	7.33	0.77	A
14	L14×T1	8.22	C-J	5.95	A-F	2.27	0.89	7.09	0.73	A
17	L17×T1	9.12	CDE	6.62	A	2.50	0.88	7.87	0.90	A
18	L18×T1	8.70	C-H	6.19	ABC	2.51	0.92	7.45	0.80	A
33	L15×T2	8.48	C-I	6.28	AB	2.19	0.83	7.38	0.79	A
35	L17×T2	9.24	BCD	5.83	A-G	3.41	1.18	7.54	0.80	A
9	L9×T1	8.65	C-H	5.03	F-I	3.62	1.34	6.84	0.65	B
10	L10×T1	9.32	BC	5.07	E-I	4.24	1.46	7.20	0.70	B
24	L6×T2	8.44	C-I	5.18	D-I	3.3	1.24	6.8	0.65	B
29	L11×T2	9.11	CDE	5.31	C-I	3.80	1.34	7.21	0.72	B
30	L12×T2	8.70	C-H	5.52	B-I	3.18	1.17	7.11	0.71	B
36	L18×T2	8.83	C-G	5.53	B-I	3.30	1.20	7.18	0.72	B
2	L2×T1	8.17	C-K	5.76	A-G	2.41	0.94	6.97	0.70	C
7	L7×T1	8.16	C-L	6.00	A-E	2.16	0.85	7.08	0.73	C
13	L13×T1	7.84	F-M	5.76	A-G	2.08	0.85	6.80	0.67	C
15	L15×T1	8.08	D-L	6.04	A-D	2.04	0.81	7.06	0.72	C
16	L16×T1	6.98	L-O	5.98	A-F	1.00	0.46	6.48	0.62	C
19	L1×T2	7.35	I-N	5.99	A-E	1.36	0.59	6.67	0.65	C
20	L2×T2	6.79	MNO	5.96	A-F	0.83	0.39	6.38	0.60	C
27	L9×T2	7.41	I-N	6.11	A-D	1.31	0.57	6.76	0.67	C
28	L10×T2	7.71	F-N	5.81	A-G	1.90	0.79	6.76	0.67	C
34	L16×T2	7.41	I-N	6.32	AB	1.09	0.47	6.86	0.69	C
3	L3×T1	7.13	J-O	4.74	I	2.38	1.07	5.94	0.50	D
6	L6×T1	7.67	G-N	5.37	B-I	2.30	0.96	6.52	0.61	D
21	L3×T2	6.60	NO	5.21	D-I	1.39	0.67	5.91	0.51	D
22	L4×T2	6.09	O	5.19	D-I	0.91	0.48	5.64	0.47	D
23	L5×T2	7.87	F-M	4.70	I	3.18	1.29	6.28	0.55	D
25	L7×T2	7.96	E-M	4.96	GHI	3.00	1.21	6.46	0.59	D
26	L8×T2	7.92	E-M	4.78	HI	3.14	1.27	6.35	0.56	D
31	L13×T2	7.60	H-N	5.47	B-I	2.13	0.90	6.53	0.62	D
32	L14×T2	7.00	K-O	4.91	GHI	2.09	0.96	5.95	0.51	D
Mean		8.21		5.65		2.56	0.97	6.93	0.69	

YP: Grain yield under non water stress condition, YS: Grain yield under water stress condition, TOL: Tolerance, SSI: Stress susceptibility index, MP: Mean productivity, STI: Stress tolerance index . +: Mean with similar letters in each column are not significantly different at 1% probability level by Duncan's Multiple Range Test (DMART). ++: The crosses grouping based on grian yield of maize crosses under water stress and non water conditions

The crosses of L1×T1, L4×T1, L5×T1 and L8×T1 had the highest rate of MP index with 8.1, 7.5, 7.5 and 8.6, respectively (Table 5). So, these crosses were selected based on MP index. These crosses had high grian yield under both stress and non water stress conditions and located in group A.

According to Fernandez (1993), more stable genotypes have higher rate of STI. The crosses L1×T1, L4×T1, L8×T1 and L17×T1 were selected based on STI index. All of these crosses were located in the group A (Table 4). So, STI and MP indices could separate the group A crosses from other group crosses. Fernandez (1993) compared effectiveness of several stress tolerance criteria and concluded that MP, SSI and TOL failed to identify genotypes with both high yield and stress tolerance potentials, whereas through STI, genotypes with these attributes could be identified. Also, Shiri (2005) and Sanjari-Pirevatlou and Yazdansepas (2008) noted the similar results.

To show the advantage of STI and separate genotypes into four groups based on yield under stress and non water stress conditions, three-D plot among Y_S (yield under water

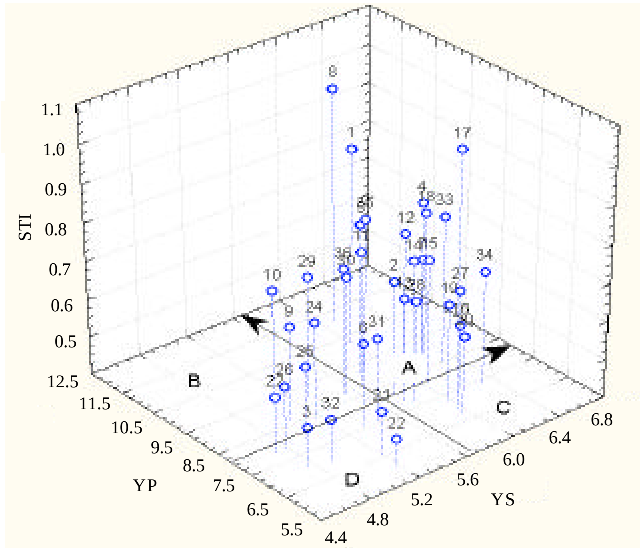

Fig. 1: The 3-D plots among grain yield under non water stress (YP), grain yield under water stress (YS) and Stress Tolerance Index (STI)

stress condition) ,Y_P (yield under non water stress condition) and STI was used. As, it was shown in Fig. 1, most of the group A crosses had high STI values. Thus, it seems that selection for drought stress tolerance based on STI index will be more fruitful than based on TOL and SSI indices.

CONCLUSION

The results showed that the effect of gene action can be both non additive and additive in the expression of grain yield under both conditions. However, non additive genetic variance was more important in the expression of grain yield than additive variance. Genetic variance, narrow sense heritability and broad sense heritability estimates in non water stress condition were higher than water stress condition. Based on broad sense heritability, narrow sense heritability and correlation of indices, STI is a successful index to select high yield and tolerant genotypes than SSI and TOL indices. According to yield in both conditions, specific combining abilities and STI index, crosses L1×T1, L4×T1 and L8×T1 were the best crosses in this study.

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