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BREEDING POTENTIAL FOR HIGH TEMPERATURE TOLERANCE IN CORN (*ZEA MAYS* L.)

TASSAWAR HUSSAIN, IFTIKHAR AHMAD KHAN, MUHAMMAD ASGHAR MALIK* AND ZULFIQAR ALI

*Department of Plant Breeding and Genetics/ *Department of Agronomy, University of Agriculture, Faisalabad-38040, Pakistan*

Abstract

Rising temperature reduces the pollen viability and silk receptivity of corn resulting in poor seed set and reduced yield. Continuously rising temperature and less frequency and distribution of rainfall coupled with usual canal–closure particularly in Pakistan have significantly been reducing the grain yield. This problem could be overcome by developing heat tolerant maize hybrids. For this purpose, five heat tolerant (lines), five heat susceptible (lines) and four heat susceptible (testers) corn inbred lines were hybridized artificially in a line x tester mating design. The 40 hybrids and 14 parents were evaluated for heat tolerance under high temperature field conditions by sowing on March 31 using triplicated randomized complete block design during spring 2004. Highly significant differences ($P \leq 0.01$) were observed among 54 corn genotypes, 14 parents, 40 crosses, parent vs crosses and interaction term of lines × tester (L × T) for all the 14 maize plant traits. The inbred lines L1, L2, L3, L5 (lines), T1, T3 (testers) and hybrids L1×T3, L2×T4, L3×T3 and L5×T1 proved to be the excellent combiners with high GCA and SCA effects respectively, for most of the traits. Large differences in heat units (111 to 326) utilized by the parents and crosses under normal and high temperature conditions to mature physiologically suggested that inbred lines as well as crosses were photosensitive as they were not utilizing similar thermal units in both the environments. The dominance type of gene action was observed to be predominant for all the traits. The proportional contribution of lines was more for seven very crucial parameters. The estimates of heritability in broad sense were high for all the traits. Hybrid breeding is suggested as hybrid plants have higher capacity to tolerate heat stress in field conditions than their parents.

Introduction

Maize (*Zea mays* L.) is one of the oldest cultivated crop. Two regular crops are being grown in Pakistan namely spring (January-February) and autumn (July-August) season planting. But in central maize belt (Okara, Sahiwal, Pakpattan and Khanewal districts of Punjab province) summer (April-May) and winter (November-December) season planting is getting popularity due to advent of wide range of maize hybrids being marketed by Pioneer, Monsanto, ICI, Syngenta and national seed companies rendering maize as almost all season crop in Pakistan. Only in June (hottest month) and December (coldest month) planting is not recommended. Off season maize is more for use as greenshoots.

Normally maize grows and yields at optimal temperature of 10 - 30^0 C. The effect of warm temperatures on maize crop is a two-edged sword. On one hand, warmer temperature has generally a favorable effect on faster crop development. On the other hand, rise in temperature ($+30^0$ C), pollen shedding starts much ahead of silks emergence while silking is delayed, so that silking period does not correspond to anthesis/tasseling, increasing anthesis-silking interval (ASI), resulting in poor synchronization of flowering (asynchrony). Further rise in temperature reduces the pollen viability and silk receptivity resulting in poor seed set and reduced yield (Samuel *et al.*, 1986). The degree of damage depends upon the intensity and duration of heat spell. High temperature waves especially coupled with low relative humidity can cause more damage to growing maize plant, pollination, seed set and yield. The situation may further be aggravated by the prevailing drought condition. According to a report, due to climate change caused by global warming, the potential annual losses of up to 10 M tons of maize has been forccast which would eventually affect 140 M people in developing countries (Wettstein & Nelson, 2003; *www.futureharvest.org*). Campos *et al*., (2004) suspected significant yield losses in maize caused by drought/heat stress, which is expected to be severe due to changing global climate, as temperature and rainfall distribution are changing in the key traditional maize production areas.

Continuously rising temperature and less frequency and distribution of rainfall coupled with usual canal–closure in Pakistan, have significantly been reducing the grain yield levels during the last few years. In the spring season (January-March) planting high prevailing temperatures (usually 52^0C maximum) at flowering (April/May) causes top firing or tassel blast which occur at 38^0 C and above, and seriously reduces the seed set. While in autumn season (Mid June-August) prevailing high temperature at planting time (usually 45^0C maximum) affects seed germination and seedling growth. Such extreme temperatures are likely to increase in frequency under future climate predictions. Broader planting and harvesting windows prevalent in Pakistan also expose the maize crop to variable broad range of temperatures affecting growth and development of this plant which needs to be precisely understood.

Some researchers worked for genetics of drought tolerance e.g., Betran *et al*., (2003) estimated the general combining abilities for secondary traits and their relationship with grain yield in a group of tropical white inbred lines and their hybrids under stress and non-stress environments across Mexico. Under stress vs. non-stress conditions high variability for ASI, ears per plant, a higher inbred hybrid correlation and significant correlations between these traits and grain yield was observed but genetic studies on heat tolerance are scanty. The present project was designed to evaluate lines, testers and their crosses under normal and high temperature stress environments for genetic variability, to estimate the general combining ability of lines and testers and specific combining ability of crosses for various parameters affecting yield and heat tolerance, and to study genetic basis of heat tolerance. This paper will generate useful information for maize breeders for the development of maize hybrid(s) with increased yield and overall performance under high temperature stress condition.

Materials and Methods

The seed of 14 maize inbred lines was collected from CIMMYT, Mexico. This plant material included five heat tolerant, five heat susceptible and four with high GCA diverse corn inbred lines viz., (CL-04317*CML-247)-B-6-1-2-B, (CL-04347 *CL-04904)-B-109-2-1-B, (CL-04347*CL-04904)-B-111-1-1-B, (CL-04347*CL-04904)-B-26-1-1-B, (CL-04347*CL-04904)-B-86-2-B coded as L1, L2, L3, L4, L5 (heat-resistant), CML-247*CML-254)-B-31-3-1-B, (CML-48*CML-401)-B-10-1-B, (CML-273*CML-401)-B-28-1-1-B, (CL-04347 *CL-04904)-B-109-1-1-B, (CL-G2407 *CML-264)-B-8-1-2-B, coded as L6, L7, L8, L9, L10 (heat–susceptible) used as female parents and four lines viz., (CML-273*CML-401)-B-16-1-1-B, (CL-O4317*CML-247)-B-3-2-3-B, CML-442, CML-444, with reported high GCA, coded as T1, T2, T3, T4, used as common male testers in the crosses. Inbred lines were hybridized in line × tester fashion during autumn, 2003. Evaluation of plant genetic material under high temperature stress conditions (by sowing genetic material on 31st March, 2004 in the field) was done during spring crop season, 2004. The plant genetic material was planted in triplicated randomized complete block design. Adequate irrigation was provided during the whole period to avoid water stress which could interfere with heat stress by enhancing its severity. However, only at flowering stage one irrigation was delayed for six days to clear the marked differences among the genotypes. All other standard agronomic practices were applied.

The data on guarded plants for seed vigour, emergence percentage, plant growth rate, leaf rolling, anthesis–silking interval, pollen size, pollen viability, silk receptivity, seed setting percentage, number of ears per plant, leaf senescence, plant maturity and grain yield per plant were recorded at appropriate stage. The collected data for various parameters were statistically analyzed using analysis of variance (Steel & Torrie, 1980) to see the significant differences among the genotypes. The significant differences among genotypes, for significant plant traits only, were further partitioned by using line × tester analysis (Kempthorne, 1957). The estimates of general combining ability (GCA) for lines, testers and specific combining ability (SCA) for crosses were also estimated following function of Kempthorne (1957).

Results and Discussions

The significant differences ($p \leq 0.01$) were observed among 54 corn genotypes, 14 parents, 40 crosses, parent vs crosses and interaction term of lines × tester (L × T) for all the 14 maize plant traits under high temperature stress condition (Table 1). Significant differences ($p \leq 0.01$) among 10 lines for seed vigour percentage, anthesis-silking interval, average pollen size, percent pollen viability, percent silk receptivity, percent seed setting, number of ears per plant and days to maturity were observed. Four testers were non-significantly different ($p > 0.05$) for all the 14 traits. Heat units difference among parental lines (female and male) and cross combinations under normal and high temperature field conditions suggested that inbred lines as well as crosses are photosensitive. Detail of daily heat units are given in appendix 1. This also confirmed the tropical origin of the inbred lines. Difference in heat units consumed may also be due to different environmental conditions under two different environments.

The lines L3, L1, L2 and L5 exhibited maximum GCA effects for most of the traits and proved to be best general combiner (Table 2). The L3 was best general combiner for 10 traits i.e., seed vigour, emergence-percentage, plant growth rate, anthesis–silking interval, pollen size, pollen viability, silk receptivity, seed setting percentage, plant maturity and grain yield per plant. Line L1 was best general combiner for emergence percentage, leaf rolling, anthesis–silking interval, pollen viability, silk receptivity, seed setting percentage, leaf senescence, plant maturity and grain yield per plant. The line L2 proved to be the best general combiner for nine traits like leaf rolling, anthesis–silking interval, pollen viability, silk receptivity, seed setting percentage, number of ears per plant, leaf senescence, plant maturity and grain yield per plant. The line L5 was best general combiner for nine traits like seed vigour, emergence-percentage, leaf rolling, anthesis–silking interval, pollen size, pollen viability, silk receptivity, seed setting percentage and plant maturity. The GCA effects of four testers are presented in Table 3. Among testers, T3 was the best general combiner for seed vigour, plant growth rate, leaf rolling, relative water contents, pollen viability, silk receptivity, seed setting percentage, plant maturity and grain yield per plant while the tester T1 had high GCA for seven traits like seed vigour, emergence percentage, anthesis–silking interval, pollen size, pollen viability, silk receptivity and seed setting percentage.

Table 3. Estimation of general combining ability effects for various traits in four common testers (male parents) of corn under high temperature stress condition.

Traits/Testers	T1	T2	T3	T4	S.E. (GCA for testers)	S.E. (gi-gj) Testers
SVP	0.62	-0.75	0.45	-0.32	0.14	0.20
FEP	0.23	-0.68	0.09	0.36	0.18	0.25
PGR	-0.01	0.01	0.03	-0.02	0.01	0.01
PLR	0.11	-0.99	-1.29	2.18	0.11	0.15
RWC	-2.85	0.51	1.86	0.48	0.58	0.82
ASI	-0.18	0.16	0.05	-0.03	0.01	0.01
APS	1.08	2.48	-1.76	-1.79	0.14	0.20
PPV	0.65	-1.92	0.62	0.65	0.13	0.19
PSR	0.48	-2.22	0.52	1.22	0.13	0.18
PSS	0.32	-2.15	0.68	1.15	0.10	0.15
NEP	0.01	0.01	0.00	-0.03	0.01	0.01
PLS	0.59	-2.18	0.33	1.26	0.14	0.19
DPM	0.40	-0.10	-0.33	0.03	0.11	0.15
GYP	-0.45	1.08	3.75	-4.38	0.13	0.18

Abbreveation as in Table 1

The SCA effects of 40 crosses are given in Table 4a & 4b. The corn hybrids L1×T3 and L2×T4 proved to be the excellent specific combiner for all the traits studied except leaf senescence. Hybrid L3×T3 and L5×T1 was useful combiner for all the traits except plant growth rate, pollen size and leaf senescence. The cross combination L9×T2 was also best specific combiner for all the traits except relative water contents, pollen viability, silk receptivity, and seed setting percentage.

The dominance gene action was predominant for all the traits studied (Table 5). The proportional contribution of lines was more for seven very crucial plant parameters i.e., seed vigour, anthesis–silking interval, pollen viability, silk receptivity, seed setting percentage, number of ears per plant and plant maturity, indicating their predominant maternal influence. Testers showed less/no paternal influence to be contributed for all the traits. The relative contribution of line × tester interaction was more important for emergence percentage, plant growth rate, leaf rolling, relative water contents, pollen size, leaf senescence and grain yield per plant.

The estimates of heritability in broad sense were high for all the traits under high temperature condition (Table 5). This suggested that all these hybrids could further be advanced for obtaining desirable pyramidized transgressants for high yield and other secondary parameters under high temperature condition. But degree of dominance greater than 1 for all the traits except plant growth rate depicts the preponderance of overdominance, which might enhance broad sense heritibility as dominance variance is a component of genetic variance being used for estimation of heritability. Therefore, hybrid breeding is suggested as hybrid plants have higher capacity to tolerate heat stress in field conditions than their parents.

Table 4a. Estimation of specific combining ability effects for various traits in forty crosses of corn under high temperature stress condition.

S. No.	Hybrids/Traits	SVP	FEP	PGR	PLR	RWC	ASI	APS
1.	L1×T1	0.22	-0.39	0.06	4.48	-5.13	0.48	10.51
2.	L1×T2	-0.42	-2.83	-0.05	7.91	-0.24	0.02	-5.22
3.	L1×T3	1.38	5.41	0.03	-12.46	4.52	-0.84	1.34
4.	L1×T4	-1.18	-2.19	-0.04	0.08	0.84	0.35	-6.63
5.	L2×T1	-2.87	-3.73	-0.14	11.31	-0.17	0.23	-9.41
6.	L2×T2	0.17	-1.16	0.00	0.41	-2.23	0.27	-2.81
7.	L2×T3	0.63	-0.26	0.05	5.38	-2.12	0.18	-2.58
8.	L2×T4	2.07	5.14	0.08	-17.09	4.53	-0.67	14.79
9.	L3×T1	-0.37	-2.64	0.07	3.81	-3.45	0.37	-2.74
10.	L3×T2	1.00	-2.41	-0.07	7.91	-1.23	0.08	0.53
11.	L3×T3	0.47	4.16	-0.02	-24.13	5.42	-0.76	3.09
12.	L3×T4	-1.10	0.89	0.02	12.41	-0.74	0.31	-0.88
13.	L4×T1	0.47	2.19	0.08	-10.44	0.73	-0.01	-3.33
14.	L4×T2	-0.5	1.09	0.06	7.66	-2.27	-0.05	1.94
15.	L4×T3	1.30	-0.68	-0.11	3.63	-0.42	0.56	-1.49
16.	L4×T4	-1.27	-2.61	-0.03	-0.84	1.96	-0.50	2.88
17.	L5×T1	4.72	4.61	0.08	-20.36	4.88	-0.68	-0.74
18.	L5×T2	-3.25	-2.16	-0.03	10.74	2.57	-0.56	0.19
19.	L5×T3	-1.78	-2.93	-0.06	9.04	-7.01	0.63	1.43
20.	L5×T4	0.32	0.48	0.02	0.58	-0.44	0.61	-0.88
21.	L6×T1	-1.17	-0.98	-0.07	10.73	2.77	-0.82	7.84
22.	L6×T2	1.25	5.26	-0.02	-19.51	-2.82	0.53	0.11
23.	L6×T3	0.72	-1.18	0.09	13.79	-1.67	-0.12	-2.66
24.	L6×T4	-0.85	-3.11	0.00	-5.01	1.75	0.41	-5.29
25.	L7×T1	0.72	3.03	-0.12	9.31	3.26	0.44	3.68
26.	L7×T2	-0.25	0.26	0.02	-14.59	-3.76	-0.01	-0.39
27.	L7×T3	0.88	-2.18	0.02	0.71	3.67	-0.20	-2.49
28.	L7×T4	-1.35	-1.11	0.08	4.58	-3.18	-0.23	-0.79
29.	L8×T1	-0.95	-1.81	0.11	-11.86	-1.17	0.11	8.26
30.	L8×T2	1.42	-0.58	0.04	5.91	3.52	0.05	3.53
31.	L8×T3	-1.78	-0.34	-0.04	2.21	0.01	-0.04	-7.58
32.	L8×T4	1.32	2.73	-0.11	3.74	-2.35	-0.12	-4.21
33.	L9×T1	0.38	1.28	-0.05	3.56	3.49	-0.05	0.18
34.	L9×T2	0.75	0.84	0.02	-16.01	2.84	-0.03	6.78
35.	L9×T3	0.88	-1.59	-0.02	16.96	-2.68	0.24	0.01
36.	L9×T4	-2.02	-0.53	0.05	-4.51	-3.65	-0.17	-6.96
37.	L10×T1	-1.20	-1.56	-0.02	-0.53	-5.21	-0.07	-14.3
38.	L10×T2	-0.17	1.68	0.02	9.58	3.62	-0.30	-4.64
39.	L10×T3	-2.70	-0.43	0.06	-15.13	0.30	0.35	10.93
40.	L10×T4	4.07	0.31	-0.07	6.08	1.29	0.02	7.96
	S.E.(SCA effects)	0.44	0.55	0.01	0.34	1.84	0.02	0.45
	S.E. (Sij-Skl)	0.63	0.78	0.01	0.48	2.60	0.03	0.63

Abbreveation as in Table 1

Table 4b. Estimation of specific combining ability effects for various traits in forty crosses of corn under high temperature stress condition.

S. No.	Hybrids/Traits	PPV	PSR	PSS	NPP	PLS	DPM	GYP
1.	L1×T1	-3.07	-1.73	-3.17	0.03	-1.84	-0.23	-10.3
2.	L1×T2	0.83	0.30	-0.10	-0.02	0.26	0.93	-8.17
3.	L1×T3	5.97	2.23	5.36	0.06	2.43	-4.83	17.5
4.	L1×T4	-3.73	-0.80	-2.09	-0.07	-0.84	4.13	0.97
5.	L2×T1	-2.57	-3.48	-4.23	0.00	-3.59	-0.32	-6.05
6.	L2×T2	-1.33	0.88	1.11	-0.03	0.84	3.18	-7.92
7.	L2×T3	-4.20	-1.18	-1.31	-0.02	-0.99	2.42	-8.92
8.	L2×T4	8.10	3.78	4.43	0.05	3.74	-5.28	22.88
9.	L3×T1	-3.57	-4.07	-4.31	-0.06	-3.59	1.68	-6.05
10.	L3×T2	0.00	-3.03	-2.92	-0.03	-2.83	6.18	-9.25
11.	L3×T3	5.13	6.23	6.68	0.05	5.68	-8.25	15.75
12.	L3×T4	-1.57	0.87	0.55	0.04	0.74	0.38	-0.45
13.	L4×T1	-2.82	-1.48	-1.47	0.00	-1.59	-7.98	-4.72
14.	L4×T2	2.08	2.22	1.94	-0.06	2.18	0.18	-0.25
15.	L4×T3	-0.12	0.48	0.55	0.05	0.68	11.08	-1.92
16.	L4×T4	0.85	-1.22	-1.03	0.01	-1.26	-3.28	6.88
17.	L5×T1	8.93	4.18	4.61	0.14	4.16	-6.82	21.45
18.	L5×T2	0.17	0.88	0.68	-0.05	0.93	-1.98	-4.08
19.	L5×T3	-3.70	-0.18	-0.57	-0.05	-0.58	5.92	-10.42
20.	L5×T4	-5.40	-4.88	-4.72	-0.04	-4.51	2.88	-6.95
21.	L6×T1	0.93	1.02	0.98	-0.01	1.16	7.02	-3.97
22.	L6×T2	0.50	2.05	2.84	0.09	1.93	3.85	19.17
23.	L6×T3	-1.03	-2.68	-3.29	-0.06	-2.58	-6.58	-6.83
24.	L6×T4	-0.40	-0.38	-0.53	-0.03	-0.51	-4.28	-8.37
25.	L7×T1	2.85	3.85	4.71	-0.02	3.49	4.68	-5.13
26.	L7×T2	-1.92	-3.12	-3.63	0.13	-2.74	-5.82	14.00
27.	L7×T3	0.55	-0.52	-1.24	-0.08	-0.24	-2.58	-12.00
28.	L7×T4	-1.48	-0.22	0.16	-0.03	-0.51	3.72	3.13
29.	L8×T1	-0.65	0.77	0.94	0.01	0.99	-6.40	6.37
30.	L8×T2	2.58	2.47	2.74	-0.03	2.09	-1.90	-2.17
31.	L8×T3	-0.28	-0.93	-1.46	-0.01	-0.74	7.33	0.83
32.	L8×T4	-1.65	-2.30	-2.22	0.03	-2.34	0.97	-5.03
33.	L9×T1	-1.98	-0.40	-0.27	-0.07	-0.09	9.35	14.62
34.	L9×T2	-3.75	-5.03	-4.89	0.06	-5.33	-3.82	2.42
35.	L9×T3	3.05	2.23	1.41	0.02	2.18	-4.92	-6.58
36.	L9×T4	2.68	3.20	3.78	-0.02	3.24	-0.62	-10.45
37.	L10×T1	1.93	1.35	2.21	-0.04	0.91	-0.98	-6.22
38.	L10×T2	0.83	2.38	2.21	-0.07	2.68	-0.82	-3.75
39.	L10×T3	-5.37	-5.68	-6.13	0.04	-5.83	0.42	12.58
40.	L10×T4	2.60	1.95	1.71	0.06	2.24	1.38	-2.62
	S.E.(SCA effects)	0.42	0.40	0.33	0.01	0.43	0.34	0.40
	S.E. (Sij-Skl)	0.59	0.56	0.47	0.02	0.61	0.49	0.57

Abbreveation as in Table 1

Table 5. Ratio of genotypic and phenotypic variances, proportional contribution of lines, testers and their interaction to the total variance phenotypic and genotypic variance, heritability (broad sense) and genetic advance for various plant traits of corn genotypes under high temperature condition.

S. No.	Traits	$\sigma^2_{sca}/\sigma^2_{gca}$	Lines (%)	Testers (%)	Lines × Testers	σ^2_g	σ^2_p	h^2_{BS}	G.A. (i=10%)
1.	SVP	23.06	57.87	4.48	37.66	10.33	10.52	0.98	5.60
2.	FEP	214.00	35.06	1.70	63.24	13.53	13.83	0.98	6.40
3.	PGR	0.00	20.85	6.99	72.16	0.08	0.08	0.99	0.49
4.	PLR	2355.00	30.19	1.14	68.67	198.96	199.07	0.99	24.82
5.	RWC	43.08	33.21	16.05	50.74	18.43	21.82	0.84	6.95
6.	ASI	12.00	72.94	2.32	24.74	1.43	1.44	0.99	2.11
7.	APS	58.24	43.32	5.27	51.41	71.62	71.82	0.99	14.87
8.	PPV	22.15	59.54	4.14	36.31	40.77	40.95	0.99	11.21
9.	PSR	11.59	68.19	6.30	25.52	36.29	36.47	0.99	10.57
10.	PSS	16.99	62.85	5.56	31.59	37.50	37.61	0.99	10.76
11.	NEP	1.00	97.12	0.22	2.66	0.09	0.10	0.99	0.55
12.	PLS	365.31	22.96	3.79	73.26	72.53	72.73	0.99	14.97
13.	DPM	38.04	54.61	0.14	45.26	55.01	55.13	0.99	13.04
14.	GYP	136.38	11.29	7.42	81.29	334.72	334.88	0.99	32.19

Abbreveation as in Table 1

The results indicated that use of single plant traits as indirect selection criteria, would be unlikely to improve yield or heat resistance rather a harmonious combination of most or all of the traits will impart whole plant thermo-tolerant abilities in a single genotype.

Significant genotype × environment interactions and significant effect of temperature on various parameters of corn grown under different temperatures, sowing dates and locations were also reported by Zaborsky *et al*., (2001), Duarte *et al*., (2003) and Badu-Apraku *et al*., (2004). These results are in agreement with those of Satyanarayana & Saikumar (1995) who observed wide and significant phenotypic variation for grain yield and other agronomic characters in corn. Highly significant differences were also observed for testers, lines and line x tester interaction by Soliman & Sadek (1999). Mendoza *et al.* (2000) also indicated that the average performance of the lines and testers was statistically different for flowering date, plant height and yield. Torrecilla *et al*., (2000) studied the genetic diversity and relationship among 19 types of native corn populations and reported variability for plant height, days to flowering and grain yield etc. Results were also in agreement with those of Venugopal *et al*., (2002), Menkir *et al*., (2003), Magorokosho *et al*., (2003), Shanthi *et al*., (2003) and Reddy *et al*., (2003) who reported significant differences among lines, testers and their interactions for various traits of corn.

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