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Study on gene action and combining abilities for thermotolerant ablilities of corn (*Zea mays* L.)

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Abstract

High temperature reduces the pollen viability and silk receptivity of corn resulting in poor seed set and reduced yield. Continuously increasing temperature and less frequency and distribution of rainfall coupled with usual canal–closure particularly in Pakistan have significantly been decreasing 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 × tester mating design. The 40 hybrids and 14 parents were evaluated for heat tolerance under moderate temperature field conditions (by sowing on March 31) using triplicated randomized complete block design during spring 2004. Large differences in heat units (111 to 326) utilized by the parents and crosses under normal and moderate 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. 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 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 were proved to be the excellent combiners with high GCA and SCA effects respectively, for most of the traits. 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.

Keywords: Corn; heat tolerance; combining ability; heritability; line × tester analysis; genotype × environment interaction.

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. Offseason maize is more for use as greenshoots.

Normally maize grows and yields at optimal temperature of 10 – 30 °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 °C) increases 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 forcasted which would eventually affect 140 M people in developing countries (Wettstein and 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.

Continuously increasing 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 moderately high prevailing temperatures (usually 42 °C maximum) at flowering (June) causes top firing or tassel blast which occur at 38 °C and above, and seriously reduces the seed set. While in autumn season (July-August) planting moderately high temperature at planting time (usually 45°C maximum) affects seed germination and seedling growth. Such 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 is designed to evaluate lines, testers and their crosses under normal and moderate 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 moderate 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 moderate 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 and 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 moderate temperature stress condition (Table 1). Table 1 further showed significant differences ($P \leq 0.01$) among 10 lines for seed vigour percentage, field emergence percentage, anthesis-silking interval, percent silk receptivity, percent seed setting, number of ears per plant, percent leaf scenescence and days to maturity. Four testers were non-significantly different ($P > 0.05$) for all the traits except relative water contents and anthesis-silking interval which were significant. Heat units difference among parental lines (female and male) and cross combinations under normal and moderate temperature field conditions suggested that inbred lines as well as crosses are photosensitive. Detail of daily heat units are given in Appendix I. 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 L2, L3 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, pollen viability, leaf scenescence and grain yield per plant. The line L2 proved to be the best general combiner leaf scencscence and grain yield per plant. The line L5 was best general combiner for seed vigour, emergence-percentage, pollen size, pollen viability, silk receptivity and seed setting percentage. The GCA effects of four testers are presented in Table 3. Among testers, T3 was the best general combiner for plant growth rate, relative water contents, anthesis-silking interval, pollen viability, silk receptivity, seed setting percentage, leaf scenescence and grain yield per plant while the tester T1 had high GCA for seed vigour and pollen size.

The SCA effects of 40 crosses are given in Table 4a and 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, emergence percentage, anthesis–silking interval, number of ears per plant, leaf senescence 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 plant growth rate, leaf rolling, relative water contents, pollen size, pollen viability, silk receptivity, seed setting and grain yield per plant.

The estimates of heritability in broad sense were high for all the traits under moderate 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 moderate temperature stress. But degree of dominance greater than 1 for all the traits except plant growth rate depicts the preponderance of overdominance, which might enhanced 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.

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 and 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 and 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

Table 1. Mean squares for line × tester analysis for various plant traits of 54 corn genotypes under moderate temperature stress condition.

	Rep.	Genotypes	Parents (P)	Pvs Crosses	Crosses	Lines (L)	Testers (T)	L × T	Error
Traits /DF	2	53	13	1	39	9	3	27	106
SVP	0.49^{NS}	23.7**	40.47**	170.07**	14.46**	36.20**	9.16 ^{NS}	7.81**	1.18
FEP	5.36**	30.90**	59.27**	203.25**	17.03**	37.56**	6.03 ^{NS}	11.40**	0.88
PGR	0.00 ^{NS}	0.16**	0.04**	7.26**	0.02**	0.01 ^{NS}	0.04 ^{NS}	0.02**	0.00
PLR	3.19*	370.18**	40.20**	8609.91**	268.91**	419.98^{NS}	36.50^{NS}	244.37**	0.68
RWC	10.48**	44.20**	29.05**	213.66**	44.91**	42.59 ^{NS}	202.92**	28.12**	0.23
ASI	0.00 ^{NS}	2.65**	6.32**	1.06**	1.47**	5.38**	0.79*	0.24**	0.00
APS	2.04*	208.38**	263.12**	30.96**	194.68**	313.74^{NS}	173.3^{NS}	157.36**	0.58
PPV	15.73**	56.02**	109.41**	158.17**	35.61**	62.50 ^{NS}	22.88^{NS}	28.06**	0.67
PSR	5.35**	48.48**	86.38**	82.51**	34.97**	70.69*	26.44^{NS}	24.01**	0.38
PSS	6.97**	43.62**	80.05**	59.71**	31.06**	59.30*	25.97^{NS}	22.21**	0.38
NEP	0.00 ^{NS}	0.30**	0.16**	0.03**	0.35**	1.51**	0.00 ^{NS}	0.01**	0.00
PLS	12.08**	326.48**	314.95**	46.78**	337.50**	857.00**	25.90 ^{NS}	198.96**	0.78
DPM	25.49**	156.79**	190.20**	9.33**	149.44**	365.07**	1.51 ^{NS}	93.99**	0.41
GYP	5.04**	1142.32**	205.15**	51126.05**	173.08**	92.02 ^{NS}	235.44^{NS}	193.16**	0.48

Rep= Replications
DF = Degree of Freedom
Gen= Genotypes
Rep×Gen= Replication x Genotypes
Env= Environments
Gen×Env= Genotype x Environments
COV= Coeff. of Variation
PLS = Percent Leaf Senescence
SVP= Seed Vigour Percentage
PPV = Percent Pollen Viability
FEP= Field Emergence Perecntage
PSR = Percent Silk Receptivity
PGR= Plant Growth Rate
PSS = Percent Seed Setting
PLR= Percent Leaf Rolling
NEP = No. of Ears per Plant
RWC= Relative Water Contents
GYP = GrainYield per Plant
ASI = Anthesis-Silking-Interval
DPM = Days to Plant Maturity
APS= Average Pollen Size
^{NS} = non-significant at P > 0.05
* = significant at P≤0.05
** = significant at P ≤ 0.0
(These will be followed in the subsequent tables).

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.

Table 2. Estimation of GCA effects for various traits in ten lines (female parents) of corn under moderate temperature stress condition.

Traits / Lines	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8	L_9	L_{10}	S.E. (GCA for lines)	S.E. (gi-gj) lines
SVP	-0.48	-0.98	2.60	1.60	2.27	-2.40	-1.98	-0.73	0.85	-0.73	0.31	0.44
FEP	-0.33	-0.83	3.43	0.68	2.09	-2.08	-1.66	-0.66	0.93	-1.58	0.27	0.38
PGR	-0.00	0.04	-0.01	0.01	0.01	-0.04	-0.02	0.01	0.04	-0.04	0.01	0.01
PLR	-8.68	-6.43	1.73	12.90	-2.60	-1.35	-1.93	3.48	1.73	1.15	0.24	0.34
RWC	-0.78	-1.86	-0.44	-1.64	0.04	-1.12	-0.10	2.98	-0.84	3.77	0.14	0.19
ASI	-0.78	-0.73	-0.76	-0.36	-0.29	0.75	0.80	0.87	0.28	0.23	0.02	0.02
APS	-3.45	-1.87	5.38	-6.37	5.72	-2.28	-5.37	6.88	4.88	-3.53	0.22	0.31
PPV	0.82	-0.10	2.98	2.32	3.23	-2.52	-2.93	-0.27	-1.43	-2.10	0.24	0.15
PSR	0.22	0.80	1.88	1.97	4.13	-3.28	-3.37	0.72	-1.03	-2.03	0.18	0.25
PSS	0.85	1.02	1.94	2.03	3.03	-3.20	-3.00	0.65	-1.17	-2.15	0.18	0.25
NEP	-0.11	0.69	-0.14	0.65	-0.18	-0.18	-0.18	-0.21	-0.17	-0.18	0.01	0.01
PLS	3.00	19.50	8.50	-1.75	-4.50	-9.50	-6.25	-2.75	-4.00	-2.25	0.25	0.36
DPM	-7.33	-6.67	-6.08	1.08	-2.50	8.92	1.50	1.33	4.67	5.08	0.18	0.26
GYP	1.03	3.53	4.70	-3.55	-2.22	-1.72	0.70	-1.47	1.70	-2.72	0.20	0.28

Table 3. Estimation of GCA effects for various traits in four common testers (male parents) of corn under moderate temperature stress condition.

Traits / Testers	T_1	T_2	T_3	T_4	S.E. (GCA for testers)	S.E. (gi-gj) testers
SVP	0.67	-0.60	-0.27	0.20	0.20	0.28
FEP	0.58	-0.46	-0.23	0.11	0.17	0.24
PGR	0.01	0.01	0.04	-0.05	0.01	0.01
PLR	-0.65	-0.55	-0.45	1.65	0.15	0.21
RWC	-3.47	0.36	2.84	0.28	0.09	0.12
ASI	-0.19	-0.05	0.20	0.05	0.01	0.01
APS	2.22	1.92	-2.38	-1.75	0.14	0.20
PPV	0.18	-1.28	0.58	0.52	0.15	0.21
PSR	0.23	-1.23	1.03	-0.03	0.11	0.16
PSS	-0.11	-1.12	1.15	0.07	0.11	0.16
NEP	0.01	0.00	-0.00	-0.01	0.01	0.01
PLS	0.05	-0.95	1.25	-0.35	0.16	0.23
DPM	-0.13	-0.13	-0.07	0.33	0.12	0.16
GYP	-0.77	1.37	2.93	-3.53	0.13	0.18

Table 4(a). Estimation of SCA effects for various traits in 40 crosses of corn under moderate temperature stress condition.

S#	Crosses./ Traits	SVP	FEP	PGR	PLR	RWC	ASI	APS
1	$L_1 \times T_1$	-0.92	1.59	0.05	3.32	-3.94	0.43	8.62
2	$L_1 \times T_2$	-1.32	-1.71	-0.08	5.22	0.98	-0.05	-5.42
3	$L_1 \times T_3$	2.02	3.06	0.01	-6.22	3.26	-0.33	1.88
4	$L_1 \times T_4$	0.22	-2.94	0.02	-2.32	-0.30	-0.05	-5.08
5	$L_2 \times T_1$	-2.08	-3.24	-0.13	12.40	0.35	0.10	-2.63
6	$L_2 \times T_2$	-0.15	-1.54	0.03	-4.03	-1.45	0.02	-11.33
7	$L_2 \times T_3$	0.18	0.23	0.08	1.87	-1.31	-0.06	-3.03
8	$L_2 \times T_4$	2.05	4.56	0.02	-10.23	2.41	-0.06	17.00
9	$L_3 \times T_1$	-0.33	-0.83	0.05	3.23	-3.95	0.13	-3.88
10	$L_3 \times T_2$	0.27	0.54	0.02	3.47	0.60	0.04	3.42
11	$L_3 \times T_3$	1.27	1.64	-0.02	-14.30	3.40	-0.13	2.38
12	$L_3 \times T_4$	-1.20	-1.36	-0.05	7.60	-0.05	-0.04	-1.92
13	$L_4 \times T_1$	3.33	0.93	0.10	-8.93	1.35	-0.21	-3.47
14	$L_4 \times T_2$	0.60	1.29	0.06	6.30	-1.78	-0.26	0.83
15	$L_4 \times T_3$	-1.07	-0.28	-0.19	3.20	-1.89	0.28	1.13
16	$L_4 \times T_4$	-2.87	-1.94	0.02	-0.57	2.32	0.18	1.50
17	$L_5 \times T_1$	1.00	1.18	0.04	-14.10	-0.29	-0.37	-2.55
18	$L_5 \times T_2$	-0.07	-0.46	-0.04	8.13	0.31	-0.44	1.75
19	$L_5 \times T_3$	-0.73	-0.69	-0.02	6.03	1.10	0.39	3.38
20	$L_5 \times T_4$	-0.20	-0.03	0.01	-0.07	-1.13	0.42	-2.58
21	$L_6 \times T_1$	0.67	0.68	-0.08	8.65	4.42	-0.13	6.78
22	$L_6 \times T_2$	0.60	2.71	-0.04	-11.12	-3.22	0.35	1.42
23	$L_6 \times T_3$	0.27	-1.19	0.13	9.12	-2.91	-0.39	-2.62
24	$L_6 \times T_4$	-1.53	-2.19	-0.01	-6.65	1.71	0.17	-5.58
25	$L_7 \times T_1$	1.92	0.93	-0.08	5.90	3.65	0.16	1.53
26	$L_7 \times T_2$	0.85	0.29	-0.03	-9.53	-5.29	-0.21	-0.17
27	$L_7 \times T_3$	-1.48	-0.61	0.04	-0.63	3.41	0.13	-1.87
28	$L_7 \times T_4$	-1.28	-0.61	0.06	4.27	-1.78	-0.08	0.50
29	$L_8 \times T_1$	-1.67	-1.74	0.11	-8.85	0.30	0.11	7.28
30	$L_8 \times T_2$	-0.07	-0.71	0.01	2.05	2.86	0.32	7.25
31	$L_8 \times T_3$	-0.73	-0.28	-0.03	-2.05	-1.51	0.05	-10.12
32	$L_8 \times T_4$	2.47	2.73	-0.10	8.85	-1.65	-0.48	-4.42
33	$L_9 \times T_1$	-1.25	0.34	-0.05	-0.10	2.14	0.06	0.62
34	$L_9 \times T_2$	0.35	0.38	0.04	-10.87	3.08	0.04	7.58
35	$L_9 \times T_3$	0.68	-1.19	-0.04	12.70	-2.59	-0.00	-0.78
36	$L_9 \times T_4$	0.22	0.48	0.06	-1.73	-2.63	-0.09	-7.42
37	$L_{10} \times T_1$	-0.67	0.18	-0.02	-1.52	-4.04	-0.27	-12.30
38	$L_{10} \times T_2$	-1.07	-0.79	0.03	10.38	3.89	0.20	-5.33
39	$L_{10} \times T_3$	-0.40	-0.69	0.03	-9.72	-0.95	0.05	9.63
40	$L_{10} \times T_4$	2.13	1.31	-0.05	0.85	1.09	0.02	8.00
S.E. (SCA Effects)		0.63	0.54	0.01	0.48	0.28	0.03	0.44
S.E. (Sij-Skl)		0.89	0.77	0.01	0.67	0.39	0.04	0.62

Table 4(b). Estimation of SCA effects for various traits in 40 crosses of corn under moderate temperature stress condition.

S#	Crosses./ Traits	PPV	PSR	PSS	NPP	PLS	DPM	GYP
1	$L_1 \times T_1$	-2.68	-2.98	-3.46	-0.00	-8.80	-3.37	-8.90
2	$L_1 \times T_2$	0.45	1.15	0.10	-0.03	-8.80	5.30	-4.70
3	$L_1 \times T_3$	2.58	3.22	4.46	0.02	10.00	-4.77	10.4
4	$L_1 \times T_4$	-0.35	-1.38	-1.10	0.01	7.60	2.83	3.20
5	$L_2 \times T_1$	-1.10	-1.23	-0.97	0.04	3.70	0.63	-5.40
6	$L_2 \times T_2$	-1.97	-1.77	-1.51	-0.07	-4.30	2.63	-7.20
7	$L_2 \times T_3$	-2.17	-1.37	-1.19	0.02	-3.50	1.90	-1.77
8	$L_2 \times T_4$	5.23	4.37	3.67	0.01	4.10	-5.17	14.37
9	$L_3 \times T_1$	-3.85	-2.98	-3.05	-0.06	-1.30	2.38	-1.90
10	$L_3 \times T_2$	-2.72	-2.85	-2.09	0.00	-4.30	1.72	-5.37
11	$L_3 \times T_3$	6.08	5.22	5.17	0.03	15.50	-4.68	4.40
12	$L_3 \times T_4$	0.48	0.62	-0.03	0.03	-9.90	0.58	2.87
13	$L_4 \times T_1$	-1.18	-0.73	-0.77	0.05	11.95	-7.78	-5.32
14	$L_4 \times T_2$	2.62	2.07	2.03	-0.03	-3.05	0.22	-2.45
15	$L_4 \times T_3$	-0.58	-0.20	0.11	0.03	-8.25	10.15	-1.02
16	$L_4 \times T_4$	-0.85	-1.13	-1.37	-0.05	-0.65	-2.58	8.78
17	$L_5 \times T_1$	6.90	5.43	3.42	0.08	-2.30	-6.53	15.02
18	$L_5 \times T_2$	0.03	0.23	-0.22	-0.03	14.70	-1.53	-0.45
19	$L_5 \times T_3$	-3.17	-1.03	0.38	-0.02	-6.50	6.40	-7.02
20	$L_5 \times T_4$	-3.77	-4.63	-3.57	-0.03	-5.90	1.67	-7.55
21	$L_6 \times T_1$	1.32	1.52	1.28	-0.01	-5.30	7.72	0.85
22	$L_6 \times T_2$	-0.22	0.32	0.18	0.07	0.70	3.72	9.72
23	$L_6 \times T_3$	-0.42	-0.28	-0.42	-0.03	0.50	-7.68	-0.85
24	$L_6 \times T_4$	-0.68	-1.55	-1.05	-0.03	4.10	-3.75	-9.72
25	$L_7 \times T_1$	1.07	1.60	1.60	-0.02	-4.55	5.13	2.77
26	$L_7 \times T_2$	-1.13	-2.27	-1.31	0.07	8.45	-5.87	6.63
27	$L_7 \times T_3$	-0.67	-0.20	-0.86	-0.02	-0.75	-2.93	-11.27
28	$L_7 \times T_4$	0.73	0.87	0.57	-0.03	-3.15	3.67	1.87
29	$L_8 \times T_1$	-0.60	-1.48	-1.12	-0.02	12.95	-6.37	8.60
30	$L_8 \times T_2$	2.20	2.98	2.79	-0.02	-7.05	-0.37	-2.87
31	$L_8 \times T_3$	1.67	-0.28	-0.46	0.03	-6.25	5.23	-0.10
32	$L_8 \times T_4$	-3.27	-1.22	-1.21	0.01	0.35	1.50	-5.63
33	$L_9 \times T_1$	-0.10	1.27	2.18	-0.05	-7.80	9.63	0.43
34	$L_9 \times T_2$	0.03	-1.60	-1.51	0.07	6.20	-5.70	7.63
35	$L_9 \times T_3$	1.17	-0.53	-1.35	-0.01	2.00	-4.43	-2.60
36	$L_9 \times T_4$	-1.10	0.87	0.68	-0.01	-0.40	0.50	-5.47
37	$L_{10} \times T_1$	0.23	-0.40	0.89	-0.02	1.45	-1.45	-6.15
38	$L_{10} \times T_2$	0.70	1.73	1.54	-0.03	-2.55	-0.12	-0.95
39	$L_{10} \times T_3$	-4.50	-4.53	-5.84	-0.03	-2.75	0.82	9.82
40	$L_{10} \times T_4$	3.57	3.20	3.41	0.08	3.85	0.75	-2.72
	S.E. (SCA Effects)	0.47	0.35	0.36	0.02	0.51	0.37	0.40
	S.E. (Sij-Skl)	0.67	0.50	0.50	0.02	0.72	0.52	0.56

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 moderate 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	20.90	57.75	4.87	37.38	7.53	7.93	0.95	4.71
2	FEP	39.00	50.92	2.72	46.36	10.01	10.30	0.97	5.49
3	PGR	0.00	12.48	17.79	69.73	0.05	0.05	0.99	0.41
4	PLR	203.08	36.04	1.04	62.91	123.17	123.39	0.99	19.51
5	RWC	33.21	21.88	34.76	43.35	14.66	14.73	0.99	6.72
6	ASI	4.00	84.72	4.17	11.11	0.88	0.88	0.99	1.65
7	APS	85.67	37.19	6.85	55.96	69.27	69.46	0.99	14.63
8	PPV	76.08	40.51	4.94	54.55	18.45	18.67	0.99	7.52
9	PSR	43.77	46.65	5.82	47.54	16.03	16.16	0.99	7.02
10	PSS	48.53	44.06	6.43	49.51	14.41	14.54	0.99	6.65
11	NEP	0.00	98.62	0.05	1.33	0.10	0.10	0.99	0.55
12	PLS	29.10	58.60	0.59	40.81	108.57	108.83	0.99	18.32
13	DPM	34.29	56.38	0.08	43.54	52.13	52.26	0.99	12.69
14	GYP	194.64	12.27	10.46	77.27	380.61	380.77	1.00	34.33

References

Badu-Apraku B., Hunter, R.B., Tollenaar, M., 1983. Effect of temperature during grain filling on whole plant and grain yield in maize (*Zea mays,* L.). Can. J. Plant Sci., 63, 357-363.

Betran, F.J., Beck, D., Banziger, M., Edmeades, G.O., 2003. Genetic Analysis of inbred and hybrid grain yield under stress and non-stress environments in tropical maize. Crop Sci., 43, 807-817.

Campos, H., Cooper, A., Habben, J.E., Edmeades, G.O., Schussler, J.R., 2004. Improving drought tolerance in maize: a view from industry. Field Crops Res., 90, 19-34.

Duarte, I.D., Ferreira, J.M., Nuss, C.N., 2003. Screening potential of three maize topcross testers. Pesqui. Agropecu. Bras. 38, 365-372.

Kempthorne, O. 1957. An introduction to Genetical Statistics. John Wiley & Sons, Inc., New York.

Magorokosho, C., Pixley, K.V., Tongoona, P. 2003. Selection for drought tolerance in two tropical maize populations. Afr. Crop Sci. J., 11, 151-161.

Mendoza, M.A., Lopez, A. Rodriguez, S.A. de Leon, C. Jeffers, D., 2002. Separation of epistatic, additive and dominant effects on corn. Agronomia Mesoamericana, Mexico. 11, 83-88.

Menkir, A., Badu-Apraku, B., Adepoju, C.A., 2003. Evaluation of heterotic patterns of IITA'S lowland white maize inbred lines. Maydica. 48, 161-170.

Pakistan Statistical Year Book, 2005. Statistic division, Federal Bureau of statistics, Government of Pakistan, Islamabad.

Reddy, V. S., Mohan, Y.C., Rao, N.V., Krishna, L., 2003. Combining ability studies through L × T design in popcorn (*Zea mays var. everta*). Res. Crops. 4, 91-96.

Samuel, R.A., Scott, W.O. Hoft, R.G. 1986. Modern Corn Production. 3rd ed. A&L Publish. Inc., Station A, Box F, Champaign, Illinois, USA.

Satyanarayana, E., Saikumar, S., 1995. Genetic variability and *per se* performance of non-conventional hybrids in maize. Himachal. J. Agri. Res. 29, 213-218.

Shanthi, P., Satyanarayana, E. Reddy, G.J.M., 2002. Genetic studies for grain yield and oil improvement in maize (*Zea mays* L.). Res. Crops 3, 588-591.

Singh R.K., Chaudhary, B.D., 1985. Biometrical Methods in Quantitative Genetic Analysis. 3rd ed. pp 205-214, Kalyani Publish. New Delhi, India.

Soliman, F.H.S., Sadek, S.E., 1999. Combining ability of new maize inbred lines and its utilization in the Egyptian hybrid programme. Bulletin Faculty Agric. Univ. Cairo. 50, 1-20.

Steel R.G.D., Torrie, J.H., 1980. Principles and Procedures of Statistics-A Biometrical Approach. 2nd ed. McGraw Hill Int. Book Co., Tokyo, Japan.

Syed, I.A. 2005. The Seed News. 7, 1-6, 2005. 77, Street 96, I-8/4, Islamabad, Pakistan.

Torrecilla, C.V., Mejia-Contreras, A. Balderrama-Castro, S. Carballo-Carballo, A., Gonzalez-Cossio, V.F., 2000. Divergence in native maize populations in high vallies of Mexico. Agro-Ciencia. 34: 167-174.

Wettstein, J., Nelson, J. 2003. "Global warming threatens food shortages in developing countries" in the website http://www.futureharvest.org/news/climate.

Zaidi, P.H., Srinivasan, G. Cordova, H.S., Sanchez, C., 2004. Gains from improvement for mid-season drought tolerance in tropical maize (*Zea mays,* L.). Field Crops Res. 89, 135-152.

Appendix I. Heat units difference among parental lines (female and male) under normal and high temperature stress conditions.

Sr.	Germplasm	Normal temperature		High temperature		Difference of heat units
		Days to physiological Maturity	Heat units	Days to physiological maturity	Heat units	
1	L_1	113	1161	81	1398	237
2	L_2	113	1161	80	1378	217
3	L_3	115	1193	82	1415	222
4	L_4	121	1292	85	1466	174
5	L_5	122	1301	87	1501	200
6	L_6	133	1484	96	1675	191
7	L_7	134	1502	98	1715	213
8	L_8	131	1446	95	1655	209
9	L_9	140	1617	104	1831	214
10	L_{10}	138	1578	101	1772	194
11	T_1	133	1484	97	1695	211
12	T_2	132	1466	102	1792	326
13	T_3	135	1520	99	1735	215
14	T_4	129	1409	93	1615	206

Appendix I(a). Heat units difference among various cross combinations under normal and high temperature stress conditions.

Sr.	Germplasm	Normal temperature		High temperature		Difference of heat units
		Days to physiological Maturity	Heat units	Days to physiological maturity	Heat units	
1	$L_1 \times T_1$	119	1262	85	1466	204
2	$L_1 \times T_2$	127	1373	86	1484	111
3	$L_1 \times T_3$	113	1161	80	1378	217
4	$L_1 \times T_4$	124	1328	89	1536	208
5	$L_2 \times T_1$	120	1278	86	1484	206
6	$L_2 \times T_2$	124	1328	89	1536	208
7	$L_2 \times T_3$	124	1328	88	1515	187
8	$L_2 \times T_4$	114	1177	81	1398	221
9	$L_3 \times T_1$	127	1373	91	1575	202
10	$L_3 \times T_2$	125	1342	95	1655	313
11	$L_3 \times T_3$	113	1161	80	1378	217
12	$L_3 \times T_4$	125	1342	89	1536	194
13	$L_4 \times T_1$	121	1292	87	1501	209
14	$L_4 \times T_2$	131	1446	95	1655	209
15	$L_4 \times T_3$	141	1636	105	1851	215
16	$L_4 \times T_4$	128	1390	91	1575	185
17	$L_5 \times T_1$	118	1244	84	1445	201
18	$L_5 \times T_2$	125	1342	89	1536	194
19	$L_5 \times T_3$	133	1484	96	1675	191
20	$L_5 \times T_4$	130	1426	94	1635	209

Appendix II(b). Heat units difference among various cross combinations under normal and high temperature stress conditions.

Sr.	Germplasm	Normal temperature		High temperature		
		Days to physiological maturity	Heat Units	Days to physiological maturity	Heat units	Difference of heat units
21	$L_6 \times T_1$	146	1729	110	1944	215
22	$L_6 \times T_2$	142	1654	106	1869	215
23	$L_6 \times T_3$	131	1446	95	1655	209
24	$L_6 \times T_4$	135	1520	98	1715	195
25	$L_7 \times T_1$	136	1540	100	1755	215
26	$L_7 \times T_2$	124	1328	89	1536	208
27	$L_7 \times T_3$	128	1390	92	1595	205
28	$L_7 \times T_4$	135	1520	99	1735	215
29	$L_8 \times T_1$	125	1342	89	1536	194
30	$L_8 \times T_2$	129	1409	93	1615	206
31	$L_8 \times T_3$	137	1559	102	1792	233
32	$L_8 \times T_4$	132	1466	96	1675	209
33	$L_9 \times T_1$	144	1693	108	1906	213
34	$L_9 \times T_2$	130	1426	94	1635	209
35	$L_9 \times T_3$	129	1409	93	1615	206
36	$L_9 \times T_4$	134	1502	98	1715	213
37	$L_{10} \times T_1$	133	1484	96	1675	191
38	$L_{10} \times T_2$	132	1466	96	1675	209
39	$L_{10} \times T_3$	134	1502	97	1695	193
40	$L_{10} \times T_4$	135	1520	98	1715	195

Appendix III. Monthly air temperatures and heat units (Year, 2004).

Months	Max Temp. (°C)	Min Temp. (°C)	Avg. Temp. (°C)	Monthly Heat Units	Accum. Heat Units (Total)	Relative Humidity (%)	Rainfall (mm) Total	Wind Velocity (km/h)
January	19.94	08.32	14.13	159.5	159.5	76.77	18.0	3.65
February	25.48	11.03	18.26	247.5	407.0	61.52	06.0	4.81
March	34.39	16.29	25.34	407.0	814.0	42.39	00.00	3.85
April	39.07	21.83	30.45	477.5	1291.5	32.60	25.00	4.59
May	40.94	25.55	33.24	545.5	1837	31.45	01.80	4.95
June	40.27	27.73	34.00	559.5	2396.5	45.43	98.11	5.81
July	40.26	28.94	34.60	598.0	2994.5	52.42	51.70	5.79
August	37.48	27.87	32.68	586.5	3581.0	66.61	80.80	4.29
September	38.53	25.37	31.95	530.5	4111.5	59.03	25.60	3.89
October	32.94	18.42	25.68	436.5	4548.0	54.00	00.80	3.79
November	29.60	13.70	21.70	-------	-------	60.10	09.00	2.60
December	23.80	09.50	16.70	------	-------	61.00	02.00	3.60
Av. 2004	33.55	19.50	26.53	454.80	------	64.53	25.73	4.28
Av. 5 Yrs	28.90	8.10	16.00	------	------	64.00	2.90	3.00
Av. 10 Yrs	22.20	08.10	15.20	------	------	72.00	05.30	2.50