

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

H. Tassawar*, A. K. Iftikhar, A. Zulfiqar

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

*Corresponding author.

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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 \times 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 \times tester ($L \times T$) for 14 maize plant traits. The inbred lines L1, L2, L3, L5 (lines), T1, T3 (testers) and hybrids L1 \times T3, L2 \times T4, L3 \times T3 and L5 \times 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 \times tester analysis; genotype \times 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 forecasted 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-04317*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 ($L \times T$) 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 senescence 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 senescence and grain yield per plant. The line L2 proved to be the best general combiner leaf senescence 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 senescence 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 heritability 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 \times tester analysis for various plant traits of 54 corn genotypes under moderate temperature stress condition.

Traits /DF	Rep.	Genotypes	Parents (P)	Pvs Crosses	Crosses	Lines (L)	Testers (T)	L \times T	Error
	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

Gen= Genotypes

Env= Environments

COV= Coeff. of Variation

SVP= Seed Vigour Percentage

FEP= Field Emergence Percentage

PGR= Plant Growth Rate

PLR= Percent Leaf Rolling

RWC= Relative Water Contents

ASI = Anthesis-Silking-Interval

APS= Average Pollen Size

* = significant at $P \leq 0.05$

(These will be followed in the subsequent tables).

DF = Degree of Freedom

Rep \times Gen= Replication \times Genotypes

Gen \times Env= Genotype \times Environments

PLS = Percent Leaf Senescence

PPV = Percent Pollen Viability

PSR = Percent Silk Receptivity

PSS = Percent Seed Setting

NEP = No. of Ears per Plant

GYP = Grain Yield per Plant

DPM = Days to Plant Maturity

^{NS} = non-significant at $P > 0.05$

** = significant at $P \leq 0.0$

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 ×T ₁	-0.92	1.59	0.05	3.32	-3.94	0.43	8.62
2	L ₁ ×T ₂	-1.32	-1.71	-0.08	5.22	0.98	-0.05	-5.42
3	L ₁ ×T ₃	2.02	3.06	0.01	-6.22	3.26	-0.33	1.88
4	L ₁ ×T ₄	0.22	-2.94	0.02	-2.32	-0.30	-0.05	-5.08
5	L ₂ ×T ₁	-2.08	-3.24	-0.13	12.40	0.35	0.10	-2.63
6	L ₂ ×T ₂	-0.15	-1.54	0.03	-4.03	-1.45	0.02	-11.33
7	L ₂ ×T ₃	0.18	0.23	0.08	1.87	-1.31	-0.06	-3.03
8	L ₂ ×T ₄	2.05	4.56	0.02	-10.23	2.41	-0.06	17.00
9	L ₃ ×T ₁	-0.33	-0.83	0.05	3.23	-3.95	0.13	-3.88
10	L ₃ ×T ₂	0.27	0.54	0.02	3.47	0.60	0.04	3.42
11	L ₃ ×T ₃	1.27	1.64	-0.02	-14.30	3.40	-0.13	2.38
12	L ₃ ×T ₄	-1.20	-1.36	-0.05	7.60	-0.05	-0.04	-1.92
13	L ₄ ×T ₁	3.33	0.93	0.10	-8.93	1.35	-0.21	-3.47
14	L ₄ ×T ₂	0.60	1.29	0.06	6.30	-1.78	-0.26	0.83
15	L ₄ ×T ₃	-1.07	-0.28	-0.19	3.20	-1.89	0.28	1.13
16	L ₄ ×T ₄	-2.87	-1.94	0.02	-0.57	2.32	0.18	1.50
17	L ₅ ×T ₁	1.00	1.18	0.04	-14.10	-0.29	-0.37	-2.55
18	L ₅ ×T ₂	-0.07	-0.46	-0.04	8.13	0.31	-0.44	1.75
19	L ₅ ×T ₃	-0.73	-0.69	-0.02	6.03	1.10	0.39	3.38
20	L ₅ ×T ₄	-0.20	-0.03	0.01	-0.07	-1.13	0.42	-2.58
21	L ₆ ×T ₁	0.67	0.68	-0.08	8.65	4.42	-0.13	6.78
22	L ₆ ×T ₂	0.60	2.71	-0.04	-11.12	-3.22	0.35	1.42
23	L ₆ ×T ₃	0.27	-1.19	0.13	9.12	-2.91	-0.39	-2.62
24	L ₆ ×T ₄	-1.53	-2.19	-0.01	-6.65	1.71	0.17	-5.58
25	L ₇ ×T ₁	1.92	0.93	-0.08	5.90	3.65	0.16	1.53
26	L ₇ ×T ₂	0.85	0.29	-0.03	-9.53	-5.29	-0.21	-0.17
27	L ₇ ×T ₃	-1.48	-0.61	0.04	-0.63	3.41	0.13	-1.87
28	L ₇ ×T ₄	-1.28	-0.61	0.06	4.27	-1.78	-0.08	0.50
29	L ₈ ×T ₁	-1.67	-1.74	0.11	-8.85	0.30	0.11	7.28
30	L ₈ ×T ₂	-0.07	-0.71	0.01	2.05	2.86	0.32	7.25
31	L ₈ ×T ₃	-0.73	-0.28	-0.03	-2.05	-1.51	0.05	-10.12
32	L ₈ ×T ₄	2.47	2.73	-0.10	8.85	-1.65	-0.48	-4.42
33	L ₉ ×T ₁	-1.25	0.34	-0.05	-0.10	2.14	0.06	0.62
34	L ₉ ×T ₂	0.35	0.38	0.04	-10.87	3.08	0.04	7.58
35	L ₉ ×T ₃	0.68	-1.19	-0.04	12.70	-2.59	-0.00	-0.78
36	L ₉ ×T ₄	0.22	0.48	0.06	-1.73	-2.63	-0.09	-7.42
37	L ₁₀ ×T ₁	-0.67	0.18	-0.02	-1.52	-4.04	-0.27	-12.30
38	L ₁₀ ×T ₂	-1.07	-0.79	0.03	10.38	3.89	0.20	-5.33
39	L ₁₀ ×T ₃	-0.40	-0.69	0.03	-9.72	-0.95	0.05	9.63
40	L ₁₀ ×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 ×T ₁	-2.68	-2.98	-3.46	-0.00	-8.80	-3.37	-8.90
2	L ₁ ×T ₂	0.45	1.15	0.10	-0.03	-8.80	5.30	-4.70
3	L ₁ ×T ₃	2.58	3.22	4.46	0.02	10.00	-4.77	10.4
4	L ₁ ×T ₄	-0.35	-1.38	-1.10	0.01	7.60	2.83	3.20
5	L ₂ ×T ₁	-1.10	-1.23	-0.97	0.04	3.70	0.63	-5.40
6	L ₂ ×T ₂	-1.97	-1.77	-1.51	-0.07	-4.30	2.63	-7.20
7	L ₂ ×T ₃	-2.17	-1.37	-1.19	0.02	-3.50	1.90	-1.77
8	L ₂ ×T ₄	5.23	4.37	3.67	0.01	4.10	-5.17	14.37
9	L ₃ ×T ₁	-3.85	-2.98	-3.05	-0.06	-1.30	2.38	-1.90
10	L ₃ ×T ₂	-2.72	-2.85	-2.09	0.00	-4.30	1.72	-5.37
11	L ₃ ×T ₃	6.08	5.22	5.17	0.03	15.50	-4.68	4.40
12	L ₃ ×T ₄	0.48	0.62	-0.03	0.03	-9.90	0.58	2.87
13	L ₄ ×T ₁	-1.18	-0.73	-0.77	0.05	11.95	-7.78	-5.32
14	L ₄ ×T ₂	2.62	2.07	2.03	-0.03	-3.05	0.22	-2.45
15	L ₄ ×T ₃	-0.58	-0.20	0.11	0.03	-8.25	10.15	-1.02
16	L ₄ ×T ₄	-0.85	-1.13	-1.37	-0.05	-0.65	-2.58	8.78
17	L ₅ ×T ₁	6.90	5.43	3.42	0.08	-2.30	-6.53	15.02
18	L ₅ ×T ₂	0.03	0.23	-0.22	-0.03	14.70	-1.53	-0.45
19	L ₅ ×T ₃	-3.17	-1.03	0.38	-0.02	-6.50	6.40	-7.02
20	L ₅ ×T ₄	-3.77	-4.63	-3.57	-0.03	-5.90	1.67	-7.55
21	L ₆ ×T ₁	1.32	1.52	1.28	-0.01	-5.30	7.72	0.85
22	L ₆ ×T ₂	-0.22	0.32	0.18	0.07	0.70	3.72	9.72
23	L ₆ ×T ₃	-0.42	-0.28	-0.42	-0.03	0.50	-7.68	-0.85
24	L ₆ ×T ₄	-0.68	-1.55	-1.05	-0.03	4.10	-3.75	-9.72
25	L ₇ ×T ₁	1.07	1.60	1.60	-0.02	-4.55	5.13	2.77
26	L ₇ ×T ₂	-1.13	-2.27	-1.31	0.07	8.45	-5.87	6.63
27	L ₇ ×T ₃	-0.67	-0.20	-0.86	-0.02	-0.75	-2.93	-11.27
28	L ₇ ×T ₄	0.73	0.87	0.57	-0.03	-3.15	3.67	1.87
29	L ₈ ×T ₁	-0.60	-1.48	-1.12	-0.02	12.95	-6.37	8.60
30	L ₈ ×T ₂	2.20	2.98	2.79	-0.02	-7.05	-0.37	-2.87
31	L ₈ ×T ₃	1.67	-0.28	-0.46	0.03	-6.25	5.23	-0.10
32	L ₈ ×T ₄	-3.27	-1.22	-1.21	0.01	0.35	1.50	-5.63
33	L ₉ ×T ₁	-0.10	1.27	2.18	-0.05	-7.80	9.63	0.43
34	L ₉ ×T ₂	0.03	-1.60	-1.51	0.07	6.20	-5.70	7.63
35	L ₉ ×T ₃	1.17	-0.53	-1.35	-0.01	2.00	-4.43	-2.60
36	L ₉ ×T ₄	-1.10	0.87	0.68	-0.01	-0.40	0.50	-5.47
37	L ₁₀ ×T ₁	0.23	-0.40	0.89	-0.02	1.45	-1.45	-6.15
38	L ₁₀ ×T ₂	0.70	1.73	1.54	-0.03	-2.55	-0.12	-0.95
39	L ₁₀ ×T ₃	-4.50	-4.53	-5.84	-0.03	-2.75	0.82	9.82
40	L ₁₀ ×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

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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 ×T ₁	119	1262	85	1466	204
2	L ₁ ×T ₂	127	1373	86	1484	111
3	L ₁ ×T ₃	113	1161	80	1378	217
4	L ₁ ×T ₄	124	1328	89	1536	208
5	L ₂ ×T ₁	120	1278	86	1484	206
6	L ₂ ×T ₂	124	1328	89	1536	208
7	L ₂ ×T ₃	124	1328	88	1515	187
8	L ₂ ×T ₄	114	1177	81	1398	221
9	L ₃ ×T ₁	127	1373	91	1575	202
10	L ₃ ×T ₂	125	1342	95	1655	313
11	L ₃ ×T ₃	113	1161	80	1378	217
12	L ₃ ×T ₄	125	1342	89	1536	194
13	L ₄ ×T ₁	121	1292	87	1501	209
14	L ₄ ×T ₂	131	1446	95	1655	209
15	L ₄ ×T ₃	141	1636	105	1851	215
16	L ₄ ×T ₄	128	1390	91	1575	185
17	L ₅ ×T ₁	118	1244	84	1445	201
18	L ₅ ×T ₂	125	1342	89	1536	194
19	L ₅ ×T ₃	133	1484	96	1675	191
20	L ₅ ×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		Difference of heat units
		Days to physiological maturity	Heat Units	Days to physiological maturity	Heat units	
21	L ₆ ×T ₁	146	1729	110	1944	215
22	L ₆ ×T ₂	142	1654	106	1869	215
23	L ₆ ×T ₃	131	1446	95	1655	209
24	L ₆ ×T ₄	135	1520	98	1715	195
25	L ₇ ×T ₁	136	1540	100	1755	215
26	L ₇ ×T ₂	124	1328	89	1536	208
27	L ₇ ×T ₃	128	1390	92	1595	205
28	L ₇ ×T ₄	135	1520	99	1735	215
29	L ₈ ×T ₁	125	1342	89	1536	194
30	L ₈ ×T ₂	129	1409	93	1615	206
31	L ₈ ×T ₃	137	1559	102	1792	233
32	L ₈ ×T ₄	132	1466	96	1675	209
33	L ₉ ×T ₁	144	1693	108	1906	213
34	L ₉ ×T ₂	130	1426	94	1635	209
35	L ₉ ×T ₃	129	1409	93	1615	206
36	L ₉ ×T ₄	134	1502	98	1715	213
37	L ₁₀ ×T ₁	133	1484	96	1675	191
38	L ₁₀ ×T ₂	132	1466	96	1675	209
39	L ₁₀ ×T ₃	134	1502	97	1695	193
40	L ₁₀ ×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