INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
18–0282/2018/20–12–2637–2646
DOI: 10.17957/IJAB/15.0801
http://www.fspublishers.org

Full Length Article

Genetic Basis of Variation for High Temperature Tolerance in Upland Cotton

Muhammad Arfan[1*], Amir Shakeel[1], Tariq Manzoor Khan[1] and Irfan Afzal[2]
[1]*Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan*
[2]*Department of Agronomy, University of Agriculture, Faisalabad, Pakistan*
[*]For correspondence: arfansial@gmail.com

Abstract

High temperature stress is one of the main abiotic stress factors responsible for decline in cotton productivity on per unit area basis. To study the genetic basis of genotypic differences for high temperature tolerance in cotton, seven highly tolerant and five highly susceptible genotypes were sorted out from previous screened fifty genotypes on the basis of cellular membrane thermostability, canopy temperature, days to first effective boll, node number of first fruiting branch and seed cotton yield. The parental genotypes (seven females and five males) were crossed following North Carolina Mating Design-II. F_1 crosses and the parents were grown in field under normal and heat stress conditions (by maintaining 5–6°C higher temperature through plastic sheet tunnel). Data regarding bolls per plant, boll weight, seed cotton yield, GOT, canopy temperature, node number of first fruiting branch, days to first effective boll, fiber length, fiber strength and fiber fineness revealed remarkable differences among genotypes under both the conditions. Female × male interaction variance was greater in magnitude for most of the traits than female and male individual variances. Dominance variance was higher than additive variance for boll weight, seed cotton yield, canopy temperature, node number of first fruiting branch, fiber lenghth and fiber strength. Heritability in broad sense was much higher than that of narrow sense. Similar response for genetic variance and heritbility on heat tolerance index, cellular membrane thermostability and heat index was observed. FH-114 and VH-389 were indicated as good general combiners for a number of traits. FH-114 × KZ-191 was desirable cross showing 22.61% and 30.19% increase in seed cotton yield over better parent under normal and heat stress conditions, respectively.

Keywords: Cotton; Genetics; High temperature tolerance; Canopy temperature; Cell membrane thermostability

Introduction

Cotton is the backbone of agriculture and decline in its production greatly affects industrial and service sector ultimately increasing poverty level. During fiscal year 2016, the production of cotton declined by -27.83% as compared to the growth of 9.33 percent of year 2015. The reasons were biotic and abiotic stresses (GOP, 2015); however principal ecological problem is high temperature which antagonistically diminishes cotton yield and quality (Abro *et al*., 2015).

Pakistan's average yield declined by 32% to 528 kg ha^{-1} and production decreased to 1.5 million tons. Cotton area is contracted by 5% to 2.7 million hectares as farmers switch to competing crops with better returns (Ruiz, 2016). Cotton is adapted to hot and semi-arid areas in the world. The crop requires a temperature between 15°C and 36°C while extreme temperatures influence its development, improvement and propagation (Baloch *et al*., 2000).

Worldwide air temperature has been increasing steadily for the last few decades that caused the reasonable reduction in yield in numerous parts of the world (Hatfield *et al*., 2011). At the end of previous century, the temperature increment was seen around 0.7°C. This expansion has surpassed in the first decade of 21st century by around 1°C (Rasul *et al*., 2011; Kamran *et al.*, 2017). By 2100, it is relied upon to an increase in average temperature from 1.1 to 6.4°C (IPCC, 2007) which could reduce the water potential of plants through the heightening of general warming process influencing the leaf cooling process by restricting the transpiration rate (Carmo-Silva and Salvucci, 2011).

Among all the abiotic factors responsible for the reduction of cotton yield, high temperature is the significant one. High day and night temperature is fundamentally responsible of year to year variation in cotton yield (Oosterhuis, 2002) which is because of drought and heat stress (Brown *et al*., 2003).

The photosynthetic rate of cotton plant reaches its optimum value at 33°C and started to diminishe at 36°C or above. The main reason for this declined rate was leakage of thylakoid membrane (Bibi *et al*., 2008). Due to daily change in mean temperature, cotton yield and fiber characteristics are badly affected (Roussopoulos *et al*., 1998). Above 30°C pollination process is affected (Kakani *et al*., 2005),

To cite this paper: Arfan, M., A. Shakeel, T.M. Khan and I. Afzal, 2018. Genetic basis of variation for high temperature tolerance in upland cotton. *Int. J. Agric. Biol*., 20: 000–000

pollen germination starts to decrease after 37°C, while above 32°C pollen tube growth is affected (Burke *et al.*, 2004). The base temperature for cotton crop is 10–15°C while the upper threshold limit for cotton crop is 45°C (Danalatos, 2007). An increment of 1°C from optimum (35 – 38°C) reduced cotton yield upto 10% (Pettigrew, 2008). In cotton yield, there is recorded decline of 110 kg ha^{-1} for 1°C rise in temperature for the maximum day limit (Singh *et al.*, 2007). Increasing high temperature stress and consequently decrease in yield are emerging as worrying issues especially for cotton crop which is grown in hot season of arid or semi-arid areas of the world.

In response to high temperature stress, plants have developed different mechanisms. But complicated genetic structure for heat resistance presents a difficult task to plant breeders, which is additionally fortified by extensive level of epistatic relationships (Khan *et al*., 2014). Under high temperature stress, the physiological processes, biochemical reactions and morphological indicators are significantly changed in cotton plant. These alterations influence plant growth and development which ultimately decreases the economic yield. These antagonistic impacts can be limited by producing high temperature tolerant genotypes through conventional and molecular methodologies (Wahid *et al*., 2007).

Tolerance and susceptibility of cultivars as well as species to heat stress varies with growth stages. However, almost all vegetative and reproductive stages of growth are significantly affected by high temperature stress (Xu *et al*., 2017). For example, during vegetative growth stage, high temperature at day time damages leaf gaseous exchange system. During reproductive stage, a short spell of heat stress is responsible for shedding of floral buds and flowers. Among plant species, there is great variety in tolerance and sensitivity (Rodríguez *et al*., 2005). Under heat stress, impaired development of anther, pollen and pollen tube also contributes to decreased flowers per plant, fruit set per plant and ultimately yield per plant in many crop species (Burke *et al*., 2004; Snider *et al*., 2011).

However, some physiological and morphological traits help to observe variation against high temperature for example more cell membrane stability percentage indicates more tolerance and greater stability in cotton yield under heat stress conditions (Rahman, 2006; Azhar *et al*., 2009; Khan *et al*., 2014), lower canopy temperature indicates tolerance to high temperature (Khan *et al*., 2014), lower node numbers of first fruiting branch indicating thermotolerance mechanism (Baloch and Baloch, 2004; Hajazi *et al*., 2014) and lesser days to first effective boll exhibiting some avoidance mechanism against high temperature tolerance indicating heat resistance (Anjum *et al*., 2001; Ali *et al*., 2003; Iqbal *et al*., 2005; Shakeel *et al*., 2008; Baloch *et al*., 2014).

For cotton breeder, learning of genetic effects, combining ability effects heterotic impacts and availability of variations in cotton germplasm against heat tolerance is essential to evolve high temperature tolerant genotypes by ordinary breeding methodologies (Rauf *et al*., 2005). Combining ability effects enables researchers to understand better general and specific trend of various genotypes to combine with each other producing desirable results (Braden *et al*., 2003). Manipulation of heterotic impacts relies upon genetic differences prevailing amongst parents, magnitude of dominance and the hereditary separation among selected parental genotypes (Kearsey and Pooni, 1996).

Keeping in view the importance of genetic effects, gene action and increasing temperature, present study was aimed to develop material against high temperature, find genetic effects, estimate combining ability effects and study heterosis over better parent.

Materials and Methods

The studies were conducted from 2014 through 2015 in the department of Plant Breeding and Genetics, University of Agriculture, Faisalabad lying under semi-arid climate.

Screening of Cotton Germplasm

Fifty upland cotton genotypes were collected from Cotton Research Institute (CRI), Faisalabad and Central Cotton Research Institute (CCRI), Multan. The collected germplasm was screened against high temperature stress during normal cotton growing season 2014. The experiment was conducted in field under two treatments *i.e.*, normal and heat stress (5–6°C above normal for 15 days at 50% flowering) following split plot arrangement under randomized complete block design (RCBD) and two replications. Temperature was raised by constructing tunnel using polythene sheet for 15 days at 50% flowering and uncovered at night. Average canopy temperature for normal crop was 32°C and for heat treatment 38°C. Available germplasm was screened to sort out heat tolerant and sensitive genotypes on the data regarding cellular membrane thermostability (CMT), canopy temperature, days to first effective boll, node number of first fruiting branch and seed cotton yield.

Cell Membrane Thermostability

After 15 days of heat treatment, immediately tender leaves from top of the plant were picked from five plants of each genotype under normal and stressed environments. Leaves were cut into circular shapes of equal size for same sample size and put in distilled water in falcon tubes at 25°C for 24 h. T_1 and C_1 were measured by EC meter. Then, falcon tubes were subjected to water bath at 50°C for 1 h. These falcon tubes were allowed to cool at room temperature, then EC of sap was measured as T_2 and C_2. Relative cellular injury (%) was calculated by the following function proposed by Sullivan (1972).

$$RCI\% = 1-[\{1-(T_1/T_2)\}/\{1-(C_1/C_2)\}] \times 100$$

Where,
T1= EC of sap (treatment) before autoclaving
T2= EC of sap (treatment) after autoclaving
C1= EC of sap (control) before autoclaving
C2= EC of sap (control) after autoclaving

Canopy Temperature

Canopy temperature of plant is an important criterion to differentiate genotypes of *Gossypium hirsutum* L and it was measured with the help of Infrared thermometer (Model 510B; Everest Interscience Inc., Tucson, AZ, USA) from 11:00 a.m. till 4:00 p.m.

Days to First Effective Boll

From five selected plants of each genotype days to first effective (splitted) boll were counted and then arithmetic mean was taken.

Node Number of First Fruiting Branch

Node number of first fruiting branch was counted in such a way that first nodes of cotyledons which were opposite to each other were not counted.

Seed Cotton Yield

At maturity, picking started after dew drops had been evaporated from five selected plants. Two pickings were carried out from selected plants. Yield of single plant was stored in separate paper bag. Average yield of seed cotton per individual plant was calculated.

On the basis of the performance of germplasm based upon data of above mentioned five traits (data not given), 12 genotypes were selected out of which seven were tolerant to high temperature while five were sensitive to the stress.

Development and Evaluation of Genetic Material

Seven tolerant and five sensitive genotypes were planted in glasshouse during winter 2014–2015. All the conditions (temperature (35/21°C±2 day/night), humidity (60–70%), day length (14 h) and natural light (1400–1600 μmol $m^{-2} s^{-1}$) necessary/optimum for growth and development of cotton were met through artificial means. At flowering stage, each of the seven female parents was crossed to five male parents following North Carolina Design-II to develop F_0 seed. Standardized procedure for emasculation and pollination was followed.

The crossed seed, thus produced, were grown along with parental genotypes in field under two normal and heat stress (5–6°C above normal for 15 days at 50% flowering under polythene sheet) following split plot arrangement under RCBD with two replications in normal cotton growing season during 2015. All the plant production and protection practices were used as per package given by Agriculture Extension Department, Punjab, Pakistan.

At maturity, data was collected from five plants of each genotype for bolls per plant and boll weight. Bolls counted after two pickings for five selected plants and their mean value was taken as bolls per plant. After pickings, the cotton seed was weighed for five plants separately and divided it by their bolls respectively. Boll weight was taken after their mean values. Fibre length, fibre strength and fibre fineness were measured using the fibro graph HVI-900. The lint obtained from each sample was weighed and lint percentage was calculated using the following formula.

Lint percentage (GOT %) = (weight of lint/weight of seed cotton) x 100

Heat index (HI) was calculated by using the formula given below

$$Heat\ Index = \frac{\text{C.T. of genotype under stress}}{\text{C.T. of genotype under normal}} \times 100$$

Where, C.T. means canopy temperature.

Statistical Analysis

Data was subjected to analysis of variance technique (Steel *et al.*, 1997). Genetic variances were drawn according to Comstock *et al.* (1949). Combining ability effects were calculated following Kearsey and Pooni (1996) while heterotic effects were estimated through formulae by Mather and Jinks (1971).

Results

There was a remarkable difference for all the studied traits under both normal and heat stress conditions.

Genetic Components

Under normal conditions, male, female and their mutual interactions were found to be significantly different from one another with respect to all the studied variables. Variances due to female × male interaction were higher than female and male individual variances for seed cotton yield, canopy temperature, node number of first fruiting branch, days to first effective boll, fibre length, fibre strength and fibre fineness (Table 1 and 2). For the characters like bolls per plant, boll weight and GOT value of female variance was higher than male and interaction variance. While under heat stress conditions, female, male and their mutual interactions revealed significant to highly significant differences for all the studied traits. Magnitude of interaction variances was higher than individual variances for seed cotton yield, GOT, canopy temperature, days to

Table 1: Mean Squares and genetic components for various traits of cotton under normal condition

SOV	d.f	BP	BW	SCY	GOT%	CT	NNFFB	DFEB	FL	FS	FF
Rep	1	2.203	0.012	1.747	0.052	1.657*	0.051	152.973**	0.063*	1.081*	0.096
Male	4	15.069	0.136**	458.827**	0.478*	6.107*	4.970**	8.859**	2.029**	5.182**	0.204*
Female	6	37.938*	0.283**	459.539**	2.171**	3.145*	4.036**	8.322**	1.984**	3.011**	0.299*
M × F	24	10.222	0.105**	365.762**	0.422*	2.708*	3.497**	7.031**	1.369**	2.859**	0.143*
Error	34	7.836	0.007	10.780	0.419	1.299	0.024	1.084	0.109	0.239	0.066
σ^2m		0.346	0.199	6.647	0.004	0.242	0.105	0.130	0.047	0.165	0.004
σ^2f		2.774	0.765	9.381	0.175	0.043	0.051	0.129	0.089	0.055	0.015
σ^2f × m		1.192	0.041	177.912	0.001	0.705	1.507	2.973	0.918	1.085	0.038
σ^2G		1.616	0.015	8.064	0.092	0.139	0.639	0.129	0.053	0.931	0.01
σ^2D		6.866	0.042	32.256	0.369	0.559	0.354	0.519	0.218	0.322	0.041
σ^2H		4.787	0.193	709.964	0.005	2.819	6.949	11.894	2.519	5.249	0.153
σ^2E		15.603	0.018	21.56	0.838	2.598	0.049	2.168	0.218	0.479	0.132
h^2 bs		0.416	0.944	0.871	0.709	0.565	0.993	0.851	0.826	0.721	0.595
h^2 ns		0.238	0.165	0.341	0.304	0.193	0.243	0.335	0.271	0.354	0.125

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

Table 2: Mean Squares and genetic components for various traits of cotton under heat stress

SOV	d.f	BP	BW	SCY	GOT%	CT	NNFFB	DFEB	FL	FS	FF
Rep	1	14.184	0.024	103.360**	0.063	0.272	9.072*	2.399	0.275*	1.721*	0.304*
Male	4	11.881*	0.206*	568.182**	1.862*	9.594**	3.606*	4.192	1.788**	3.286**	0.177*
Female	6	38.590**	1.012**	1189.93**	2.993*	8.129**	3.605*	4.284	1.667**	8.952**	0.084
M × F	24	8.681*	0.194**	422.480**	1.047*	7.078**	1.119	3.854*	1.396**	3.202**	0.083*
Error	34	3.799	0.031	7.225	0.679	0.811	0.535	1.820	0.113	0.376	0.046
σ^2m		0.228	0.008	10.404	0.057	0.178	0.180	0.024	0.028	0.935	0.006
σ^2f		2.998	0.081	76.744	0.152	0.104	0.262	0.043	0.021	0.875	0.001
σ^2f × m		2.472	0.067	207.674	0.195	3.129	0.102	1.016	0.641	1.433	0.413
σ^2G		1.652	0.042	44.723	0.122	0.140	0.223	0.033	0.027	0.869	0.098
σ^2D		6.629	0.170	178.880	0.490	0.560	0.892	0.135	0.110	1.063	0.091
σ^2H		9.765	0.269	830.502	0.778	12.518	0.411	4.067	2.564	5.497	0.073
σ^2E		7.598	0.119	14.451	1.355	1.633	1.730	3.641	0.227	0.740	0.092
h^2 bs		0.605	0.788	0.985	0.483	0.888	0.429	0.535	0.921	0.898	0.483
h^2 ns		0.307	0.304	0.174	0.186	0.038	0.294	0.019	0.037	0.145	0.073

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

Table 3: Mean Squares and genetic components for of HTI, CMT% and HI of cotton

SOV	d.f.	HTI	CMT%	
Replicatio	1	4.303*	0.034	2.126
Male	4	285.117**	132.093**	132.562**
Female	6	383.314**	103.953**	84.343**
M × F	24	149.846**	100.479**	75.391**
Error	34	3.204	8.106	3.215
σ^2m		9.662	2.259	4.088
σ^2f		23.349	0.349	0.942
σ^2f × m		73.315	46.117	36.485
σ^2G		16.787	1.195	2.442
σ^2D		66.747	5.088	9.788
σ^2H		293.674	184.767	144.299
σ^2E		6.417	16.217	6.343
h^2 bs		0.982	0.921	0.946
h^2 ns		0.185	0.026	0.864

* Significant ** Highly significant whereas Heat Tolerance Index (HTI), Cell membrane thermostability (CMT) and Heat index (HI)

first effective boll, fibre length, fibre strength and fibre fineness. Female variance was higher than other components for bolls per plant, boll weight and node number of first fruiting branch (Table 1, 2 and 3). Under normal conditions, magnitude of dominance variance was higher than additive variance for the traits including boll weight, seed cotton yield, canopy temperature, node number of first fruiting branch, days to first effective boll, fibre length, fibre strength and fibre fineness and for bolls per plant and GOT higher influence of environment was observed (Table 1). While under heat treatment, dominance variance was higher than additive variance and environmental variance for all the traits except GOT, node number of first fruiting branch and fibre fineness (Table 2). Under normal environment, heritability in broad sense was high for boll weight, seed cotton yield, node number of first fruiting branch, days to first effective boll and fibre length, moderate for GOT, canopy temperature and fibre strength, while low for bolls per plant and fibre fineness (Table 1). Narrow sense haritability was low for all the traits ranging from 12.5% (for FF) to 35.4% (for FS) (Table 1). While under heat treatment, broad sense heritability was high for seed cotton yield, canopy temperature, fibre length and fibre strength, moderate for boll weight, while low for rest of the traits was estimated. Narrow sense haritability was low for all the traits (Table 2).

Mean square values of females, males and their interaction were highly significant for heat tolerance index (HTI), cellular membrane thermostability (CMT) and heat index (HI). All three types of variance (female, male and interaction variance) were significant for the three indices; however, values of interaction variances were much higher than the female and male individual variances. Dominance variance was much higher than additive one for all the three traits. Like wise, high broad sense heritability was observed for all the three indices, while narrow sense heritability was high only for HI (Table 3).

Combining Ability Effects

Under normal growing conditions, the female parent FH-114 showed the highest general combining effects (GCA) for bolls per plant, days to first effective boll and fibre fineness. For the traits like seed cotton yield, GOT and node number of first fruiting branch, the female genotype FH-113 presented the superlative GCA effects. The lowest canopy temperature effects were shown by KZ-189. Among male parents, VH-389 revealed the unsurpassed GCA effects for boll weight, seed cotton yield, canopy temperature and node number of first fruiting branch. While for fibre length and fibre strength, AGC-501 showed desirable GCA effects (Table 4). While under heat stress conditions, the female parent FH-114 showed the highest GCA effects for bolls per plant, GOT, canopy temperature, CMT and fibre fineness. For seed cotton yield and node number of first fruiting branch, FH-113 displayed the best GCA effects. Among male parents, VH-389 revealed the most desirable effects for boll weight, seed cotton yield and CMT. For fibre length and fibre strength, AGC-501 showed the

Table 4: General combining ability effects of male and female parents under mormal conditions

Parents	BPP	BW	SCY	GOT%	CT	NNFEB	DFEB	FL	FS	FF
Female parents										
CIM-600	0.348	-0.107**	-7.851**	0.020	0.286	0.826**	0.358	-0.757**	0.013	0.052
FH-113	1.136	0.182**	12.994**	0.640**	0.686	-1.013**	0.576	-0.014	-0.127	0.189*
CIM-616	0.812	-0.126**	-0.246	-0.590**	0.115	0.143**	0.078	0.717**	0.372*	0.187*
FH-114	2.418**	-0.157**	-1.642	0.370	-0.071	-0.152**	-2.037**	0.082	-0.024	-0.214**
CIM-602	0.581	-0.066*	-5.500**	-0.290	0.096	-0.444**	0.221	0.242*	0.942**	0.087
KZ-189	-3.142**	-0.007	-1.077	-0.470*	-1.171**	0.756**	0.456	-0.067	-0.777**	-0.194*
Cyto-178	-2.153*	0.282**	3.323**	0.320	0.064	-0.064	0.348	-0.197	-0.397*	-0.057
S.E.	1.803	0.156	6.276	0.431	0.519	0.588	0.845	0.412	0.508	0.160
Male parents										
VH-389	1.286	0.116**	7.519**	-0.074	1.153**	-0.791**	0.715*	-0.258**	-0.374**	0.117
KZ-191	-0.404	-0.056*	-2.149*	-0.241	-0.177	-0.043	-1.066**	0.136	-0.324*	0.057
AGC-501	0.599	0.038	2.710**	0.229	-0.515	0.857	0.786**	0.327**	0.975**	-0.143
AA-802	-1.457	-0.137**	-7.909**	0.186	-0.129	-0.043	-0.986	-0.53**	-0.488**	0.081
ARK-3	-0.016	0.038	-0.172	-0.071	-0.571	0.875**	0.571	0.327**	0.211	-0.147*
S.E.	0.928	0.088	5.120	0.165	0.591	0.533	0.712	0.340	0.544	0.108

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

Table 5: General combining effects of male and female parents under heat stress

Parents	BPP	BW	SCY	GOT%	CT	NNFEB	DFEB	CMT%	HI	FL	FS	FF
Female parents												
CIM-600	-1.920**	-0.291**	-10.119**	0.192	-0.629	0.192	-0.093	1.026	-1.171*	-0.217*	-0.344	-0.036
FH-113	1.013	0.308**	13.36**	-0.843**	0.714*	-0.974**	1.186	1.886*	0.045	0.350**	0.795**	-0.076
CIM-616	1.944**	-0.151	-7.071**	-0.383	0.164	0.457	-0.043	-0.471	1.116	-0.034	0.335	-0.086
FH-114	2.670**	0.128	8.254**	0.971**	-1.958**	-0.294	-0.543	5.806**	-5.571**	-0.074	-0.524**	0.143*
CIM-602	0.160	-0.341**	-12.13**	-0.163	0.314	-0.367	0.571	-2.571**	-0.101	0.635**	1.275**	0.063
KZ-189	-2.050**	-0.151	-4.369**	0.052	0.544	0.877**	-0.443	-3.691**	3.786**	-0.647**	-1.454**	-0.056
Cyto-178	-1.815**	0.498**	12.130**	0.201	0.433	0.092	-0.903	-1.971*	1.886**	-0.014	-0.084	0.013
S.E.	1.819	0.295	10.099	0.499	0.834	0.563	0.606	2.985	2.689	0.378	0.835	0.085
Male parents												
VH-389	0.460	0.165*	9.353**	0.234	0.586*	-0.311	0.918	4.543**	-3.658**	0.207*	-0.018	0.198**
KZ-191	0.153	0.087	0.190	-0.346	-1.193**	-0.246	0.056	-0.857	-2.104**	-0.382**	-0.09	-0.033
AGC-501	1.229	-0.048	1.828*	0.218	0.873**	-0.097	-0.986	-4.143**	3.857**	0.328**	0.795**	-0.043
AA-802	-1.026	-0.127	-7.529**	-0.445*	-0.414	-0.259	-0.182	-0.197	-0.957	-0.394**	-0.518**	-0.971
ARK-3	-0.797	-0.084	-3.844**	0.336	0.156	0.814**	-0.343	0.221	2.714**	0.241*	-0.168	-0.029
S.E.	0.284	0.109	5.698	0.327	0.739	0.454	0.489	2.747	2.752	0.319	0.433	0.101

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

Table 6: Specific combining ability effects of crosses under normal conditions

Crosses	BPP	BW	SCY	GOT%	CT	NNFFB	DFEB	FL	FS	FF
CIM-600 × VH-389	0.96	0.24**	6.87**	-0.16	-0.54	0.77**	1.43	1.28**	2.39**	-0.17
CIM-600 × KZ-191	-2.88	-0.34**	-16.02**	0.47	0.68	-0.6**	-0.84	-0.51*	-1.46**	0.10
CIM-600 × AGC-501	1.83	0.07	-5.93*	-0.14	-0.94	-0.56**	-3.36**	-1.66**	-0.66	-0.14
CIM-600 × AA-802	-0.89	-0.05	-1.50	-0.03	0.97	0.25*	1.11	1.35**	0.81*	0.06
CIM-600 × ARK-3	0.98	0.07	16.59**	-0.13	-0.16	0.14	1.65*	-0.46	-1.09**	0.15
FH-113 × VH-389	0.99	0.01	-0.19	0.07	0.83	-0.35**	0.35	-1.31**	0.13	0.20
FH-113 × KZ-191	0.72	0.07	8.83**	-0.45	-0.15	-0.07	-0.16	-0.75**	-0.87*	-0.08
FH-113 × AGC-501	-4.27*	-0.22**	-9.77**	0.04	-0.56	1.37**	-1.22	0.65**	0.63	0.03
FH-113 × AA-802	0.77	0.06	-1.87	0.01	1.53	-1.17**	1.49*	0.71**	0.30	-0.32
FH-113 × ARK-3	1.79	0.08	3.00	0.35	-1.64*	0.22*	-0.45	0.70**	-0.20	0.17
CIM-616 × VH-389	-2.69	0.11	-7.59**	0.45	-0.79	-0.25*	2.13**	0.16	-0.27	0.20
CIM-616 × KZ-191	0.92	0.29**	8.65**	-0.17	-0.04	-1.57**	-2.97**	-0.23	1.03**	-0.13
CIM-616 × AGC-501	-0.96	0.14*	6.39**	-0.23	-0.81	1.62**	-0.26	0.02	0.48	0.18
CIM-616 × AA-802	1.29	-0.43**	-6.57**	0.73	0.53	0.73**	1.44	0.23	-0.80*	0.08
CIM-616 × ARK-3	1.44	-0.11	-0.88	-0.77	1.11	-0.53**	-0.35	-0.18	-0.45	-0.33
FH-114 × VH-389	0.71	-0.46**	-11.72**	-0.36	-0.75	1.59**	-3.44**	-0.21	0.53	-0.42*
FH-114 × KZ-191	0.32	0.01	11.55**	0.17	0.09	1.42**	3.12**	0.9**	-0.42	0.05
FH-114 × AGC-501	0.12	0.22**	11.12**	-0.64	0.70	-1.64**	3.14**	-0.40	-1.52**	-0.04
FH-114 × AA-802	2.54	0.3**	10.67**	0.37	-1.30	-1.13**	-1.34	-0.69**	-1.00**	0.21
FH-114 × ARK-3	-3.69	-0.08	-21.62**	0.47	1.26	-0.24*	-1.50*	0.40	2.40**	0.20
CIM-602 × VH-389	0.13	-0.15*	-4.64	0.25	0.02	-1.32**	-0.09	-0.02	-1.14**	-0.25
CIM-602 × KZ-191	-1.10	0.22**	1.95	0.43	1.51	-0.69**	0.90	-0.26	-0.94**	0.12
CIM-602 × AGC-501	1.13	-0.07	1.81	0.17	0.08	1.15**	-0.03	0.69**	1.26**	-0.27
CIM-602 × AA-802	0.98	0.11	3.49	-0.67	-1.23	-0.64**	-1.77*	-0.60*	0.43	-0.17
CIM-602 × ARK-3	-1.15	-0.12	-2.61	-0.17	-0.38	1.50**	0.99	0.19	0.38	0.57**
KZ-189 × VH-389	0.12	0.24**	17.04**	0.28	-0.82	0.29*	-0.13	-0.21	-1.12**	0.13
KZ-189 × KZ-191	-2.16	-0.34**	-34.58**	-0.34	0.22	0.12	0.25	-0.15	0.93**	-0.10
KZ-189 × AGC-501	2.70	0.07	-3.28	0.15	1.17	0.16	1.38	0.80**	0.58	0.26
KZ-189 × AA-802	-2.63	-0.05	10.86**	0.06	0.07	1.72**	-0.07	0.06	-0.10	0.01
KZ-189 × ARK-3	1.97	0.07	9.96**	-0.14	-0.64	-2.29**	-1.43	-0.50*	-0.30	-0.30
Cyto-178 × VH-389	-0.23	0.01	0.22	-0.56	2.06*	-0.7**	-0.26	0.32	-0.55	0.29
Cyto-178 × KZ-191	4.17*	0.07	19.62**	-0.08	-2.31**	1.38**	-0.32	1.03**	1.70**	0.06
Cyto-178 × AGC-501	-0.53	-0.22**	-0.34	0.66	0.36	-2.08**	0.34	-0.12	-0.80*	-0.03
Cyto-178 × AA-802	-2.07	0.06	-15.07**	-0.43	-0.56	0.23*	-0.86	-1.06**	0.37	0.12
Cyto-178 × ARK-3	-1.34	0.08	-4.43	0.42	0.44	1.17**	1.09	-0.17	-0.73*	-0.44*
SE.	1.87	0.19	11.20	0.38	0.96	1.10	1.55	0.68	0.99	0.22

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

superlative values of GCA while KZ-191 was indicated as the most desirable genotype for canopy temperature owing to its unsurpassed GCA effects for the trait (Table 5).

Results pertaining to specific combining ability under normal conditions revealed that the cross Cyto-178 × KZ-191 was indicated as the desirable cross for bolls per plant, seed cotton yield and canopy temperature owing to its highest specific combining ability effects (SCA) for the traits. For days to first effective boll and fibre fineness, the cross FH-114 × VH-389 was considered the best. While for boll weight, CIM-616 × KZ-191 showed the superlative SCA effects (Table 6). While under stressed condition, the cross Cyto-178 × KZ-191 displayed the highest SCA effects for seed cotton yield while for CT, FH-114 × KZ-191 was the most desirable cross on the basis of specific combining ability effects. CIM-1 × KZ-191 showed the unsurpassed value of SCA effects for CMT (Table 7).

Heterosis Over Better Parent

Critical review of the results pertaining to heterosis over better parent (heterobeltiosis) revealed that Cyto-178 × KZ-191 showed 32.88% increased seed cotton yield as compared to its higher parent under normal conditions. CIM-616 × VH-389 showed the highest decrease (48.44%) in node number of first fruiting branch while the highest heterobeltiosis for bolls per plant, canopy temperature and fibre fineness was shown by the cross Cyto-178 × ARK-3. While under heat stress, FH-114 × KZ-191 showed the highest percentage of heterosis over better parent for seed cotton yield and fibre fineness. The cross Cyto-178 × KZ-191 showed highest heterosis for boll weight and fibre length. FH-114 × VH-389 performed relatively better for node number of first fruiting branch and showed minimum decline in cellular membrane thermostability as compared to relevant parents while no other cross showed markedly increased membrane thermo-tolerance (Table 8 and 9).

Discussion

Under field conditions, plants are often subjected to various stresses like high temperature, drought, salinity and frost conditions while capacity of plant to withstand stress is fundamental requirement for sustainable economic yield.

Table 7: Specific combining ability effects of crosses under heat stress

Crosses	BPP	BW	SCY	GOT%	CT	NNFFB	DFEB	CMT%	HI	FL	FS	FF
CIM-600 × VH-389	-0.58	0.13	-4.84*	-0.15	0.66	1.02	-1.67*	-4.49*	5.19**	1.45**	2.36**	0.08
CIM-600 × KZ-191	-0.23	-0.19	-9.76**	0.19	-1.61*	-0.40	0.53	8.44**	-8.62**	-0.07	-0.27	0.22
CIM-600 × AGC-501	-0.26	-0.05	2.03	-0.33	-2.85**	-0.55	-0.37	3.52	-4.6**	-0.93**	-0.11	-0.13
CIM-600 × AA-802	-1.26	-0.08	-2.70	0.09	1.63*	0.31	-0.52	-2.15	1.02	-0.30	0.06	-0.27
CIM-600 × ARK-3	2.33	0.18	15.27**	0.21	2.17**	-0.39	1.55*	-5.32*	7.02**	-0.15	-2.04**	0.11
FH-113 × VH-389	2.03	0.03	3.08	0.25	0.47	-0.46	0.03	0.64	-0.47	0.13	-0.58	-0.18
FH-113 × KZ-191	0.61	0.26	4.73*	0.19	-0.03	0.22	0.44	0.58	-0.46	0.24	-0.41	-0.24
FH-113 × AGC-501	-3.28*	-0.15	-13.3**	-0.03	-1.31*	1.02	0.80	1.91	-1.27	-1.84**	-0.05	0.01
FH-113 × AA-802	0.56	-0.18	-5.17**	-0.17	1.40*	-0.32	1.74*	-1.25	-1.93	1.48**	0.97*	0.27
FH-113 × ARK-3	0.09	0.03	10.65**	-0.24	-0.54	-0.47	-0.99	-1.87	4.13**	-0.01	0.07	0.15
CIM-616 × VH-389	-2.85*	0.04	-7.34**	-0.22	2.26**	0.18	-0.14	-13.25**	10.55**	-0.29	0.28	-0.23
CIM-616 × KZ-191	-0.63	-0.43*	-5.87**	-0.38	-2.84**	-1.19	0.96	12.5**	-7.4**	-0.25	1.35**	-0.04
CIM-616 × AGC-501	-0.35	0.21	12.17**	1.75**	-0.34	0.51	-0.78	-3.10	2.62*	0.89**	-0.39	0.21
CIM-616 × AA-802	3.07*	0.18	4.08*	-0.63	1.35*	0.32	-1.59*	-1.94	1.14	-0.64*	-1.17**	0.02
CIM-616 × ARK-3	0.77	-0.01	-3.04	-0.51	-0.44	0.17	-0.66	5.79**	-6.91**	0.28	-0.07	0.05
FH-114 × VH-389	1.43	-0.44*	-1.71	-0.52	-3.31**	0.56	-1.14*	4.51*	-6.56**	-0.95**	-0.76	-0.08
FH-114 × KZ-191	2.53	-0.36*	-8.92**	1.27*	3.25**	1.09	-0.68	-5.84**	8.95**	0.14	-2.19**	0.01
FH-114 × AGC-501	-0.56	0.23	8.42**	-0.55	3.06**	-0.81	0.65	-9.23**	7.91**	0.18	0.12	0.01
FH-114 × AA-802	-0.63	0.70**	23.33**	0.07	-1.42*	-0.65	-0.30	-1.47	-0.26	0.35	0.79	-0.13
FH-114 × ARK-3	-2.77*	-0.14	-21.11**	-0.26	-1.58*	-0.20	2.81**	12.04**	-10.05**	0.27	2.04**	0.20
CIM-602 × VH-389	0.28	-0.02	-1.72	-0.34	0.04	-0.97	-0.67	11.01**	-3.49**	0.59*	-0.26	0.23
CIM-602 × KZ-191	-2.32	0.51**	12.78**	-1.16	1.03	-0.14	1.33*	-8.48**	-2.33	0.03	-0.89*	-0.03
CIM-602 × AGC-501	2.17	0.10	3.91*	0.78	-0.12	1.06	1.02*	2.44	1.39	0.37	1.52**	-0.23
CIM-602 × AA-802	-0.48	-0.23	-5.20**	0.15	-1.86**	-0.58	0.73	0.26	-0.56	-1.16**	0.39	-0.02
CIM-602 × ARK-3	0.35	-0.37*	-9.77**	0.57	0.90	0.62	-1.28	-5.24*	4.99**	0.16	-0.76	0.06
KZ-189 × VH-389	-1.89	0.29	15.78**	1.14	0.01	-0.11	-1.54*	-4.82*	1.62	-1.02**	-0.48	0.10
KZ-189 × KZ-191	-0.75	-0.23	-24.89**	-0.27	0.38	-0.33	-0.68	-1.36	2.31	-0.49*	1.24**	-0.11
KZ-189 × AGC-501	0.14	-0.09	-9.08**	-1.24*	1.30*	-0.28	0.41	5.37*	-6.09**	0.8**	-1.00*	-0.06
KZ-189 × AA-802	2.7	-0.12	7.38**	-0.12	-0.16	0.63	0.20	4.07*	1.91	0.26	-1.23**	0.20
KZ-189 × ARK-3	-0.21	0.14	10.80**	0.50	-1.52*	0.08	-2.15**	-3.26	0.24	0.44	1.47**	-0.12
Cyto-178 × VH-389	1.58	-0.06	-3.25	-0.16	-0.13	-0.23	1.32*	6.39**	-6.85**	0.09	-0.55	0.07
Cyto-178 × KZ-191	0.78	0.42*	31.92**	0.18	-0.19	0.75	1.28*	-5.83**	7.56**	0.38	1.17**	0.22
Cyto-178 × AGC-501	2.15	-0.24	-4.15*	-0.39	0.26	-0.95	-0.68	-0.91	0.05	0.52*	-0.12	0.22
Cyto-178 × AA-802	-3.95**	-0.27	-21.73**	0.63	-0.95	0.26	-1.38*	2.49	-1.33	-0.01	0.20	-0.07
Cyto-178 × ARK-3	-0.55	0.14	-2.79	-0.25	1.01	0.16	1.41*	-2.14	0.57	-0.99**	-0.70	-0.44**
SE.	1.725	0.26	12.04	0.61	1.56	0.61	1.15	5.87	5.08	0.69	1.03	0.17

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

To include thermo tolerant and high yield potential material in a breeding programme, a rapid assessment of germplasm is essential (Bita and Gerats, 2013). In the present study, cellular membrane thermostability (CMT), canopy temperature, days to first effective boll, node number of first fruiting branch and seed cotton yield were taken in account to screen the germplasm against high temperature stress.

The relationship between CMT and crop yield under high temperatures may vary from plant to plant and appeals for investigating study of individual crop before using it as significant physiological selection standard. The findings of present investigation enclosed that cell membrane thermostability was found higher for heat tolerant genotypes while susceptible ones showed lower value of cell membrane thermostability hence, it could be concluded that tolerant genotypes resist high temperature while sensitive one become leacky at high temperature. CMT% was found rapid and can assess material at early stage of life cycle so it can be taken as a reliable technique for screening and selecting the cotton genotypes against heat tolerance as reported by Rahman (2006) and Azhar *et al.* (2009). Evaluation of varieties on the basis of heat index calculated from canopy temperature is a useful mean (Azhar *et al*., 2005; Akhtar *et al*., 2008; Iqbal *et al*., 2011; Khan *et al*., 2014).

The significant response of diverse varieties to high temperature can also be observed on the basis of indices of heat tolerance. The method had also been widely used in the study of heat tolerance (Azhar *et al*., 2009) and drought tolerance (Iqbal *et al*., 2011) of various plant species. Narrow sense heritability was found maximum (0.864) for heat index (HI) thus it can also be used as more reliable tool for screening germplasm against high temperature (Khan *et al*., 2014). For CMT%, HTI and HI non-additive component of variance was found to be involved which has complex genetics suggesting hybrid development in cotton to withstand higher tempersatures. Similar findings were reported by Rahman (2006), Khan *et al*. (2008) and Azhar *et al*. (2009) while evaluating cotton genotypes under various temperature regimes.

Seed cotton yield is the ultimate outcome of the plant after facing all types of stresses. The seed cotton yield significantly reduced by fruit (flower and boll) shedding due to high temperature stress. Water deficit stress and

Table 8: Better parent heterosis of crosses under normal conditions

Crosses	BPP	BW	SCY	GOT%	CT	NNFFB	DFEB	FL	FS	FF
CIM-600 × VH-389	1.45	1.78	-4.38	-1.78	6.10	-11.6**	12.49**	-4.50**	-1.11	-3.23
CIM-600 × KZ-191	-20.29**	-14.13*	-31.53**	-1.51	9.82**	-9.14**	11.73**	-5.87**	-5.98**	-3.09
CIM-600 × AGC-501	-5.80*	2.27	-19.07**	-1.02	-2.99	-11.11**	5.71**	-9.15**	-1.17	2.38
CIM-600 × AA-802	-14.49**	-11.45	-24.23**	-0.89	10.81**	-10.91**	11.07**	-1.73	-1.17	-1.05
CIM-600 × ARK-3	-5.80*	-1.93	-2.69	-1.65	6.45	-17.03**	17.87**	-5.01**	-2.91	-3.19
FH-113 × VH-389	4.41	12.04	18.73**	0.00	12.00**	-14.58**	9.82**	-10.67**	-8.69**	7.53
FH-113 × KZ-191	2.99	5.99	18.13**	-2.27	9.79*	2.26	6.97**	-1.25	-1.24	-4.12
FH-113 × AGC-501	-2.99	-6.38	5.43	0.63	-0.40	-43.89**	7.96**	2.44*	2.67	9.52
FH-113 × AA-802	0.01	2.88	2.91	0.38	14.15**	-26.67**	9.71**	0.88	-3.34*	-6.32
FH-113 × ARK-3	5.97*	10.51	14.56**	0.76	5.11	-15.93**	8.02**	2.44*	1.39	0.01
CIM-616 × VH-389	-1.47	6.59	13.33**	-3.86*	-4.17	-48.44**	5.85**	-3.33**	-8.37**	5.26
CIM-616 × KZ-191	6.51*	12.95	20.23**	-5.85**	-5.93	-17.51**	-2.28	4.69**	-2.41	-5.15
CIM-616 × AGC-501	4.76	10.02	22.97**	-4.86**	-9.28**	-30.00**	3.11	2.79*	0.01	0.01
CIM-616 × AA-802	-19.05**	10.68	-1.82	-2.62	-4.16	-30.91**	3.58*	1.77	-8.84**	2.11
CIM-616 × ARK-3	-3.17	15.96	12.3**	-6.85**	-2.83	-0.55	2.15	1.92	-5.47**	-11.58*
FH-114 × VH-389	-19.12**	27.92**	7.55*	-3.00	-3.03	-16.67**	-3.14	-6.67**	-7.11**	-15.05**
FH-114 × KZ-191	-6.15*	20.77*	22.61**	-2.13	-4.52	-12.99**	2.51	2.08	-2.56	-10.31*
FH-114 × AGC-501	3.08	23.49**	27.29**	-3.00	-3.69	-12.78**	4.72**	-1.73	-4.17*	-10.87*
FH-114 × AA-802	0.01	24.76**	15.59**	-0.63	-8.76**	1.82	-2.10	-5.71**	-7.35**	-4.21
FH-114 × ARK-3	-6.15*	8.29	-10.40**	-0.88	-1.32	-39.56**	-1.61	1.04	8.89**	-8.51
CIM-602 × VH-389	-8.7**	5.06	-7.64**	-1.40	0.90	-39.06**	4.09*	-5.50**	-9.32**	-8.25
CIM-602 × KZ-191	-2.90	-3.76	-10.33**	-2.40	1.40	-12.99**	3.15	1.60	-1.86	-2.06
CIM-602 × AGC-501	-8.7**	6.00	-6.20*	-0.89	-4.10	-48.33**	4.24*	3.49**	8.35**	-13.4**
CIM-602 × AA-802	-8.55**	-0.66	-14.02**	-3.31*	-7.08*	-27.27**	0.63	-2.83*	0.67	-7.22
CIM-602 × ARK-3	-10.14**	-2.73	-12.59**	-2.42	-4.88	-12.09**	4.61**	1.57	4.41*	3.09
KZ-189 × VH-389	5.88*	-3.99	25.25**	-3.26*	-4.78	-36.98**	4.21*	-7.17**	-14.69**	-2.15
KZ-189 × KZ-191	-12.31**	-16.28*	-33.08**	-5.27**	-5.67	3.39	2.55	1.25	-0.85	-12.37*
KZ-189 × AGC-501	3.08	1.82	1.33	-2.89	-3.74	-17.78**	6.09**	2.79*	0.33	5.95
KZ-189 × AA-802	-6.15*	-21.00**	4.68	-3.26*	-6.09	-3.64	2.82	-1.59	-6.84**	-7.37
KZ-189 × ARK-3	3.08	-2.30	11.18**	-4.27**	-8.75*	-10.44**	1.89	-1.92	-3.24	-18.09**
Cyto-178 × VH-389	7.35**	6.25	22.85**	-0.13	-0.23	-0.52	0.82	-5.83**	-11.69**	4.30
Cyto-178 × KZ-191	9.06**	15.32	32.88**	-2.14	-16.7**	-26.55**	-1.30	4.63**	-1.47	-6.19
Cyto-178 × AGC-501	2.92	2.90	17.31**	3.76*	-9.98**	-37.22**	1.60	-0.87	-5.37**	-7.53
Cyto-178 × AA-802	5.99*	-9.14	-8.82**	-1.15	2.42	-23.96**	-1.28	-6.01**	-6.35**	-2.11
Cyto-178 × ARK-3	12.14**	-1.86	10.13**	2.20	-43.41**	3.95*	1.64	-1.22	-7.65**	-18.09**

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

temperature stress are the principal constraints for seed cotton yield (Brown *et al*., 2003). Node number of first fruiting branch and days to first effective boll was found as efficient morphological parameters for indicating tolerance to high temperature stress in cotton and had been reported by Baloch and Baloch (2004), Shakeel *et al*. (2008), Baloch *et al*. (2014) and Hajazi *et al*. (2014). General combining ability effects are equivalent to additive effects, which are important genetic information to find out the desirable general combiner for improving traits of interest (Wu *et al*., 2010).

Heterosis is the superiority in the performance of F_1 hybrids over better parent. Heterosis gives a method of increasing cotton lint yield and quality, which is the core objective of breeder (Meredith and Brown, 1998). For certain characters, positive heterosis is desirable while for some other characters negative heterosis is desired. Negative heterosis for height of plant, micronaire value, canopy temperature, node number of first fruiting branch and days to first effective boll is desirable (Singh *et al.*, 2012). In present investigation, cross FH-114 × KZ-191 was found to be good specific combiner with highest heterotic effects over better parent for seed cotton yield under stress environment and performed well under normal environment. These results find support from Khan *et al.* (1999) and Rauf *et al*. (2005) where considerable amount of heterosis was observed for seed cotton yield and related traits. Results from the current study showed dominant type of gene action for most of the traits both under normal and heat stress conditions supporting the hypothesis of hybrid development in cotton to cope with high temperature for sustainable seed cotton yield and lint quality. The above results signify the importance of exploitation of both additive and non-additive gene action for attaining maximum improvement of yield and quality traits. Khan *et al*. (2014) obtained similar results regarding gene action, heritability and combining ability. It was observed that superior cross combinations involved at least one high general combining parent, which is in accordance with the finding of Rauf *et al*. (2005) who conluded that all the yield and fiber traits were predominantly controlled by non-additive gene action. It was also reported that the cross combinations having better specific combining ability had at least one parent with

Table 9: Better parent heterosis of crosses under heat stress

Crosses	BPP	BW	SCY	GOT%	CT	NNFFB	DFEB	CMT%	FL	FS	FF
CIM-600 × VH-389	-20.22**	-12.70	-14.35**	-1.27	3.58	-2.72	-4.35	-32.28**	-24.42**	-1.99	1.60
CIM-600 × KZ-191	-29.78**	-25.4**	-14.20**	-8.43	2.89	-5.54*	-8.59	-20.78**	-37.89**	-7.08**	-6.32**
CIM-600 × AGC-501	-13.57*	-25.4**	-11.13*	-5.48	3.03	-12.07**	-16.76	-33.2**	-25.05**	-7.64**	-2.53
CIM-600 × AA-802	-26.89**	-28.57**	-20.87**	-12.00*	2.34	-1.92	-15.10	-35.72**	-38.52**	-8.01**	-6.68**
CIM-600 × ARK-3	-12.20*	-19.05**	-9.36	-8.75	4.81*	10.9**	1.18	-39.68**	-17.82**	-5.08**	-13**
FH-113 × VH-389	-18.81**	-8.45	12.36*	-8.86	1.51	-1.14	-33.15**	-23.04**	2.85	-4.71**	-4.79*
FH-113 × KZ-191	-22.27**	-4.23	6.64	-20.48**	-0.27	0.90	-15.34	-30.32**	-4.14	-2.09	-0.92
FH-113 × AGC-501	-28.02**	-19.72**	-2.71	-2.74	0.68	-6.31**	-12.29	-33.77**	-19.4**	-7.30**	2.36
FH-113 × AA-802	-33.59**	-22.54**	2.58	1.33	-1.51	-0.44	-33.85**	-32.65**	-20.55**	2.56*	2.57
FH-113 × ARK-3	-9.36	-15.49*	1.80	-8.75	0.42	5.70*	-13.53	-32.95**	-2.39	-0.66	0.55
CIM-616 × VH-389	-27.14**	-1.75	4.85	-11.25*	-4.64*	2.06	-10.33	-45.7**	1.03	-7.61**	-5.22*
CIM-616 × KZ-191	-14.76*	-18.18*	11.55	-15.66**	-6.57**	-7.98**	-14.72	-15.01**	-8.74**	-1.58	-1.74
CIM-616 × AGC-501	-1.47	0.01	16.2**	-6.25	0.39	-5.17*	-1.68	-43.5**	16.23**	5.93**	-4.70*
CIM-616 × AA-802	-13.33*	-3.64	20.31**	-11.25*	-7.47**	-1.80	-11.98	-35.99**	-5.90	-2.39	-12.00**
CIM-616 × ARK-3	9.84	-9.09	13.09*	-11.25*	-5.15**	4.61	11.18	-23.96**	-10.27**	0.25	-6.96**
FH-114 × VH-389	-15.02**	-8.77	27.32**	-4.82	1.47	-17.01**	-14.67	-1.59	37.84**	-10.14**	-10.9**
FH-114 × KZ-191	-1.76	-1.89	30.19**	-8.43	4.67*	2.70	3.68	-26.36**	15.40**	-8.33**	-16.17**
FH-114 × AGC-501	-28.64**	15.09	22.81**	-8.43	1.34	-2.03	-25.14*	-37.85**	41.41**	-5.62**	-4.92*
FH-114 × AA-802	-21.7**	30.19**	14.42*	-12.05*	1.20	-14.05**	-30.21**	-18.93**	49.02**	-7.61**	-7.21**
FH-114 × ARK-3	4.81	0.01	7.48	-4.82	2.40	-4.36	-2.35	3.63	-6.85	-5.62**	-1.58
CIM-602 × VH-389	-28.55**	-17.74*	-0.52	3.75	-0.67	-3.10	-32.07**	-5.59	-18.11**	-1.99	-1.95
CIM-602 × KZ-191	-1.91	-3.23	-9.74	-12.05*	-4.42*	2.79	-12.27	-44.77**	-12.66**	-3.00*	-2.88
CIM-602 × AGC-501	-20.02**	-20.97**	7.84	-13.75*	2.28	-4.26	-5.03	-33.21**	-20.05**	0.94	9.01**
CIM-602 × AA-802	-4.72	-33.87**	-7.65	-8.75	-1.19	-9.49**	-30.21**	-30.4**	-38.92**	-7.49**	0.18
CIM-602 × ARK-3	9.74	-37.1**	-4.29	-7.50	2.01	8.7**	6.47	-38.55**	-39.84**	-0.19	-2.70
KZ-189 × VH-389	-21.08**	7.02	-12.28*	-1.27	3.88	-2.62	-9.24	-30.56**	34.32**	-12.5**	-12.41**
KZ-189 × KZ-191	-16.59**	-3.92	-9.56	-16.87**	-1.47	1.68	0.61	-33.02**	-29.17**	-7.49**	-2.04
KZ-189 × AGC-501	-31.73**	-3.92	-3.25	-4.11	-2.54	-0.23	-6.15	-28.01**	-6.94*	0.19	-9.26**
KZ-189 × AA-802	-20.5**	-7.84	-2.21	0.01	-1.34	-4.65*	-4.69	-23.67**	2.11	-4.66**	-12.83**
KZ-189 × ARK-3	-20.41**	3.92	-10.91	-15**	2.41	2.67	14.71	-35.1**	11.16**	-1.54	-1.49
Cyto-178 × VH-389	-32.34**	17.54*	8.61	-0.25	3.86	-3.20	-19.02*	-13.63**	46.86**	-6.16**	-9.72**
Cyto-178 × KZ-191	5.15	66.67**	4.72	-7.23	3.17	-0.15	4.29	-40.63**	112.11**	0.39	-3.99
Cyto-178 × AGC-501	-29.07**	31.11**	13.28*	5.48	3.17	-3.04	-22.35*	-38.72**	55.46**	3.73**	-5.38**
Cyto-178 × AA-802	-0.53	32.56**	-16.22*	-5.33	4.14*	-6.89**	-16.67	-27.19**	11.13*	-1.18	-8.85**
Cyto-178 × ARK-3	-7.59	34.69**	-3.38	-21.25**	3.86	7.94**	6.47	-33.82**	48.35**	-4.55**	-10.76**

* Significant ** Highly significant whereas Bolls per plant (BP), Boll weight (BW), Seed cotton yield (SCY), Ginning out turn (GOT), Canopy temperature (CT), Node number of first fruiting branch (NNFFB), Days to first effective boll (DFEB), Fiber length (FL), Fiber strength (FS), Fiber fineness (FF)

positive and high general combining ability effects. Thus, it can be recommended from the previous and present findings that heterosis breeding could be rewarding in cottion heat stress breeding.

Conclusion

It is concluded that canopy temperature and cell membrane thermostability could be used as reliable parameters for the assessment of heat tolerant cotton germplasm and since the variation appears to be heritable, therefore, heat tolerant cotton varieties could be developed. Due to involvement of non-additive variance (H), estimates of h^2 bs were of larger magnitude, and hence, hybrid breeding would be rewarding in the present cotton germplasm. The information generated from the current investigations about the genetic basis of variations for heat tolerance may be advantageously used by the cotton breeders.

Acknowledgments

First author is grateful to the Higher Education Commission of Pakistan for providing financial assistance for the study.

References

Abro, S., M.T. Rajput, M.A. Khan, M.A. Sial and S.S. Tahir, 2015. Screening of Cotton (*Gossypium hirsutum* L.) genotypes for heat tolerance. *Pak. J. Bot.,* 47: 2085–2091

Akhtar, K.P., M. Wasim, W. Ishaq, M. Ahmad and M.A. Haq, 2008. Deterioration of cotton fibre characteristics caused by cotton leaf curl disease. *Span. J. Agric. Res.,* 7: 913–918

Ali, C.R., M. Arshad, M.I. Khan and M. Afzal, 2003. Study of earliness in commercial cotton (*G. hirsutum* L.) genotypes. *J. Res. Sci.,* 14: 153–157

Anjum, R., A.R. Soomro and M.A. Chang, 2001. Measurement of earliness in upland cotton. *Pak. J. Biol. Sci.,* 4: 462–463

Azhar, F.M., Z. Ali, M.M. Akhtar, A.A. Khan and R. Trethowan, 2009. Genetic variability of heat tolerance, and its effect on yield and fibre quality traits in upland cotton (*Gossypium hirsutum* L.). *Plant Breed.,* 128: 356–362

Azhar, M.T., A.A. Khan and I.A. Khan, 2005. Combining Ability Analysis of Heat Tolerance in *Gossypium hirsutum* L. *Czech J. Genet. Plant Breed.,* 41: 23–28

Baloch, M.J. and Q.B. Baloch, 2004. Plant characters in relation to earliness in cotton (*Gossypium hirsutum* L.). *Pak. Acad. Sci.,* 41: 103–108

Baloch, M.J., N. Ghandahi, W.A. Jatoi, R.Z. Butt, I.H. Rind, F.M. Halo and A.A. Keerio, 2014. Genetic constitution of multigenic traits in F_2 Populations of Intrahirsutum crosses. *Acta Adv. Agric. Sci.,* 2: 35–40

Baloch, M.J., A.R. Lakho, H. Bhutto, A.M. Memon, G.N. Panhwar and A.H. Soomro, 2000. Estimates of combining ability and genetics parameters for yield and fibre traits in upland cotton. *Pak. J. Biol. Sci.,* 3: 1183–1186

Bibi, A.C., D.M. Oosterhuis and E.D. Gonias, 2008. Photosynthesis, quantum yield of photosystem II and membrane leakage as affected by high temperatures in cotton genotypes. *J. Cotton Sci.,* 12: 150–159

Bita, C. and T. Gerats, 2013. Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. *Front. Plant Sci.*, 4: 273

Braden, C., C.W. Smith and P. Thaxton, 2003. Combining ability for near extra long fibres in upland cotton. *In*: *Proceeding of the Beltwide Cotton Conferrences,* January 6–10, Nashville, Tennessee, USA

Brown, R.S., D.M. Oosterhuis, D.L. Coker and L. Fowler, 2003. The dynamics of dry matter partitioning in the cotton boll of modern and obsolete cultivars. *In*: *Proceeding of the Beltwide Cotton Conferences,* pp: 1886–1889. National Cotton Council of America, Cordova, Tennessee, USA

Burke, J.J., J. Velten and M.J. Oliver, 2004. *In vitro* analysis of cotton pollen germination. *Agron. J.,* 96: 359–368

Carmo-Silva, A.E. andM.E. Salvucci, 2011. The activity of Rubisco's molecular chaperone, Rubisco activate, in leaf extracts. *Photosynth. Res.,* 108: 143–155

Comstock, R.E., H.F. Robinson and P.H. Harvey, 1949. A breeding procedure designed to make maximum use of both general and specific combining ability. *J. Agron.,* 41: 360–367

Danalatos, N., 2007. *An Introduction in Crop Production Simulation*. University of Thessaly press, Volos, Greece

Govt. of Pakistain (GOP), 2015. Ministry of Finance Division, Economic Advisor Wing, Islamabad, Pakistan

Hajazi, M.Z.U.I., A. Shakeel, J. Farooq, A. Mahmood, A. Saeed, M.F. Saleem and M.T. Azhar, 2014. Genetic basis for earliness and yield contributing traits in cotton *Gossypium hirsutum* L. *J. Agric. Res.,* 52: 294–302

Hatfield, J.L., K.J. Boote, B.A. Kimball, L.H. Ziska, R.C. Izaurrale, D. Ort, A.M. Thomson and D. Wolfe, 2011. Climate impacts on agriculture: Implications for crop protection. *Agron. J.,* 103: 351–370

IPCC, 2007. Climate change 2007. The physical science bases. *In: Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panelon Climate Change*, p: 1009. Cambridge University Press, Cambridge, UK

Iqbal, M., M.A. Khan, M. Jameel, M.M. Yar, Q. Javaed, M.T. Aslam, B. Iqbal, S. Shakir and A. Ali, 2011. Study of heritable variation and genetics of yield and yield components in upland cotton (*Gossypium hirsutum* L.). *Afr. J. Agric. Res.,* 6: 4099–4103

Iqbal, M., M.Z. Iqbal, R.S.A. Khan and K. Hayat, 2005. Comparison of obsolete and modern varieties in view to stagnancy in yield of cotton (*G. hirsutum* L.). *Asian J. Plant Sci.,* 4: 374–378

Kakani, V.G., K.R. Reddy, S. Koti, T.P. Wallace, P.V.V. Parasad, V.R. Reddy and D. Zhao, 2005. Differences in *in vitro* pollen germination and pollen tube growth of cotton cultivarse in response to high temperature. *Ann. Bot.,* 96: 59–67

Kamran, M., I. Afzal, S.M.A. Basra, S.H.U. Khan and A. Mahmood, 2017. Improvement of cotton crop performance by estimating optimum sowing and picking time. *Int. J. Agric. Biol*., 19: 241–247

Kearsey, M.J. and H.S. Pooni, 1996. *The Genetical Analysis of Quantitative Traits*. Chapman and Hall, London

Khan, A.I., I.A. Khan and H.A. Sadaqat, 2008. Heat tolerance is varıable in cotton (*Gossypium hirsutum* L.) and can be exploited for breeding of better yieldıng cultivars under high temperature regimes. *Pak. J. Bot.,* 40: 2053–2058

Khan, N., F.M. Azhar, A.A. Khan and R. Ahmad, 2014. Measurement of canopy temperature for heat tolerance in upland cotton: variability and its genetic basis. *Pak. J. Agric. Sci.,* 51: 359–365

Khan, N.U., H.K. Abro, H. Gul, M.B. Kumbhar and M. Khan, 1999. Exploitation of heterosis can combat leaf curl virus (CLCV) incidence in cotton (*Gossypium hirsutum* L.). *Pak. Cotton,* 43: 21–34

Mather, K. and J.L. Jinks, 1971. *Biometrical Genetics. The Study of Continuous Variation*. Chapman and Hall, London

Meredith, R.W. and S.J. Brown, 1998. Heterosis and combining ability of cottons originating from different regions of the United States. *J. Cotton Sci.,* 2: 77–84

Oosterhuis, D.M., 2002. Day or night high temperature: A major cause of yield variability. *Cotton Grower,* 46: 8–9

Pettigrew, W., 2008. The effect of higher temperatures on cotton lint yield production and fiber quality. *Crop Sci.,* 48: 278–285

Rahman, H., 2006. Number and weight of cotton lint fibres: Variation due to high temperatures in the field. *Aust. J. Agric. Res.,* 57: 583–590

Rasul, G., Q.Z. Chaudhry, A. Mahmood and K.W. Hyder, 2011. Effect of temperature rise on crop growth and productivity. *Pak. J. Meterol.,* 8: 53–62

Rauf, S., T.M. Khan and S. Nazir, 2005. Combining ability and heterosis in *Gossypium hirsutum* L. *Int. J. Agric. Biol.,* 7: 109–113

Rodríguez, M., E. Canales and O. Borrás-Hidalgo, 2005. Molecular aspects of abiotic stress in plants. *Biotecnol. Apl.,* 22: 1–10

Roussopoulos, D., A. Liakatas and W. Whittington, 1998. Controlled temperature effects on cotton growth and development. *J. Agric. Sci.,* 130: 451–462

Ruiz, L., 2016. *The World Cotton Market: Structure and Outlook*. International Cotton Advisory Committee. Texas International Cotton School. Lubbock, Texas, USA

Shakeel, A., F.M. Azhar and I.A. Khan, 2008. Assessment of earliness in *G. hirsutum* L. *Pak. J. Agric. Sci.,* 45: 80–87

Singh, P., M.S. Kairon and S.B. Singh, 2012. *Breeding Hybrid Cotton*. Cicr Technical Bulletin No: 14. Breeding Hybrid Cotton

Singh, R.P., P.V.V. Prasad, K. Sunita, S.N. Giri and K.R. Reddy, 2007. Influence of high temperature and breeding for heat tolerance in cotton: A review. *Adv. Agron.,* 93: 313–385

Snider, J.L., D.M. Oosterhuis and E.M. Kawakami, 2011. Diurnal pollen tube growth rate is slowed by high temperature in field-grown *Gossypium hirsutum* pistils. *J. Plant Physiol.,* 168: 441–448

Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1997. *Principles and Procedures of Statistics: A Biometrical Approach,* pp: 400–428. McGraw Hill Book Co. Inc. New York, USA

Sullivan, C.Y., 1972. Mechanisms of heat and drought resistance in grain sorghum and methods of measurement. *In: Sorghum in the Seventies*. Rao, N.G.P. and L.R. House (eds.). Oxford and IBH Publishing Co., New Delhi, India

Wahid, A., S. Gelani, M. Ashraf and M.R. Foolad, 2007. Heat tolerance in plants: An overview, *Environ. Exp. Bot.,* 61: 199–223

Wu, J., J.C. McCarty, J.N. Jenkins and W.R. Meredith. 2010. Breeding potential of introgressions into upland cotton: genetic effects and heterosis. *Int. J. Plant Breed.,* 129: 526–553

Xu, J., M. Wolters-Arts, C. Mariani, H. Huber and I. Rieu, 2017. Heat stress affects vegetative and reproductive performance and trait correlations in tomato (*Solanum lycopersicum*). *Euphytica,* 213: 156

(Received 22 February 2018; Accepted 26 June 2018)