SALMAN *et al. Journal of Cotton Research* (2019) 2:9
https://doi.org/10.1186/s42397-019-0025-2

Journal of Cotton Research

RESEARCH Open Access

Genetic effects conferring heat tolerance in upland cotton (*Gossypium hirsutum* L.)

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Abstract

Background: Climate change and particularly global warming has emerged as an alarming threat to the crop productivity of field crops and exerted drastic effects on the cropping patterns. Production of cotton has been dropped down to one million bales from 1.4 million bales since 2015 in Pakistan due to the increase in temperature at critical growth stages, i.e., flowering and boll formation. Keeping in view the importance of cotton in the country, this study was conducted to investigate the genetic effects conferring heat tolerance in six populations (P_1, P_2, F_1, F_2, BC_1 and BC_2) developed from cross-1 and cross-2, i.e., VH-282 × FH-142 and DNH-40 × VH-259.

Results: The results revealed that cross-1 performed better in heat stress as compared with cross-2 for majority of the traits recorded. Boll weight and ginning outturn (GOT) were highly effected under heat stress and had negative correlation with Relative cell injury (RCI). Boll weight, fiber length, fiber strength and fiber fineness were under the control of non-additive gene action, whereas RCI was controlled by additive gene effects. Lower values of genetic advance coupled with higher values of broad sense heritability for these traits except RCI confirmed the role of non-additive genetic effects. Duplicate types of epistasis were recorded for fiber strength in cross-1 in normal condition. However, complementary type of non-allelic interaction was recorded for fiber strength under normal condition, fiber fineness and RCI under heat stressed condition in cross-1. Likewise, boll weight, GOT and fiber length in populations derived from cross-2 in normal condition were also under the influence of complementary type of non-allelic interaction. Significant differences among values of mid parent and better parent heterosis for boll weight in both normal and heat stress condition provided the opportunity to cotton breeders for utilization of this germplasm for improvement of this trait through exploitation of heterosis breeding.

Conclusion: Cross-1 performed better in heat stress and could be utilized for development of heat tolerant cultivar. RCI was under the influence of additive gene action, so one can rely on this trait for screening of large number of accessions of cotton for heat stress. While other traits were predominantly controlled by non-additive gene action and selection based on these should be delayed in later generations.

Keywords: Heat stress, Heritability, Heterosis, Relative cell injury, Upland cotton

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Background

Cotton belongs to family Malvaceae containing more than 200 genera and about 2 300 species. There are more than 50 species of *Gossypium* reported till now, which are native to Africa, Australia, Central and South America and Asia, respectively (Fryxell 1992; Wendel and Grover 2015). Out of 50 species, only four are domesticated and widespread. Two diploid (2n = 26) species, namely *G. arboreum* and *G. herbaceum* belong to Old World cotton produce only 1% of the total cotton production in the world, whereas two tetraploid (2n = 52) species, namely *G. barbadense* and *G. hirsutum* belong to New World cotton produce 94% of the total world cotton production. *G. barbadense* produces 4%, while *G. hirsutum* also known as upland cotton produces about 90% of the total cotton production in the world (Lu et al. 1997; McCarty et al. 2004).

Upland cotton is a key source of spinnable fiber and cultivated in more than 61 countries in the world on an area of 29.3 million hectares (ICAC 2018). Cotton and cotton-based industry has a pivoting role in the economy of Pakistan. Pakistan ranks the fourth in terms of area and production in the world after India, China and USA, 3rd in consumption and 2nd in yarn production in the world. Cotton contributes 1% share in GDP, while 55% in total foreign exchange earnings of Pakistan. Cotton was planted on an area of 2.7 million hectares in 2017, showing an increase of 10% over the previous year. About 8% more cotton production, i.e., 11.54 million bales was recorded during 2017/2018 as compared with 2016/2017 where 10.72 million bales was recorded (PCCC 2017). However, in terms of per acre yield (679 kg·hm^{-2}), Pakistan is lagging far behind from the major cotton producing countries like Australia (1 816 kg·hm^{-2}), China (1 719 kg·hm^{-2}), Turkey (1 826 kg·hm^{-2}) and USA (985 kg·hm^{-2}) (ICAC 2018).

A loss of about one-third of cotton produce was recorded in Pakistan during 2015/2016 due to adverse climatic conditions particularly heavy rains during reproductive phase of crop. But high temperature with dry weather conditions favored the spread of whitefly in 2016 and 2017 which affected the productivity of cotton crop on a wide range of area in Punjab province. In recent times besides drought, salinity, insect pests, diseases and seed quality: high temperature has emerged as a major threat to cotton productivity. It is estimated that the global temperature is increasing by 0.4~0.8 °C/year (PMD 2016). The consequences of high temperature in cotton could be low germination, higher fruit shedding (≥ 30 °C/22 °C), pollen sterility and abortion (Guilioni et al. 1997; Ismail and Hall 1999), unavailability of macro and micro nutrients due to increase in soil pH, higher levels of CO_2 in the air will increase photosynthetic activity resulting in enhanced nutrient requirement of cotton plants.

Keeping in view the importance of emerging threat of climate change, it is need of the day to develop climate smart varieties of cotton which could withstand harsh climatic conditions particularly heat stress due to significant adverse effects on yield of seed cotton. So, this experiment was conducted to explore and understand the genetic mechanisms controlling resistance to high temperature and to identify the potential germplasm having tolerance against heat stress which could be used in breeding programs for the introgression and development of new germplasm of upland cotton.

Materials and methods

Screening of germplasm for heat tolerance

The germplasm consisting of 80 accessions of cotton was collected from various Agricultural Research Institutes and Centers of Pakistan to determine heat tolerant and susceptible parental genotypes. Relative cell injury (RCI) percentage was calculated by using the following formula proposed by Sullivan (1972).

$$\mathrm{RCI\%} = [1-[(1-(\mathrm{T1}-\mathrm{T2}))]/(1-(\mathrm{C1}/\mathrm{C2}))]] \times 100$$

Where, "T" is EC of heat treated and "C" is EC of controlled samples, subscripts 1 and 2 represent initial and final EC readings, respectively.

Based on means from RCI, two heat tolerant, namely VH-259 and FH-142, and two susceptible genotypes, namely VH-282 and DNH-40 were identified against high temperature (Table 1). First part of this study about the details of 80 accessions and screening procedure has already been published (Salman et al. 2016).

Development of populations

The four genotypes were hybridized which are named as cross-1 (VH-282 × FH-142) and cross-2 (DNH-40 × VH-259) in the manuscript. A crossing scheme was designed for the development of various populations, i.e., F_1, F_2, BC_1 and BC_2 to fulfill the criteria of generation mean analysis. BC_1 populations were developed by keeping F_1 as female parent and parent 1 as male parent, whereas BC_2 was developed by using F_1 as female parent and parent 2 as a male parent. Some of flowers were self-pollinated for the development of seed for F_2 population. These populations were developed by using greenhouse and field facilities of the Department.

Table 1 List of identified heat tolerant and susceptible genotypes of *G. hirsutum* L.

Sr. No.	Genotypes	Response
1	VH-259	High cell membrane stability
2	FH-142	High cell membrane stability
3	VH-282	Low cell membrane stability
4	DNH-40	Low cell membrane stability

Table 2 Generation means for boll weight, gin turn out, fibre length, fibre strength, fibre fineness and relative cell injury in two crosses VH-282 × FH-142 (1) and DNH-40 × VH-259 (2) under normal (N) and heat stress (H) conditions

Traits	Stress Levels	Generation Means						Pop Effect
		P_1	P_2	F_1	BC_1	BC_2	F_2	
BW	N1	3.50	3.46	3.63	3.56	3.61	3.59	*
	H1	3.43	3.38	4.00	2.08	2.57	3.33	*
	N2	3.14	3.13	3.62	3.12	3.30	3.45	*
	H2	3.40	3.12	3.53	3.32	3.17	3.22	*
GOT	N1	39.63	39.78	39.44	38.27	38.23	39.19	**
	H1	38.25	38.28	38.39	38.31	38.33	38.28	**
	N2	39.55	38.89	39.11	37.11	38.41	37.98	**
	H2	38.60	37.33	39.46	37.94	38.35	37.69	**
FL	N1	24.98	24.74	24.71	24.31	25.25	23.31	**
	H1	26.97	27.51	28.05	26.94	27.30	26.91	**
	N2	26.91	27.53	27.93	27.10	27.21	26.97	**
	H2	26.88	26.75	27.77	27.10	27.00	27.18	**
FS	N1	25.06	24.63	24.92	24.61	24.90	23.19	**
	H1	25.17	24.55	24.75	23.52	24.22	23.95	**
	N2	24.70	24.65	24.55	24.54	24.52	24.53	**
	H2	24.91	24.33	24.67	24.66	24.64	24.56	**
FF	N1	4.30	4.26	4.32	4.33	4.37	4.28	*
	H1	4.24	4.29	4.20	4.68	4.47	4.47	*
	N2	4.30	4.21	4.25	4.40	4.26	4.46	*
	H2	4.27	4.28	4.29	4.49	4.44	4.47	*
RCI	N1	28.30	28.45	21.86	26.66	26.57	26.97	**
	H1	24.27	37.17	25.67	35.23	36.73	32.48	**
	N2	25.36	25.32	21.47	31.27	29.94	28.34	**
	H2	24.78	35.02	25.72	33.79	33.93	32.01	**

Assessment of populations for heat stress

Average daily temperature during summer season of last five years was collected from AgriMet to determine the duration of maximum heat stress during cotton crop. By having this information all of populations from cross-1 and cross-2 alongwith parents were planted during 2016–2017 on two different sowing times, i.e., early and late. These two sowings were planned based on temperature data of last ten years. The flowering stage in early sowing coincides with maximum annual temperature whereas late sowing coincides with optimal temperature (Ahamed et al. 2010; Abro et al. 2015). The plant material was sown in the experimental area of the department in triplicate by following randomized complete block design. During planting, plant to plant and row to row distance were maintained at 30 cm and 75 cm, respectively, for optimal supply of nutrition and plant protection practices to get good population except effects of heat stress. At the time of reproductive stage RCI %, boll weight and fiber traits were determined.

Statistical analysis

Analysis of variance among the generations was conducted according to Steel et al. (1997). The populations showing significant differences for certain traits were used to conduct generation mean analysis by following the method described by Mather and Jinks (2013).

Results

Assessment of populations

Mean values of F_1 were higher than F_2, BC_1 and BC_2 populations for all of the traits included in this study except fiber fineness and RCI for both crosses under normal and stress conditions (Table 2). The range of boll

Table 3 Genetic effects for boll weight, ginning outturn, fibre length, fibre strength, fibre fineness and relative cell injury in cross VH-282 × FH-142 (1) under normal (N) and heat stress (H)

Traits		Genetic Effects						X^2(DF)
		m ± S.E.	[d] ± S.E.	[h] ± S.E.	[i] ± S.E.	[j] ± S.E.	[l] ± S.E.	
BW	N1	3.50 ± 0.04	0.02 ± 0.04	0.16 ± 0.07	–	–	–	1.77 (3)
	H1	2.93 ± 0.03	–	–	0.43 ± 0.06	−1.38 ± 0.13	–	2.62 (3)
GOT	N1	37.86 ± 0.40	–	–	1.84 ± 0.52	−1.91 ± 0.82	1.58 ± 0.68	0.07 (2)
	H1	38.26 ± 0.14	–	–	–	− 0.03 ± 0.78	–	0.10 (4)
FL	N1	24.19 ± 0.10	0.93 ± 0.18	–	–	–	–	6.26 (4)
	H1	26.57 ± 0.30	0.27 ± 0.22	–	0.67 ± 0.41	1.30 ± 0.74	1.48 ± 0.54	0.00 (1)
FS	N1	26.76 ± 1.57	0.21 ± 0.10	−6.77 ± 3.60	−1.92 ± 1.57	3.35 ± 0.80	4.92 ± 2.09	000 (0)
	H1	23.30 ± 0.28	0.30 ± 0.09	–	1.56 ± 0.31	–	1.46 ± 0.34	0.20 (2)
FF	N1	4.34 ± 0.05	–	0.07 ± 0.10	–	–	–	7.12 (4)
	H1	5.18 ± 0.21	0.02 ± 0.05	−0.98 ± 0.26	− 0.91 ± 0.23	–	–	0.03 (2)
RCI	N1	71.62 ± 0.50	–	–	–	0.82 ± 2.77	6.51 ± 1.03	0.02 (3)
	H1	66.79 ± 6.23	6.45 ± 0.55	−15.61 ± 14.36	2.50 ± 6.20	−21.41 ± 3.32	23.16 ± 8.45	000 (0)

Note: m = mean, d = additive effect, h = dominant effect, i = additive × additive, j = additive × dominance, l = dominance × dominance

Table 4 Genetic effects for boll weight, ginning outturn, fibre length, fibre strength, fibre fineness and relative cell injury in cross DNH-40 × VH-259 (2) under normal (N) and heat stress (H)

Traits		Genetic Effects						X^2(DF)
		m ± S.E.	[d] ± S.E.	[h] ± S.E.	[i] ± S.E.	[j] ± S.E.	[l] ± S.E.	
BW	N2	2.01 ± 0.27	0.03 ± 0.03	2.84 ± 0.61	1.12 ± 0.27	–	−1.24 ± 0.35	1.86 (1)
	H2	3.26 ± 0.05	0.14 ± 0.05	−0.39 ± 0.23	–	− 0.33 ± 0.20	0.67 ± 0.23	2.03 (1)
GOT	N2	35.16 ± 0.87	0.35 ± 0.22	3.96 ± 1.17	4.05 ± 0.95	–	–	0.05 (2)
	H2	37.96 ± 0.26	0.63 ± 0.22	−1.34 ± 1.09	–	–	2.84 ± 1.11	0.02 (2)
F	N2	27.79 ± 1.38	0.12 ± 0.18	−2.90 ± 3.05	−0.57 ± 1.36	–	3.04 ± 1.80	2.04 (1)
	H2	26.81 ± 0.13	–	–	–	–	1.06 ± 0.29	6.20 (4)
FS	N2	24.53 ± 0.11	–	–	0.15 ± 0.16	–	–	0.30 (4)
	H2	24.64 ± 0.07	0.28 ± 0.10	–	–	–	–	0.29 (4)
FF	N2	4.46 ± 0.14	0.05 ± 0.05	–	−0.20 ± 0.15	−0.52 ± 0.32	− 0.21 ± 0.17	0.00 (1)
	H2	4.28 ± 0.05	0.02 ± 0.05	0.06 ± 0.28	–	–	−0.02 ± 0.27	0.19 (2)
RCI	N2	66.17 ± 6.81	–	−9.94 ± 16.84	8.49 ± 6.78	−3.20 ± 3.94	14.47 ± 9.86	0.12 (1)
	H2	66.83 ± 7.17	5.12 ± 0.63		3.27 ± 7.14	−14.08 ± 4.09	17.38 ± 10.03	000 (0)

Note: m = mean, d = additive effect, h = dominant effect, i = additive × additive, j = additive × dominance, l = dominance × dominance

weight was found to be 2.08~4 g, GOT 37.11~39%, fiber length 23.31~28.05 mm, fiber strength 23.52~25.17 $g·tex^{-1}$ and fiber fineness 4.21~4.68 $μg·inch^{-1}$ for all of population derived from two crosses under normal and heat stress conditions.

Genetic effects

The additive [d) and dominant [h] effects were statistically significant for boll weight and fiber strength in normal conditions while d and h were involved in the inheritance of fiber fineness and relative cell injury in heat stressed condition in cross-1 (Tables 3 and 4). In cross-2, additive and dominant effects were significant for boll weight and GOT in normal and heat stressed conditions, for fiber length in normal condition, for fiber fineness and relative cell injury in heat stressed condition. It indicates that both additive and dominant genes played an important role in inheritance of these traits.

Dominance [h], additive × dominance [j] and dominance × dominance [l] variances referred as non-additive gene action, were significant for RCI under heat stress in cross-1, and this pattern of inheritance was found for boll weight under heat stress and RCI under both normal and heat stress condition in case of cross-2. This indicated that these traits were affected by dominance as main affect and epistasis as interallelic interaction.

Correlation

Genotypic correlation was lower than phenotypic correlation that showed involvement of environmental ×

Table 5 Phenotypic (lower diagonal) and genetic correlation (upper diagonal) matrix for boll weight, ginning outturn, fibre length, fibre strength, fibre fineness and relative cell injury in cross VH-282 × FH-142 (1) under normal (N) and heat stress (H) conditions

TRAITS	Stress Conditions	BW	GOT	FL	FS	FF	RCI
BW	N1		0.205	−0.394	−0.029	−0.22	− 0.034
	H1		0.077	0.374	0.026	0.11	−0.129
GOT	N1	−0.068		0.382	0.016	−0.015	0.1
	H1	−0.034		−0.092	−0.029	0.269	−0.25
FL	N1	0.031	0.103		−0.175	−0.107	− 0.155
	H1	0.019	0.092		0.038	0.385	−0.088
FS	N1	−0.013	−0.073	0.156		−0.254	−0.029
	H1	0.082	−0.048	−0.045		−0.212	0.07
FF	N1	0.132	0.013	0.026	0.009		−0.057
	H1	−0.042	−0.075	− 0.082	−0.113		−0.228
RCI	N1	−0.096	0.043	−0.005	−0.051	0.049	
	H1	−0.266**	0.034	−0.01	−0.039	− 0.02	

*and ** mean significant differences at 5% and 1% probability levels, respectively

Table 6 Phenotypic (lower diagonal) and genetic correlation (upper diagonal) matrix for boll weight, ginning outturn, fibre length, fibre strength, fibre fineness and relative cell injury in cross DNH-40 × VH-259 (2) under normal (N) and heat stress (H) conditions

TRAITS	Stress Conditions	BW	GOT	FL	FS	FF	RCI
BW	N2		0.159	−0.124	−0.127	0.092	−0.242
	H2		0.234	−0.02	0.177	0.18	−0.048
GOT	N2	−0.011		−0.191	0.000	−0.205	−0.072
	H2	−0.056		0.059	−0.031	−0.103	− 0.068
FL	N2	0.039	0.013		−0.213	0.41	−0.34
	H2	0.001	0.123		−0.13	0.073	−0.489
FS	N2	0.054	−0.065	−0.03		−0.173	− 0.092
	H2	0.026	−0.003	−0.01		−0.272	− 0.165
FF	N2	0.11	−0.01	−0.079	− 0.011		− 0.167
	H2	−0.144	0.056	−0.024	−0.027		−0.015
RCI	N2	−0.088	−0.124	− 0.043	−0.081	0.035	
	H2	−0.067	−0.197*	− 0.007	−0.084	0.035	

*mean significant differences at 5% probability level

genotypic interaction. The correlation analysis revealed that boll weight was significantly but negatively correlated with cell membrane stability at phenotypic level grown in heat stress condition for cross-1 (Table 5 and Fig. 1). Likewise, in cross-2, GOT was also negatively and significantly correlated with relative cell injury under heat stress condition (Table 6 and Fig. 1).

Heritability and genetic advance

Narrow sense heritability was moderate (0.43–0.74) whereas broad sense heritability was found high (0.76–0.96) in both crosses (Table 7 & Fig. 2). Narrow sense heritability was lower than broad sense heritability for all the traits under study in both crosses. Genetic advance was low to moderate for both the crosses under both normal and heat stress conditions and ranged from 0.52 to 16.91 (Table 7 & Fig. 2).

Heterosis

Heterosis and Heterobeltiosis was statistically significant for boll weight under heat stress condition for cross-1, while it was significant for cross-2 in normal condition. The values of heterosis and heterobeltiosis were ranged from − 0.2 to 17.47 and − 0.24 to 16.73, respectively, for both crosses under normal and heat stress conditions (Table 7).

Discussion

Cotton production is facing several biotic and abiotic challenges including CLCV (Cotton leaf curl virus), wilting disease, sucking and chewing insect pests, drought and elevated temperature. In recent years, high temperature has been reported as a serious threat to crop productivity (Zafar et al. 2018). So, when cotton is exposed to high temperature for longer duration lead to wilting of leaf (Ahuja et al. 2010; Zahid et al. 2016), shedding of fruiting bodies, i.e., squares,

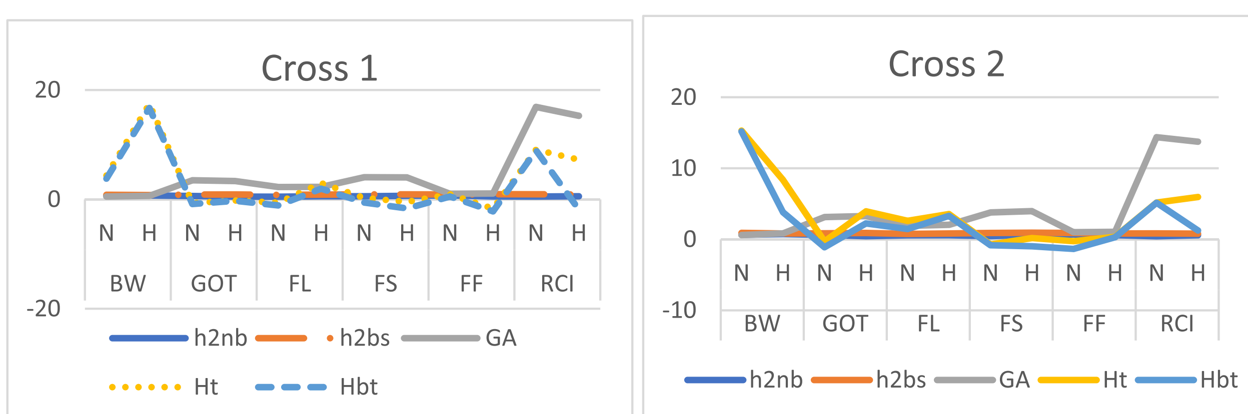

Fig. 1 Correlation coefficients under normal(N) and heat stressed(H) conditions for cross-1 and cross-2

Table 7 Narrow sense heritability (h^2ns), broad sense heritability (h^2bs), Genetic Advance (GA), Heterosis (Ht) and Better parent heterosis (Hbt) for boll weight, ginning outturn, fibre length, fibre strength, fibre fineness and relative cell injury in VH-282 × FH-142

Traits	Stress Conditions	Cross-1					Cross-2				
		h^2_{nb}	h^2_{bs}	GA	Ht	Hbt	h^2_{nb}	h^2_{bs}	GA	Ht	Hbt
BW	N	0.66	0.86	0.52	4.36	3.81	0.64	0.91	0.60	15.30*	15.18*
	H	0.71	0.81	0.65	17.47*	16.73*	0.74	0.82	0.83	8.38	3.82
GOT	N	0.62	0.89	3.49	−0.66	−0.84	0.63	0.85	3.13	−0.28	−1.11
	H	0.51	0.92	3.35	−0.20	−0.24	0.44	0.90	3.27	3.94	2.24
FL	N	0.49	0.84	2.27	−0.60	−1.09	0.57	0.76	1.90	2.61	1.46
	H	0.57	0.89	2.28	2.98	1.97	0.58	0.82	2.05	3.56	3.31
FS	N	0.56	0.93	4.05	0.28	−0.57	0.45	0.89	3.79	−0.72	−0.83
	H	0.64	0.94	4.01	−0.43	−1.65	0.61	0.93	3.97	0.19	−0.98
FF	N	0.72	0.91	1.02	0.94	0.54	0.69	0.90	1.01	−0.26	−1.34
	H	0.54	0.96	1.08	−1.68	−2.18	0.59	0.82	1.06	0.36	0.29
RCI	N	0.52	0.95	16.91	9.09	8.98	0.43	0.83	14.39	5.18	5.16
	H	0.56	0.91	15.30	7.28	−1.85	0.58	0.80	13.75	5.96	1.25

*mean significant differences at 5% probability level

buds, flowers and bolls (Cao et al. 2008; Iqbal et al. 2017), and decreased rate of photosynthesis is reported by Marchand et al. (2005). Therefore, it is need of the time to focus on development of new germplasm which can cope with high temperature.

The biometrical analysis indicated that values of dominance or epistasis were many times greater than those of additive effects which shows that these traits were governed by non-additive gene action (Ahmad et al. 2009; Batool et al. 2013; Iqbal et al. 2013). In contrary, these traits had higher values of broad sense heritability but low values of genetic advance which further elaborated the role of non-additive gene action (Singh and Verma 2018). According to Jagtap (1986) when dominant effects are larger than the additive ones then the intensive selection is required for improvement of these traits and selection may be delayed in later generations. Lower values of narrow sense heritability than broad sense heritability for these traits showed that the environmental component was contributing significantly. Low heritability under heat stress condition validate the role of environmental component as well as genotypic × environmental interaction (Murtaza 2006; Desalegn et al. 2009; Batool et al. 2010).

Correlation study revealed that the boll weight (Farooq et al. 2014) and GOT (Azhar et al. 1999; Farooq et al. 2014) had a significant and negative phenotypic correlation with RCI under heat stress conditions. Under heat stress RCI was increased which resulted in increased transpiration and less assimilation of photosynthates which had an adverse effect on boll weight and GOT. Consequently, injury of cell membrane lead to the disturbance of normal functioning of cell which exerts adverse effects on synthesis of fiber. The information from heterosis help plant breeders to identify the superior parental and certain combinations for the development of hybrids. The same data was also exploited for heterosis where it was known that boll weight had significant and positive values over mid parent and better parent under heat stress condition.

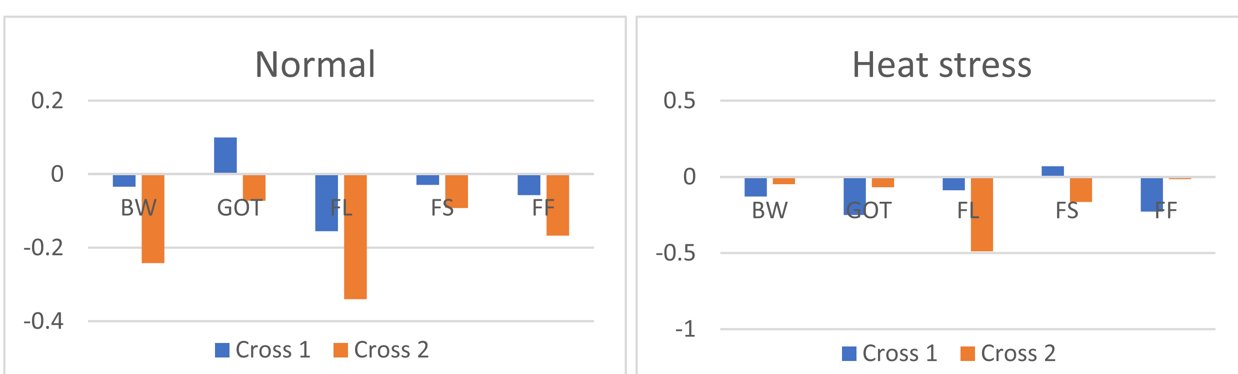

Fig. 2 Heritability, genetic advance and heterosis for cross-1 and cross-2

This revealed that heterozygosity could increase the weight of boll in cotton. A significant gain in boll weight due to heterosis has been reported by several researchers (Abd-El-Haleem et al. 2010; Panni et al. 2012; El-Refaey and El-Razek 2013). Th progeny from cross-1 exhibited high heterosis under heat stressed condition due to the involvement of heat tolerant donor parent, i.e., FH-142. The germplasm derived from cross-1 had higher values for majority of the traits under heat stress which showed that this particular combination was comparatively more heat tolerant than cross-2. On the basis of these results one could conclude that FH-142 and VH-282 could be the desirable parents for their utilization in the breeding programs for the development of heat tolerant germplasm.

Conclusion

All of traits studied in this experiment were predominantly controlled by non-additive gene action except RCI where additive gene action was involved. Therefore, selection based on RCI could be reliable for development of heat tolerant varieties. It is determined that heat stress had role in reduction of boll weight and GOT, which are important yield contributing parameters. The parental lines VH-282 and FH-142 performed better under normal and heat stress conditions and could be utilized for the development of new germplasm for high temperature areas in addition fiber related parameters can be improved.

Abbreviations

BW: Boll weight; d: Additive effect; FF: Fiber fineness; FL: Fiber length; FS: Fiber strength; GOT: Ginning outturn; h: Dominant effect; i: Additive × additive; j: Additive × dominance; l: Dominance × dominance; m: Mean; RCI: Relative cell injury

Acknowledgements

Authors are thankful to Higher Education Commission, Pakistan for provision of funds through Indigenous 5 000 PhD Scholarship Scheme.

Authors' contributions

Salman M conducted this study for his PhD research and collected the data. Azhar MT and Rana IA designed this study and served as supervisory committee for PhD studies of Salman M. Maqsood RH and Zia ZU helped in collection of the data and biometrical analysis. While Ahmad S and Bukhsh A have critically reviewed every section of the manuscript before submission to Journal. All the authors read and approved the final manuscript.

Funding

The funding for this research was provided by Higher Education Commission, Pakistan.

Availability of data and materials

Data supporting the finding will be provided on demand. For demand of data any one can contact Salman M and Zia ZU through email and institutional addresses.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Received: 14 January 2019 Accepted: 6 June 2019
Published online: 05 July 2019

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