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Original Article

Hybrid vigor studies for different yield contributing traits in wheat under normal and heat stress conditions

Jehanzeb Farooq[1*], Ihsan Khaliq[2], Muhammad Akbar[1], Muhammad Kashif[2], Shahzadi Mahpara[2]

[1]Ayub Agricultural Research Institute, Faisalabad, Pakistan
[2] Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Pakistan
*Corresponding author, e-mail: jehanzeb1763@hotmail.com

Abstract

Terminal heat stress is among one of the major constraints in wheat productivity in many countries of the world including Pakistan. To combat this natural calamity,one hundred spring wheat genotypes were assessed for heat stress tolerance under plastic sheet tunnel resulting in seven parents with varied heat stress tolerance. The seven parents including tolerant, moderately tolerant and susceptible but high yielders were later hybridized in a 7×7 diallel fashion. Analysis of variance revealed significant differences for all the studied traits.The heterosis and heterobeltiosis estimates revealed that thereisdesirable hybrid vigor in the current studies for all the traits evaluated.For grain yield maximum heterosis of 28.70% under normal and 27.02% under heat stress conditions were observed. Regarding heterobeltiosis it remained at 15.58% under normal and 13.62% under heat stress conditions. Similarly desirable negative results were obtained for relative cell injury%, days to heading and maturity and positive significant heterosis and heterobeltiosis was obtained for flag leaf area, biomass per plantand harvest index%. The cross combinations like Inqilab-91×Shalimar-88, Shalimar-88 × Maya/Pavon, Chenab-2000 × Punjab-85, Maya/Pavon × Chenab-2000, Shalimar-88 × Uqab-2000 and Uqab-2000 × Maya/Pavonhave shown good hybrid vigor in terms of various traits studied. Suggestively, they may be further exploited following pedigree or bulk method to develop heat tolerant wheat varieties because of their ability to perform well under normal and even diverse environments.

Key words: *Triticum aestivum*, heat stress, relative cell injury, heterosis

Estudos de vigor híbrido para diferentes produtividades do trigo sob condições normais e de estresse por calor

Resumo

Estresse por calor está entre um dos maiores problemas quanto à produtividadede trigo em muitos países do mundo, incluindo o Paquistão. Para combater esta calamidade natural, cem genótipos de trigo de primavera foram avaliados quanto à tolerância ao estresse térmico sob túnel plástico, resultando em sete pares com tolerância variada a esse estresse. Os sete pares incluindo tolerantes, moderadamente tolerantes e suscetíveis, com exceção do mais elevado foramhibridizados em um esquema7 × 7, emformadialélica.A análise de variância reveloudiferenças significativas paratodas as características estudadas. As estimativasde heterosee heterobeltioserevelaram que há desejávelvigor híbrido,nos estudosatuais, paratodas ascaracterísticas avaliadas.Para a produção de grãoshouve heterosemáxima de28,70%sob condiçõesnormais e27,02%sob condições de estresse térmico. Quanto àheterobeltiose,manteve-se em15,58%normais e13,62%sob condições de estressetérmico.Da mesma forma,desejáveisresultados negativosforam obtidos para% em relação à lesão celular, aos dias para crescimento e maturidade e positivaheteroseeheterobeltioseforam obtidaspara a áreada folha, a biomassa por planta eíndice de colheita%. Ascombinações híbridascomoInqilab-91 ×Shalimar-88, Shalimar-88 ×Maya/Pavon, Chenab-2000 ×Punjab-85, Maya /Pavon×Chenab-2000, Shalimar-88 ×Uqab-2000 e Uqab-2000 ×Maya/Pavontêm mostradovigor híbridobom em termos devárias característicasestudadas.Sugestivamente, eles podem ser mais explorados,seguindométodo genealógicoou a granelpara desenvolvervariedades de trigotolerantesao calordadasuahabilidade de desenvolver-se bemem condições normaise até mesmo emdiversos ambientes.

Palavras-chave: *Triticum aestivum*, estresse térmico, injúria celular, heterose

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Introduction

Wheat (*Triticum aestivum* L.) is the most extensively cultivated crop among the cereals. Wheat cultivation is best suited to cool growing conditions (Modhej et al., 2008). Its cultivation is increasing into regions that are too warm for most favorable growth and yield (Farooq et al., 2011). Among many parameters, affecting wheat production, temperature stress or heat shocks are the most vital, especially in regions where temperature fluctuations are abrupt. Lower yields in wheat in warm areas are due to shorter crop duration and grain filling period which results due to higher temperatures during crop growth, particularly during the grain-filling period which is the most critical stage of grain development. Short heat stress (≥ 35 °C) during this time reduces starch contents, thus decreasing grain quality and weight (Sial et al., 2005). Mating of wheat genotypes possessing desired characters has so far been the most efficient method of improvement. Heterosis studies can also be utilized for getting desired information on the increase or decrease of F_{1s} over their mid and better parental values.

Selection of parents is the most vital stage in any breeding program. For this purpose, many researcher shave use d parents with contrasting traits such as combination of hard red and soft white wheat, winter and spring wheat cultivars (Baric et al., 2004), old and modern day wheat cultivars (Morgan, 1998), short and tall (Bailey et al., 1980). According to Morgan et al. (1989), parents utilized in breeding programs may show less heterosis for grain yield because they already have several valuable genes in homozygous state. In addition to that, Fabrizius et al. (1998) have reported that the parents with greater genetic differences may produce more hybrid vigor for grain yield. Singh et al. (2004) have recommended heterobeltiosisas being valuable for influencing true heterotic cross combinations.

Comparison of mean of two sowing extremes i.e., normal and heat stress conditions revealed that days to heading, days to maturity, and grain yield are greatly reduced as a result of difference in sowing times (Mahboob et al., 2005; Arain et al., 2002). El-Shami et al. (1996) have reported high heterosis percentage for grain yield per plant. For days to heading some researchers found negative desirable heterosis (Sadeque et al., 1991). Masood et al. (2005) have found both positive and negative estimates ofheterosis for days to maturity. Maximum positive heterosis in flag leaf area was reported by (Chowdhry et al., 2001; Ullah, 2004). The trait like biomass per plant showed positive and significant heterosis in wheat (Akbar et al., 2007). Heterotic studies for harvest index also revealed positive and had maximum positive heterosis estimates (Jan et al., 2005) while low heterosis effects were reported by Akbar et al. (2007).

The experiment was carried out aiming to study the out yielding effects of wheat hybrids under normal and heat stress conditions for different traits and their possible exploitation for commercial use.

Material and Methods

For evaluation of heat stress tolerance 100 spring wheat genotypes were exposed to heat stress in plastic sheet tunnel (PST), the technique developed by Rehman et al. (2009) and used by (Farooq et al., 2011).The germplasm was sown in two sets following randomized complete block design (RCBD) with three replications, one in plastic tunnel and one in open adjacent to the tunnel during 2005-06 cropping season. The genotypes evaluated in the experiment were highly variable in terms of heading date. So the genotypes that head earlier were sown later and thegenotypes that head later were sown earlier to get Synchronization in heading. Each genotype was sown in a single meter row with 30cm and 7.5cm inter and intra row spacing. The genotypes sown under tunnel were exposed to heat stress atanthesis and grain filling for a period of almost one month (Rehman et al., 2009). Daily temperature was noted both inside and outside the tunnel and maintained at almost >32°C inside the tunnel (Figure 1). Three criteria were used for screening the parents for crossing program; first, measurement of relative cell injury percentage (RCI%), second, the heat tolerance of different genotypes was measured as relative ratio (ratio of stressed/non-stressed) for each variety/line for spike traits like grains/ spike, 1000 kernel weight, and yield/ spike and third, ability to stay green (Rehman et al., 2009) and seed development (Data not shown).

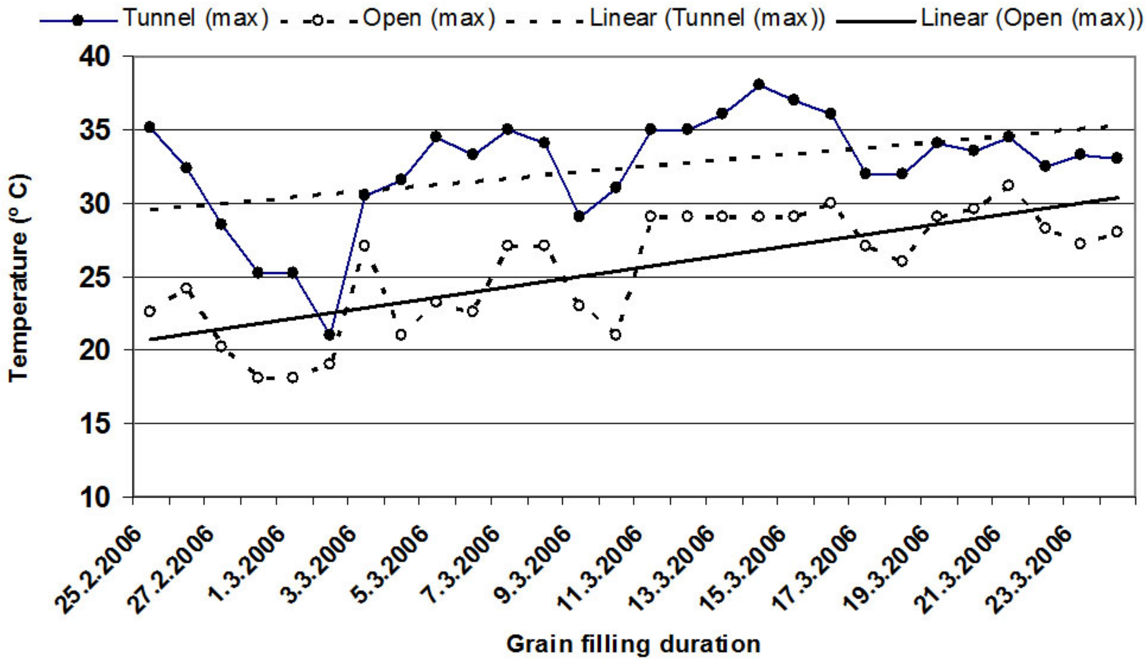

Figure 1. Difference of temperature inside the plastic tunnel and outside the tunnel during anthesis and grain filling stage.

The experimental material developed after screening against heat was comprised of seven wheat cultivars including five local varieties, such as Shalimar-88 (Tolerant), Chenab-2000 (Tolerant), Inqilab-91(Moderately tolerant), Uqab-2000 (Susceptible but yielder) Punjab-85(Susceptible but yielder) and two exotic cultivars Weebli-1(susceptible but yielder) and Maya/Pavon (Tolerant) were sown in the field on November, 05th, 2006 in the experimental area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Paquistanand later hybridized in all possible combinations including reciprocals following diallel mating system. During next crop season, seven wheat varieties/lines (parents) and their hybrids (F_1) were planted in field in two sowing dates on November, 10th, 2007(Under normal conditions) and December, 25th (under heat stress conditions) following a triplicated randomized complete block design. In late sowing, the crop was subjected to natural heat stress regime around 30-40° C at grain filling stage (Figure 2).

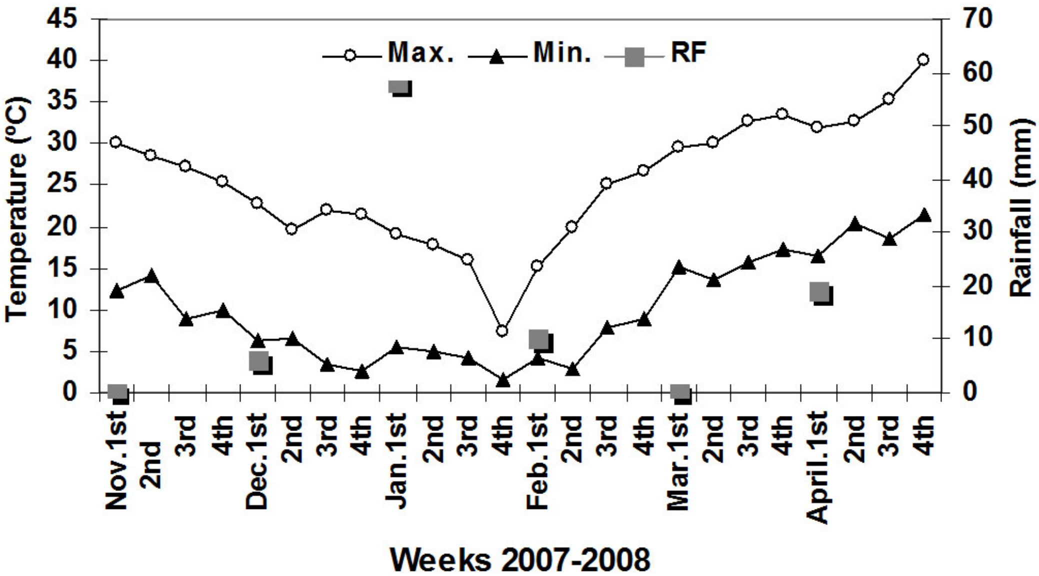

Figure 2. Maximum and minimum temperature through the growing season of the crop in 2007-2008. It showed high temperature stress (>30°C) at grain filling stage which started from third week of March 2008.

Thirty plants of each genotype were grown in a 5 m long row in each replication. The plants were spaced 15 and 30 cm apart within and between the rows, respectively. Two seeds were dibbled per hole and after germination one healthy seedling was retained at each hole after thinning. All standard agronomic practices were adopted. For data collection ten plants for each parent and cross were tagged at random for each replication in both regimes and data were recorded for Days to 50% heading, heading stage, days to maturity, maximum length and breadth of shoot. The data were recorded in the morning hours when leaf was fully turgid. Flag leaf area was measured according to the method of Muller (1991):

Flagleafarea = Flagleaflength x FlagleafWidth x 0.74

At the time of harvesting ten randomly selected plants were weighed separately with the help of an electric balance (Compax-Cx-600) before threshing for obtaining their biological yield in grams.. For grain yield, all spikes of individual selected plants were threshed manually and weighed using electric balance (Compax- Cx-600). Average grain yield per plant was estimated for each genotype in each replication. Harvest index for each of the genotype was computed using the following formula;

Haverst index(%) = Grainyieldperplant/Biologicalyieldperplant x 100

For estimating relative cell injury (%), age of the parent's artificial desiccation was induced by polyethylene glycol (PEG-6000) method as proposed by Sullivan (1971). At the time of anthesis, flag leaves of 10 randomly selected plants were taken from field grown plants to study the electrolyte leakage from leaves by using conductivity meter, following the technique described by Shanahan et al. (1990). Ten fully expanded flag leaves of 10 randomly selected guarded plants were collected at noon from the field plots. Samples were rinsed twice with deionized water to remove surface contamination and then blotted dry.

Two groups of fifteen leaf discs of 1.0 cm^2 size were made from the selected leaves sample of both regimes. One group was exposed to 30% polyethylene glycol (PEG-6000) in 25 ml test tubes and the second group was submerged in 15 ml deionized water in the test tubes (control sample). One set of leaf discs were used as a control and kept at room temperature (25°C) and the other was treated at (49°C) in water bath (MEMMERT-WB1, Germany) for 1 hour. After treatment the readings of both control and treated leaf discs were taken by using conductivity meter (Model No. JENWAY- 4510 Sr. No-02370 Barlow World Scientific Limited, UK) after keeping the test tubes over night. In the next day, both controlled and treated test tubes were placed in autoclave (Model No. HVA-85 HRAYAMA Manufacturing Company, Japan) at 120^{0}C and 0.10 Mpa, for a period of 10 minutes to kill tissues completely and leakage was measured again. Then, the relative cell injury % was calculated by using the formula;

RelativeCellInjury %age = 1-{(1-T1/T2/1-C1/C2)}x100

In which,

T1 = conductivity reading at 49°C,
T2 = conductivity reading at 120°C
C1 = conductivity reading at room temperature,
C2 = conductivity reading at 120°C

The collected data were analyzed to determine significant varietal differences among the 42 genotypes under both regimes following the method of Steel et al. (1997).

Heterosis

Heterosisestimates over the mid parent and better parent (heterobeltiosis) were calculated using the procedure of Matzinger et al. (1962);

Heterosis (%) = (F1-MP)/MPx100

Heterobeltiosis (%) = (F1-BP)/BPx100

In which,

MP = mid parental value of the particular F_1 cross $(P_1 + P_2) / 2$,
BP = better parent value in the particular F_1 cross.

Difference of F_1 mean from the respective mid parent and better parent value was evaluated by using a t-test according to Wynne et al. (1970);

$$t = \overline{F1}ij - \frac{MPij}{\sqrt{\frac{3}{8\sigma 2e}}}$$

In which,

$\mathbf{F_{1ij}}$ = the mean of the ijth F_1 cross,

MP_{ij} = mid parent value of the ij[th] cross, and

σ^2_e = estimate of error variance

Results

Genotypic differences among the parents

Analysis of variance have indicated significant differences (P<0.01) for all the traits among 49 genotypes under both regimes. The mean squares for the traits are represented in Table 1 describing high significance of the 'F' test for all the traits under study. The relative cell injury% of the parents selected for crossing is given in Figure 3 and crosses obtained from these parents, in Figure 4.

Table 1. Mean squares of various plant traits in a 7x7 diallel cross under normal and heat stress conditions of Wheat.

Source (Normal)	DF	Days to Heading	Days to Maturity	Flag leaf area	Biomass per plant	Grain yield per plant	Harvest index	RCI%
Replication	2	30.74[NS]	15.31[NS]	4.31[NS]	13.39[NS]	1.44[NS]	13.97[NS]	15.26[NS]
Genotypes	48	38.22**	45.96**	15.72**	68.43**	10.65**	40.23**	269.78**
Error	96	11.64	7.09	1.76	14.93	1.37	19.77	14.93
Mean		**91.42**	**146.41**	**24.60**	**46.37**	**18.64**	**40.74**	**43.82**
CV %		**3.73**	**1.82**	**5.39**	**8.33**	**6.28**	**10.92**	**7.34**
Source (H.Stress)	**DF**	**Days to Heading**	**Days to Maturity**	**Flag leaf area**	**Biomass per plant**	**Grain yield per plant**	**Harvest index**	**RCI%**
Replication	2	3.62[NS]	6.76[NS]	0.15[NS]	3.43[NS]	0.174[NS]	1.59[NS]	1.13[NS]
Genotypes	48	13.49**	23.96**	8.09**	18.94**	3.057**	80.57**	22.33**
Error	96	6.49	10.80	1.34	3.82	0.156	8.23	9.04
Mean		**73.68**	**106**	**16.15**	**19.44**	**5.63**	**29.36**	**51.31**
CV %		**3.46**	**3.10**	**7.16**	**10.07**	**7.03**	**9.77**	**5.86**

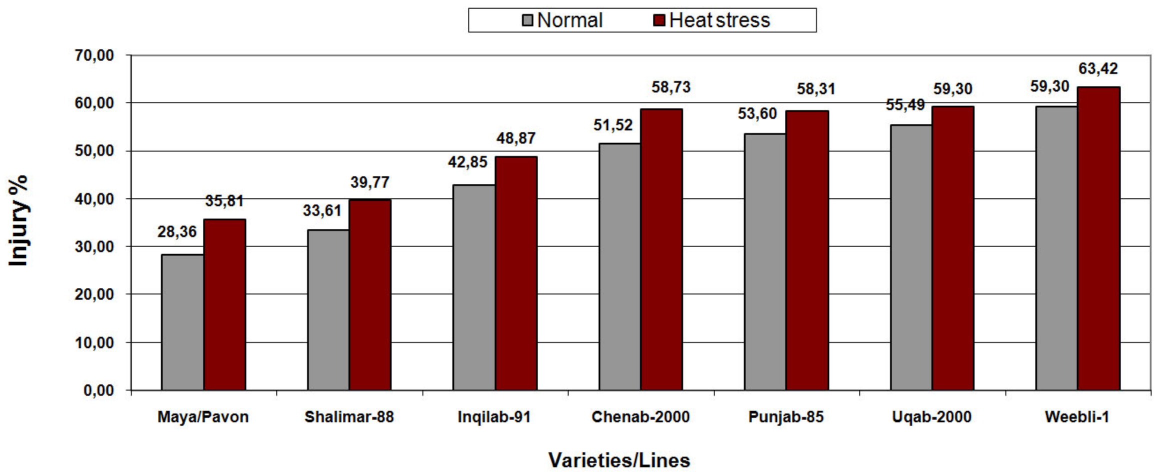

Figure 3. Relative cell injury% of the parents under normal and heat stress conditions.

Heterosis and heterobeltiosis for days to heading under normal and heat stress conditions

Heterosis for days to heading under normal conditions (Table2) revealed that 21 crosses showed negative heterosis, being 2 crosses highly significant, 2 significant and 17 crosses with non-significant results. Highest negative heterosis (-7.14%) and heterobeltiosis(-9.00%) were shown by the cross combination i.e., Weebli-1 × Maya/Pavon followed by Inqilab-91 × Chenab-2000, which showed heterosis (-5.67%) and heterobeltiosis (-7.86%).

Under heat stress conditions only 6 crosses showed negative and highly significant heterotic effects and 4 exhibited significant estimates. Maximum decrease in mid parental value was shown by the cross Maya/Pavon × Weebli-1 (-6.46%) and Weebli-1 × Punjab-85 (-5.67%). Maximum negative heterobeltiosis was shown by the cross combination Weebli-1 × Punjab-85 (-10.34%) followed by Maya/Pavon × Weebli-1 (-9.48%).

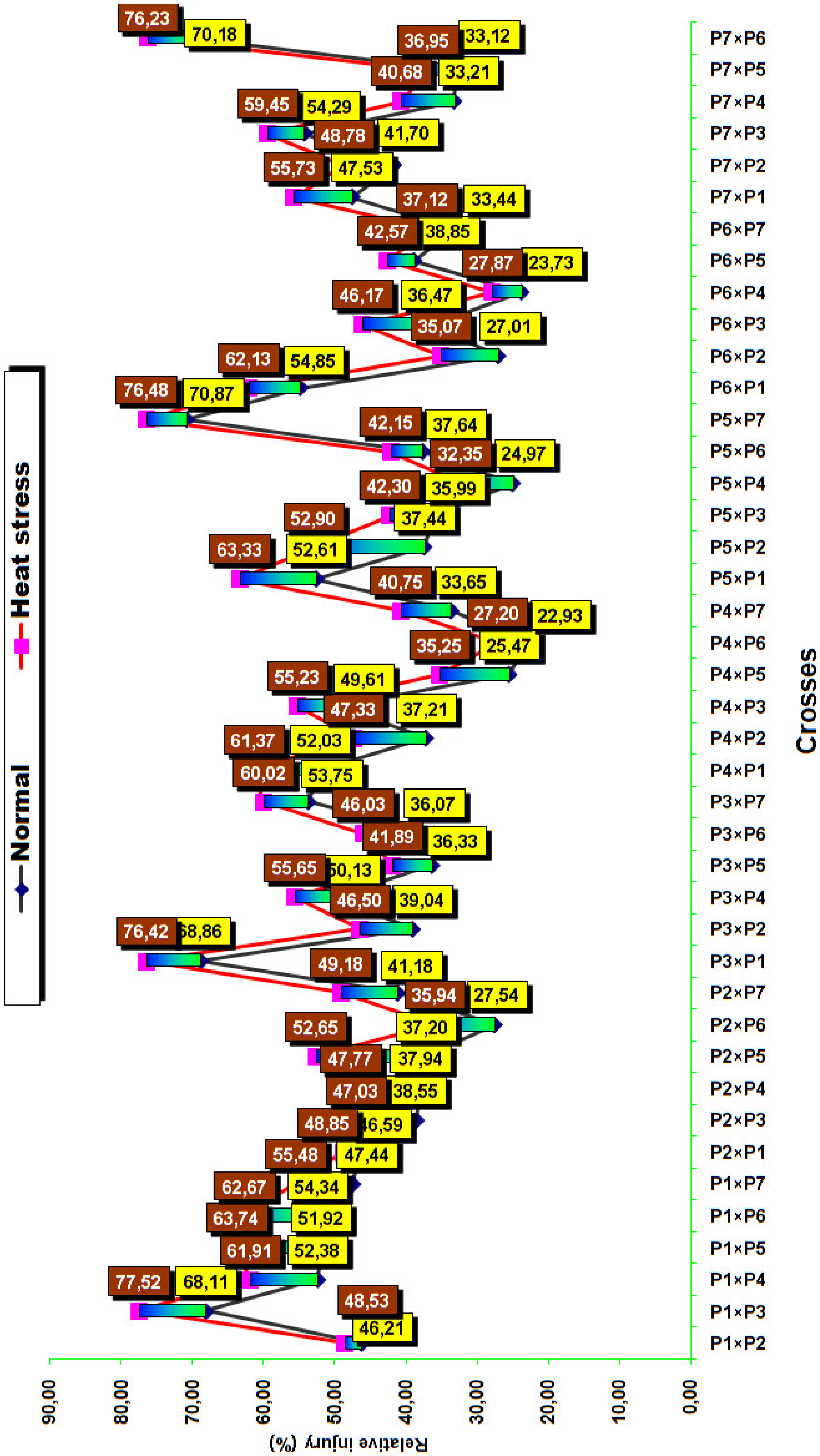

Figure 4. Relative cell injury% of crosses in a 7x7 diallel cross of bread wheat.

Table 2. Heterosis (HT) and heterobeltiosis(HBT) for various traits in wheat under normal and heat stress conditions.

Cross combinations	Days to heading under normal		Days to heading under heat stress		Days to maturity under normal		Days to maturity under heat stress		Flag leaf area under normal		Flag leaf area under heat stress	
	HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT
INQILAB-91×SHALIMAR-88	0.75^{NS}	0.37^{NS}	-5.36**	-6.61**	0.34^{NS}	-1.35^{NS}	-5.16**	-7.34**	2.75^{NS}	-0.02^{NS}	73.30**	65.33**
INQILAB-91×CHENAB-2000	-5.67**	-7.86**	2.73^{NS}	-0.44^{NS}	-0.57^{NS}	-1.80^{NS}	2.03^{NS}	-0.31^{NS}	-5.74^{NS}	-15.76**	18.05**	4.41^{NS}
INQILAB-91×UQAB-2000	-1.14^{NS}	-2.25^{NS}	-1.98^{NS}	-2.19^{NS}	1.90*	1.56^{NS}	-1.52^{NS}	-1.82^{NS}	-6.98*	-16.44**	4.98^{NS}	-4.36^{NS}
INQILAB-91×PUNJAB-85	-3.62*	-5.24*	3.21*	-0.88^{NS}	0.34^{NS}	-1.80^{NS}	2.38^{NS}	-1.22^{NS}	-6.37*	-16.27**	52.34**	48.87**
INQILAB-91×MAYA/PAVON	0.54^{NS}	-3.13^{NS}	-1.35^{NS}	-3.52*	0.58^{NS}	-2.92*	-0.16^{NS}	-3.36*	-19.57**	-20.44**	36.10**	34.69**
INQILAB-91×WEEBLI-1	3.35*	-2.33^{NS}	2.83^{NS}	1.72^{NS}	1.86*	-0.64^{NS}	1.97^{NS}	1.20^{NS}	-19.79**	-20.47**	40.76**	33.06**
SHALIMAR-88×INQILAB-91	1.87^{NS}	1.49^{NS}	-4.91**	-6.17**	1.26^{NS}	-0.45^{NS}	-6.42**	-8.56**	1.50^{NS}	-1.24^{NS}	70.96**	63.10**
SHALIMAR-88×CHENAB-2000	-2.73^{NS}	-4.64*	4.61**	2.71^{NS}	-0.46^{NS}	-0.92^{NS}	0.00^{NS}	0.00^{NS}	1.77^{NS}	-6.77*	29.83**	19.89**
SHALIMAR-88×UQAB-2000	1.13^{NS}	-0.37^{NS}	2.00^{NS}	0.44^{NS}	-1.14^{NS}	-3.13**	2.03^{NS}	-0.61^{NS}	21.70**	12.09**	58.33**	50.84**
SHALIMAR-88×PUNJAB-85	-0.57^{NS}	-2.60^{NS}	2.79^{NS}	0.00^{NS}	-0.23^{NS}	-0.70^{NS}	-1.95^{NS}	-3.21*	-9.45**	-16.98**	24.57**	21.55**
SHALIMAR-88×MAYA/PAVON	-0.54^{NS}	-3.82^{NS}	-2.74^{NS}	-3.62*	0.95^{NS}	-0.93^{NS}	-3.88**	-4.81**	-7.56*	-9.08*	5.07^{NS}	1.25^{NS}
SHALIMAR-88×WEEBLI-1	0.88^{NS}	-4.33*	0.66^{NS}	-1.72^{NS}	-1.56^{NS}	-5.56**	1.24^{NS}	-1.81^{NS}	-9.00**	-10.70**	44.26**	42.88**
CHENAB-2000×INQILAB-91	-4.20*	-6.43**	0.91^{NS}	-2.20^{NS}	-0.57^{NS}	-1.80^{NS}	0.47^{NS}	-1.83^{NS}	-6.62*	-16.55**	18.91**	5.18^{NS}
CHENAB-2000×SHALIMAR-88	-1.64^{NS}	-3.57^{NS}	3.23*	1.36^{NS}	0.00^{NS}	-0.46^{NS}	0.00^{NS}	0.00^{NS}	-1.63^{NS}	-9.88**	30.14**	20.18**
CHENAB-2000×UQAB-2000	0.92^{NS}	-2.50^{NS}	0.68^{NS}	-2.63^{NS}	1.13^{NS}	-0.45^{NS}	-1.09^{NS}	-3.65*	10.15**	9.50*	26.06**	21.99**
CHENAB-2000×PUNJAB-85	0.74^{NS}	-3.21^{NS}	2.84^{NS}	1.88^{NS}	-0.23^{NS}	-1.15^{NS}	8.12**	7.25**	-1.15^{NS}	-1.22NS	17.02**	5.65^{NS}
CHENAB-2000×MAYA/PAVON	-1.76^{NS}	-3.13^{NS}	-2.79^{NS}	-3.69*	3.07**	0.69^{NS}	9.06**	8.53**	-6.18*	-15.33**	32.21**	18.02**
CHENAB-2000×WEEBLI-1	-0.34^{NS}	-3.67*	-0.67^{NS}	-4.74*	-1.33^{NS}	-4.91**	1.55^{NS}	-1.51^{NS}	-3.43^{NS}	-13.04**	12.55**	4.86^{NS}
UQAB-2000×INQILAB-91	0.76^{NS}	-0.37^{NS}	-3.74*	-3.95*	1.46^{NS}	1.12^{NS}	-2.44*	-2.74*	-7.37*	-16.78**	4.12^{NS}	-5.14^{NS}
UQAB-2000×SHALIMAR-88	2.26^{NS}	0.74^{NS}	2.90^{NS}	1.32^{NS}	-1.82*	-3.79**	2.03^{NS}	-0.61^{NS}	21.00**	11.45**	60.15**	52.56**
UQAB-2000×CHENAB-2000	0.92^{NS}	-2.50^{NS}	0.23^{NS}	-3.07^{NS}	0.45^{NS}	-1.12^{NS}	-0.47^{NS}	-3.04*	8.46*	7.83^{NS}	24.18**	20.17**
UQAB-2000×PUNJAB-85	-1.73^{NS}	-2.30^{NS}	-3.89*	-7.89**	-0.69^{NS}	-3.13**	-4.58**	-8.21**	5.07^{NS}	4.53^{NS}	10.20*	2.56^{NS}
UQAB-2000×MAYA/PAVON	-1.28^{NS}	-5.90**	-3.82*	-6.14**	-1.62^{NS}	-5.36**	3.62**	0.00^{NS}	-10.18**	-18.51**	21.91**	12.13**
UQAB-2000×WEEBLI-1	1.25^{NS}	-5.33**	-2.61^{NS}	-3.45*	-1.31^{NS}	-3.42**	-2.57*	-3.01*	-2.80^{NS}	-12.01**	22.75**	18.02**
PUNJAB-85×INQILAB-91	-2.86^{NS}	-4.49*	5.50**	1.32^{NS}	1.03^{NS}	-1.12^{NS}	0.79^{NS}	-2.75*	-5.34^{NS}	-15.35**	50.56**	47.13**
PUNJAB-85×SHALIMAR-88	0.57^{NS}	-1.49^{NS}	4.19*	1.36^{NS}	-0.70^{NS}	-1.16^{NS}	-2.60*	-3.85*	-10.92**	-18.33**	28.75**	25.62**
PUNJAB-85×CHENAB-2000	1.86^{NS}	-2.14^{NS}	3.79*	2.82^{NS}	-0.70^{NS}	-1.61^{NS}	7.14**	6.28**	-1.11^{NS}	-1.18^{NS}	19.04**	7.48^{NS}
PUNJAB-85×UQAB-2000	-2.12^{NS}	-2.68^{NS}	-4.81**	-8.77**	0.00^{NS}	-2.46*	-4.58**	-8.21**	4.52^{NS}	3.98^{NS}	9.42*	1.83^{NS}
PUNJAB-85×MAYA/PVN	0.37^{NS}	-4.86*	4.23*	2.30^{NS}	5.00**	3.52**	6.89**	5.84**	-4.46^{NS}	-13.72**	52.70**	50.77**
PUNJAB-85×WEEBLI-1	-0.36^{NS}	-7.33**	4.76**	-0.43^{NS}	0.67^{NS}	-3.85**	4.72**	0.30^{NS}	-16.38**	-24.64**	14.21**	10.39*
MAYA/PAVON×INQILAB-91	-0.18^{NS}	-3.82*	0.90^{NS}	-1.32^{NS}	0.12^{NS}	-3.37**	-1.11^{NS}	-4.28**	-17.80**	-18.69**	35.21**	33.81**
MAYA/PAVON×SHALIMAR-88	0.18^{NS}	-3.13^{NS}	-2.74^{NS}	-3.62*	0.71^{NS}	-1.16^{NS}	-3.88**	-4.81**	-9.58**	-11.07**	7.13^{NS}	3.24^{NS}
MAYA/PAVON×CHENAB-2000	0.00^{NS}	-1.39^{NS}	-5.12**	-5.99**	2.83**	0.46^{NS}	10.03**	9.50**	-8.08*	-17.05**	32.75**	18.51**
MAYA/PAVON×UQAB-2000	-2.00^{NS}	-6.60**	-3.37*	-5.70**	-1.16^{NS}	-4.91**	3.31*	-0.30^{NS}	-8.95**	-17.40**	19.85**	10.23*
MAYA/PAVON×PUNJAB-85	-0.73^{NS}	-5.90**	5.63**	3.69*	5.24**	3.76**	7.54**	6.49**	-2.74^{NS}	-12.17**	55.46**	53.49**
MAYA/PAVON×WEEBLI-1	-0.68^{NS}	-2.67^{NS}	-6.46**	-9.48**	4.08**	-1.92^{NS}	1.57^{NS}	-2.41^{NS}	1.68^{NS}	1.44^{NS}	42.04**	35.61**
WEEBLI-1×INQILAB-91	1.94^{NS}	-3.67*	1.96^{NS}	0.86^{NS}	1.20^{NS}	-1.28^{NS}	1.67^{NS}	0.90^{NS}	-18.80**	-19.49**	43.25**	35.42**
WEEBLI-1×SHALIMAR-88	0.53^{NS}	-4.67*	2.43^{NS}	0.00^{NS}	-2.00*	-5.98**	1.24^{NS}	-1.81^{NS}	-6.60*	-8.35*	45.88**	44.48**
WEEBLI-1×CHENAB-2000	0.69^{NS}	-2.67^{NS}	-2.47^{NS}	-6.47**	-2.00*	-5.56**	1.86^{NS}	-1.20^{NS}	-3.70^{NS}	-13.28**	13.13**	5.41^{NS}
WEEBLI-1×UQAB-2000	-0.18^{NS}	-6.67**	-2.17^{NS}	-3.02^{NS}	-1.97*	-4.06**	-1.36^{NS}	-1.81^{NS}	-3.16^{NS}	-12.34**	25.53**	20.70**
WEEBLI-1×PUNJAB-85	6.09**	-1.33^{NS}	-5.67**	-10.34**	2.01*	-2.56*	1.26^{NS}	-3.01*	11.90**	0.83^{NS}	38.89**	34.24**
WEEBLI-1×MAYA/PAVON	-7.14**	-9.00**	4.68**	1.29^{NS}	1.81*	-4.06**	5.96**	1.81^{NS}	-22.93**	-23.11**	13.00**	7.89^{NS}

Continuation of table 2

Biomass per plant under normal		Biomass per plant under heat stress		Harvest index under normal		Harvest index under heat stress		Grain yield per plant under normal		Grain yield per plant under heat stress		Relative cell injury% under normal		Relative cell injury% under heat stress	
HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT	HT	HBT
3.13^{NS}	-1.32^{NS}	2.68^{NS}	-6.79^{NS}	3.19^{NS}	-2.12^{NS}	-0.55^{NS}	-16.82**	1.66^{NS}	0.80^{NS}	3.80^{NS}	-5.27*	20.86**	7.83**	9.52**	-0.68^{NS}
-11.05**	-15.72**	-27.14**	-31.76**	-9.40**	-14.50**	22.18**	7.99^{NS}	-18.99**	-27.36**	-23.54**	-28.21**	44.33**	32.19**	44.11**	32.01**
-14.64**	-17.16**	-30.98**	-34.89**	17.29**	15.76**	52.23**	46.80**	0.10^{NS}	-1.54^{NS}	-6.23*	-8.28**	6.53**	-5.60**	14.47**	4.40**
-2.84^{NS}	-5.30*	-10.68*	-23.81**	5.11*	-1.83^{NS}	30.52**	16.33**	1.87^{NS}	-7.14*	16.92**	11.24**	7.65**	-3.14*	18.95**	9.32**
13.88**	7.73**	22.87**	7.61^{NS}	-8.78**	-15.30**	-22.66**	-31.98**	4.28^{NS}	2.30^{NS}	-18.89**	-28.89**	52.61**	26.81**	48.01**	28.24**
-9.39**	-20.86**	-0.01^{NS}	-22.25**	2.04^{NS}	-0.05^{NS}	-9.10^{NS}	-13.52*	-7.29**	-17.52**	-9.88**	-32.54**	-7.12**	-20.00**	-1.18^{NS}	-12.51**
3.95*	-0.54^{NS}	1.17^{NS}	-8.16^{NS}	3.33^{NS}	-1.98^{NS}	4.57^{NS}	-12.54**	7.58**	6.67*	4.07^{NS}	-5.03*	21.85**	8.72**	10.23**	-0.03^{NS}
-7.65**	-8.59**	-9.63^{NS}	-12.61*	5.81*	-4.97*	-19.57**	-24.55**	3.61^{NS}	-7.79**	-27.36**	-29.54**	-9.45**	-25.19**	-4.51**	-19.92**
-8.85**	-15.23**	1.24^{NS}	-2.83^{NS}	1.27^{NS}	-5.13*	26.71**	9.25*	-3.33^{NS}	-4.11^{NS}	27.02**	13.62**	-14.83**	-31.62**	-3.55*	-19.44**
-15.20**	-16.79**	34.83**	25.76**	11.99**	-0.39^{NS}	-26.78**	-31.92**	-2.01^{NS}	-11.36**	-12.53**	-23.68**	-14.69**	-30.60**	7.37**	-9.70**
-2.39^{NS}	-3.54^{NS}	52.19**	46.22**	12.10**	9.58**	4.20^{NS}	-1.72^{NS}	9.48**	8.30**	12.33**	7.45**	-11.14**	-18.08**	-4.90**	-9.63**
-2.76^{NS}	-18.21**	19.40****	0.34^{NS}	-5.67**	-12.25**	-21.87**	-37.22**	-6.94**	-16.58**	-1.94^{NS}	-30.86**	-11.35**	-30.55**	-4.68*	-22.45**
-9.49**	-14.24**	-31.33**	-35.68**	-12.54**	-17.46**	23.64**	9.28^{NS}	-21.14**	-29.29**	-14.08**	-19.32**	45.93**	33.66**	42.06**	30.14**
-6.60**	-7.56**	-5.28^{NS}	-8.40^{NS}	4.45*	-6.19**	-24.39**	-29.07**	-2.81^{NS}	-13.50**	-28.17**	-30.32**	-8.29**	-24.23**	-5.57**	-20.82**
17.10**	7.87**	0.42NS	-0.30^{NS}	9.68**	4.82^{NS}	-18.41**	-25.48**	27.94**	13.06**	-17.99**	-24.57**	-6.30**	-9.65**	-5.70**	-6.16**
-3.52^{NS}	-6.28**	10.82*	0.20^{NS}	4.36^{NS}	3.21^{NS}	-14.12**	-14.94**	0.79^{NS}	-1.03^{NS}	-4.67^{NS}	-14.55**	-30.88**	-32.22**	-28.41**	-28.66**
13.70**	13.52**	-11.28*	-17.46**	-5.35*	-16.68**	-11.24*	-11.75*	7.30**	-5.40*	-32.01**	-36.83**	-9.69**	-29.99**	-2.61^{NS}	-21.61**
15.39**	-3.75*	-1.63^{NS}	-19.54**	-14.85**	-18.03**	10.98*	-6.05^{NS}	1.19^{NS}	-18.12**	15.01**	-17.40**	-3.00**	-9.37**	-1.73^{NS}	-5.37**
-14.34**	-16.86**	-33.41**	-37.18**	15.60**	14.09**	53.96**	48.47**	-0.96^{NS}	-2.59^{NS}	2.42^{NS}	0.18NS	5.81**	-6.23**	13.47**	3.49*
-6.66**	-13.20**	-2.17^{NS}	-6.11^{NS}	0.74^{NS}	-5.62*	18.79**	2.43^{NS}	-5.62*	-6.39*	17.36**	4.98*	-16.47**	-32.94**	-4.44**	-20.1**
18.63**	9.28**	1.76^{NS}	0.97^{NS}	7.09*	2.34^{NS}	-18.88**	-25.91**	26.31**	11.62**	-22.62**	-28.83**	-7.29**	-10.60**	-6.40**	-6.86**
23.80**	17.20**	-7.35^{NS}	-16.80**	4.28^{NS}	-1.39^{NS}	-12.01*	-18.93**	28.70**	15.58**	-24.51**	-26.61**	-53.31**	-54.10**	-40.05**	-40.56**
2.96^{NS}	-5.30*	24.49**	14.99*	-8.44**	-16.02**	-5.10^{NS}	-13.77**	-4.93*	-5.18*	8.32**	-6.82**	-45.31**	-58.68**	-42.81**	-54.13**
-10.74**	-19.96**	-4.94^{NS}	-22.72**	1.90^{NS}	1.13^{NS}	11.73*	2.69^{NS}	-7.42**	-16.40**	4.23^{NS}	-20.79**	-41.37**	-43.26**	-33.58**	-35.74**
-4.43*	-6.86**	-15.63**	-28.03**	0.47^{NS}	-6.16*	30.53**	16.34**	-4.37^{NS}	-12.83**	12.06**	6.63*	9.09**	-1.85^{NS}	18.19**	8.62**
-16.32**	-17.89**	31.23**	22.40**	10.36**	-1.85^{NS}	-23.94**	-29.28**	-7.58**	-16.39**	-0.39^{NS}	-13.09**	-14.14**	-30.15**	7.88**	-9.27**
-2.05^{NS}	-4.85*	18.92**	7.54^{NS}	6.24*	5.07^{NS}	-14.07**	-14.89**	4.27^{NS}	2.39^{NS}	1.54^{NS}	-8.99**	-31.53**	-32.86**	-27.71**	-27.97**
23.16**	16.59**	-15.94**	-24.51**	2.16^{NS}	-3.39^{NS}	-9.04^{NS}	-16.19**	25.43**	12.65**	-22.66**	-24.81**	-54.21**	-54.99**	-44.99**	-45.45**
28.46**	24.59**	2.57NS	-0.50^{NS}	-2.68^{NS}	-15.15**	-13.12**	-14.43**	20.88**	8.30**	-24.12**	-36.25**	-8.15**	-29.77**	-10.43**	-27.71**
-11.79**	-24.63**	18.65**	5.98^{NS}	2.80^{NS}	-2.08^{NS}	-9.91^{NS}	-23.14**	-14.00**	-29.41**	8.71*	-15.73**	25.55**	19.51**	25.67**	20.60**
16.20**	9.93**	20.16**	5.2^{NS}	-9.91**	-16.36**	-15.14**	-25.37**	5.15*	3.15^{NS}	-11.06**	-22.02**	54.03**	27.98**	46.75**	27.15**
-2.52^{NS}	-3.67^{NS}	46.94**	41.18**	8.16**	5.73*	4.71^{NS}	-1.24^{NS}	5.51*	4.38^{NS}	10.93**	6.11**	-12.83**	-19.64**	-7.20**	-11.82**
13.69**	13.50**	-11.25*	-17.43**	-1.49^{NS}	-13.29**	-11.53*	-12.04*	12.13**	-1.14^{NS}	-32.58**	-37.36***	-8.69**	-29.21**	-2.33^{NS}	-21.38**
-0.18^{NS}	-8.19**	21.64**	12.36*	-11.77**	-19.07**	-3.72^{NS}	-12.52*	-11.15**	-11.39**	0.96^{NS}	-13.15**	-43.40**	-57.24**	-41.40**	-53.01**
26.59**	22.77**	4.02^{NS}	0.80^{NS}	-1.79^{NS}	-14.37**	-9.15*	-10.52*	24.68**	11.71**	-19.71**	-32.55**	-5.20**	-27.52**	-9.55**	-26.99**
-6.37**	-22.00**	15.75**	0.62^{NS}	-2.34^{NS}	-11.03**	38.27**	16.50**	-6.66*	-15.52**	21.63**	-16.41**	-23.70**	-43.61**	-25.19**	-41.47**
-8.60**	-20.17**	3.66^{NS}	-19.40**	4.83*	2.69^{NS}	-8.67^{NS}	-13.12*	-3.94^{NS}	-14.54**	-5.85^{NS}	-29.53**	-6.94**	-19.85**	-0.73NS	-12.12**
-1.01^{NS}	-16.73**	24.68**	4.77^{NS}	-5.29*	-11.89**	-27.04**	-41.37**	-5.12*	-14.95**	-12.47**	-38.28**	-10.24**	-29.68**	-5.44**	-23.08**
14.85**	-4.20*	-1.79^{NS}	-19.67**	-14.73**	-17.92**	8.98^{NS}	-7.74^{NS}	-2.83^{NS}	-21.38**	3.44^{NS}	-25.71**	-2.03*	-8.46**	-2.66*	-6.26**
-11.49**	-20.63**	-2.89^{NS}	-21.05**	-1.29^{NS}	-2.04^{NS}	13.44*	4.26^{NS}	-12.30**	-20.81**	8.31*	-17.70**	-42.13**	-43.99**	-33.70**	-35.85**
-9.12**	-22.35**	-15.22*	-24.27**	12.08**	6.75*	44.57**	23.35**	0.96^{NS}	-17.14**	20.88**	-6.29*	-41.34**	-44.16**	-39.29**	-41.74**
-10.88**	-25.76**	11.44^{NS}	-3.12^{NS}	-10.61**	-18.57**	-12.20*	-26.03**	-18.71**	-26.43**	-22.22**	-46.54**	60.12**	18.35**	53.64**	20.20**

Heterosis and heterobeltiosis for days to maturity under normal and heat stress conditions

Percentage increase or decrease of F_1 over mid parental value under normal conditions (Table 2) indicated that only 4 crosses showed desirable negative significant results. Cross combinations Weebli-1 × Chenab-2000 and Weebli-1 × Uqab-2000 showed the maximum negative heterosis (-2.00%).Percentage decrease over better parental value indicated that 36 crosses showed decline in better parental value,14 crosses showed highly significant results and 3 crosses showed significant estimates. Maximum negative heterobeltiosis was shown by the cross combinations Weebli-1 × Shalimar-88 (-5.98%) and Weebli-1 × Chenab-2000 (-5.56%).

Under heat stress conditions sixteen crosses showed decrease in mid parental value. Among these, 6 crosses were highly significant and 3 were significant. Maximum negative desirable value was shown by the cross combination Shalimar-88 × Inqilab-91 (-6.42%) and it is reciprocal (-5.16%). In terms of better parental values, twenty nine crosses showed decrease over better parental value. However, only 7 crosses showed negative and highly significant results, while 9 crosses showed significant results. Maximum negative heterobeltiosis was shown by the cross Shalimar-88 × Inqilab-91 (-8.56%).

Heterosis and heterobeltiosis for Flag leaf under normal and heat stress conditions

Heterosis studies for flag leaf area under normal conditions indicated that 11 out of 42 crosses showed positive heterosis, but only 4 crosses showed positive and highly significant results while one cross showed significant positive value and 6 crosses showed non-significant results. Maximum positive heterosis was shown by the cross combination Shalimar-88 × Uqab-2000 (21.70%) followed by its reciprocal Uqab-2000 × Shalimar-88 (21.00%). Heterobeltiosis studies indicated that 8 crosses showed increase over better parental value but only 2 crosses showed highly significant results and one was significant. Remaining 5 crosses found to be non-significant. Maximum positive desirable results were shown by the cross Shalimar-88 × Uqab-2000 (12.09%).

Positive and highly significant heterosis was found under heat stress for flag leaf area in 36 crosses out of 42 crosses. Two crosses showed positive and significant heterosis and 4 crosses showed positive but non-significant heterosis. Crosses which showed maximum positive heterosis under heat stress conditions were Inqilab-91 × Shalimar-88 with a positive value of (73.30%), Shalimar-88 × Inqilab-91 (70.96%) and Uqab-2000 × Shalimar-88 (60.15%). Under stress condition, 40 crosses showed positive heterobeltiosis values. Among these 27 crosses showed positive and highly significant heterosis with maximum values shown by the crosses Inqilab-91 × Shalimar-88 (65.33%) followed by Shalimar-88 × Inqilab-91 (63.10%) and Maya/Pavon × Punjab-85 (53.49%). However, two crosses showed positive but significant heterobeltiosis and 11exhibited positive and non-significant results.

Heterosis and heterobeltiosis for biomass per plant under normal and heat stress conditions

As for biomass per plant under normal environments (Table 2), 15 cross combinations showed positive heterosis. Among these, 12 were highly significant, while 1 cross was significant and 2 were non-significant. Among crosses showing positive heterosis, the cross combination Punjab-85 × Maya/Pavon exhibited the best value (28.46%), followed by its reciprocal cross Maya/Pavon × Punjab-85 (26.59%). Heterobeltiosis studies revealed that only 10 crosses showed increase over better parental values and all these crosses showed highly significant results. Hybrids Punjab-85 × Maya/Pavon (24.59%) and its reciprocal Maya/Pavon × Punjab-85 (22.77%) followed by Uqab-2000 × Punjab-85 (17.20%) showed maximum positive heterobeltiosis.

Under heat stress conditions 12 crosses were highly significant, 2 were significant and 9 were non-significant in terms of heterosis. The crosses that showed maximum positive heterosis were Shalimar-88 × Maya/Pavon (52.19%), Maya/Pavon × Shalimar-88 (46.94%) and Inqilab-91 × Punjab-85 (34.83%).Regarding heterobeltiosis, 16 crosses showed increase in better parental value under heat stress environments. Among crosses showing increase, 4 were highly significant, 2 were significant and 10 were non-significant. Maximum increase over better parental value was shown by the cross Shalimar-88 × Maya/Pavon (46.22%), followed by Maya/Pavon × Shalimar-88 (41.18%) and Shalimar-88 × Punjab-85 (25.76%).

Heterosis and heterobeltiosis for harvest index under normal and heat stress conditions

Heterosis for harvest index under normal conditions revealed that 25 hybrids showed positive heterotic effects. Out of them, 9 were highly significant, 5 were significant and 11 were non-significant. Maximum positive heterosis was shown by the cross combination Inqilab-91 × Uqab-2000 (17.29%), followed by Uqab-2000 × Inqilab-91 (15.60%) and Shalimar-88 × Maya/Pavon (12.10%). For heterobeltiosis studies, only 11 crosses showed an increase over better parental values with 3 crosses showing highly significant, 2 crosses significant and 6 crosses showed non-significant results. Maximum positive heterobeltiosis was found in the cross combinations Inqilab-91 × Uqab-2000 (15.76%), Uqab-2000 × Inqilab-91 (14.09%) and Shalimar-88 × Maya/Pavon (9.58%).

Heterotic effects for harvest index under stress environments indicated that, out of 42 crosses, 17 crosses showed increase over midparental values, 10 crosses showed highly significant increase, while 4 showed significant and 3 crosses showednon-significant values. Maximum increase over mid parental value were shown by the crosses like Uqab-2000 × Inqilab-91 (53.96%), Inqilab-91 × Uqab-2000 (52.23%) followed by Weebli-1 × Punjab-85 (44.57%). As far as the increase over better parental values is concerned, 6 crosses manifested positive and highly significant, 1 cross showed significant and 5 crosses indicated positive and non-significant results. Maximum positive increase was shown by the cross combinations Uqab-2000 × Inqilab-91 (48.47%), Inqilab-91 × Uqab-2000 (46.80%) and Weebli-1 × Punjab-85 (23.35%).

Heterosis and heterobeltiosis for grain yield under normal and heat stress conditions

Percentage increase of F_1 over their mid parental values for grain yield per plant under normal conditions (Table2) revealed that 21 crosses showed positive desirable heterosis. Maximum positive heterosis was manifested by the cross combinations Uqab-2000 × Punjab-85 (28.70%), Chenab-2000 × Uqab-2000 (27.94%) followed by Uqab-2000 × Chenab-2000 (26.31%). Heterobeltiosis studies showed that 13 crosses out of 42 showed positive increase over better parental value. However, only 7 crosses were found highly significant, one cross remained significant and 5 crosses showed non-significant results. Maximum positive heterobeltiosis values were shown by the cross combinations Uqab-2000 × Punjab-85 (15.58%) and Chenab-2000 × Uqab-2000 (13.06%).

Under stress environment only 10 crosses exhibited positive and highly significant desirable heterosis over mid parental values. While, 2 crosses showed positively significant values and 7 showed positive and non-significant results. Maximum positive heterosis was recorded by cross combination Shalimar-88 × Uqab-2000 (27.02%) followed by Maya/Pavon × Weebli-1 (21.63%) and Weebli-1 × Punjab-85 (20.88%). In case of heterobeltiosismost of the crosses showed a decline and only 7 crosses reported positive heterosis with 4 crosses showing positive and highly significant, 2 positive and significant and 1 remained positive but showed non-significant results. Maximum positive heterobeltiosis was shown by the cross combinations Shalimar-88 × Uqab-2000 (13.62%) and Inqilab-91 × Punjab-85 (11.24%).

Heterosis and heterobeltiosis for relative cell injury % under normal and heat stress conditions

Heterosis for relative cell injury (%) under normal conditions revealed that 29 crosses exhibited negative and highly significant desirable heterosis, while 1 cross exhibited significant and negative heterotic values. Highest negative heterosis was shown by the cross combination Punjab-85 × Uqab-2000 (-54.21%), followed by Uqab-2000 × Punjab-85 (-53.31%). Regarding heterobeltiosis studies, 32 crosses showed negative and highly significant results, 1 cross combination showed significant and 1 exhibited non-significant result. Maximum negative heterosis was shown by the cross combinations Uqab-2000 × Maya/Pavon (-58.68%) and its reciprocal cross (-57.24%).

Under heat stress conditions,28 crosses showed negative results. Among negative effects, 20 crosses were highly significant, 3 were significant and 5 crosses were non-significant. The crosses showing maximum negative heterosis were Punjab-85 × Uqab-2000 (-44.99%) and Uqab-

2000 × Maya/Pavon (-42.81%).Better parental values under late sown conditions exhibited that 32 crosses showed negative and highly significant results. Three crosses showed negative and significant results. Maximum negative value was shown by the cross combination Uqab-2000 × Maya/Pavon (-54.13%) and by its reciprocal cross (-53.01%), followed by Punjab-85 × Uqab-2000 (-45.45%).

Discussion

Temperature stress in wheat is associated with moderately high temperature above the optimum level for photosynthetic activity and below the optimum temperature for respiratory functions. Significant reduction in wheat yield has been reported due to average temperature above 15^{0}C during grain filling stage (Weigand & Cuellar, 1981). In temperate environments, terminal heat stress is a limiting factor during anthesis and grain filling (Reynolds et al., 1994). Plants respond differently to heat stress at different phenological stages (Fischer, 1985). Chen et al. (2000) have reported that the late sown wheat seeds and seeds sownin plastic sheet tunnel could simulate heat stress. They suggested grain weight per spike and yield per plant as selection criteria against heat stress.

The possibility of obtaining predominant genotype is greater if both parents have at par performance instead of one parent being inferior or superior in terms of one or more characters (Busch et al., 1974; Bailey & Comstock, 1976; Cox & Murphy, 1990; Picard et al., 1992). However, genetic variation between parents is a prerequisite to developing superior hybrids (Martin et al., 1995; Güler & Özgen, 1994; Fonseca & Patterson, 1968; Baric et al., 2004; Morgan, 1998; Fabrizius et al., 1998). The commercial utilization of heterosis depends upon the superiority of hybrids over the better parents and it is also important for identifying the parental combinations capable of producing the highest level of transgressive segregants.

Days to heading and days to maturity are very important traits and the negative values of heterosis are desirable for these traits. In the present study, the cross combinations showing desirable negative heterosis for days to heading and maturity were obtained, what can be exploited in future breeding programs. Sadeque et al. (1991) have also found negative heterosis for these traits, while Palve et al. (1987) have found contradictory results. But Masood et al. (2005)have reported both positive and negative heterosis for days to maturity.

Flag leaves are the chief photosynthetic organs in wheat. It does therefore mean that increase number in flag leaves will lead to higher photosynthetic activities resulting to greater wheat yield. The desirability of flag leaf stems from the fact that it has lower water potential and turgor pressure but produces maximum photosynthates. This leads to more dry matter production than lower leaves of the plant (Aggarwal & Sinha, 1984). Under stress environments, leaves should have more surface area (Foutz et al., 1974). In the current studies, numerous crosses were obtained and they have showed positive heterosis and heterobeltiosis both under normal and heat stress conditions. Positive heterosis in flag leaf area has also been reported by (Mahmood & Chowdhry, 2000; Chowdhry et al., 2001; Ullah, 2004).

Yield and yield related characters having significant positive heterosis and heterobeltiosis are important for selection of these characters in crosses for future breeding programs. Grain yield is an important selection criterion in most of wheat breeding programs. In current studies for grain yield per plant under normal conditions maximum heterosis of 28.70% and heterobeltiosis of 15.58% were obtained and under stress environments, this range was about 27.02% for heterosis and 13.62% for heterobeltiosis. These results are betterthan the findings of Borghi et al. (1986) who have found only 6% increaseof crosses over their mid parental values. However, Zehr et al. (1997) and Solomon et al. (2006) have observed heterosis of about 41% and 72%, respectively, which is even more than the current findings. Some other researchers have also found positive heterosis estimates for grain yield (Singh et al., 2004; Gooding & Kindred, 2005). Similarly, some researchers reported negative heterosis for grain yield (Farooq & Khaliq, 2004). In the current experiment some of the crosses showed negative estimates of heterosis and heterobeltiosis, so these crosses may be discarded. For biomass per plant many cross combinations in the current studies showed positive heterosis and heterobeltiosis estimates, which are in conformity to the findings of (Chowdhry et al., 2001; Akbar et al., 2007). Similarly, for harvest index positive estimates were obtained, which is in agreement to the findings of (Jan et al., 2005).

Temperature stress results in the leakage of ions and organic solute movements across membranes, which disrupts photosynthesis and respiration (Christiansen, 1978). There is great diversity available for thermo tolerance in wheat (Al-Khatib & Paulsen, 1990; Wardlaw et al., 1989; Reynolds et al., 2001). Electrolyte leakage and cell membrane thermostability have been used in wheat as modified methods to develop heat tolerant lines (Saadalla et al., 1990a; Saadalla et al., 1990b; Tahir & Singh, 1993; Ibrahim & Quick, 2001). In the present investigations, electrolyte leakage technique has been employed to obtain crosses with less relative cell injury %age. Some studies regarding heat tolerance with respect to cell injury (%) revealed that the genotypes with less injury to plasma membranes are tolerant if compared to the genotypes with more injury to cell membrane (Renu et al., 2004). Negative estimates of heterosis and heterobeltiosis are desirable in case of Relative cell injury%. Some of the hybrids, like Maya/Pavon × Punjab-85, Maya/Pavon × Chenab-2000 and Shalimar-88 × Weebli-1, showed very promising results with relative injuries even less than their parents.

Conclusions

Selection of heat tolerant cultivars on physiological basis can be made following the method of relative cell injury% calculations and field screening may be practiced following delayed sowing that receives temperature stress at the time of anthesis.The cross combinations, like Inqilab-91 ×Shalimar-88, Shalimar-88 × Maya/Pavon, Chenab-2000 × Punjab-85, Maya/Pavon × Chenab-2000, Shalimar-88 × Uqab-2000 and Uqab-2000 × Maya/Pavon, showed promising results under both environments. These crosses showed desirable heterosis thus can be exploited in the development of heat tolerance cultivars following pedigree method of selection.

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