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GENETIC STUDIES FOR SOME AGRONOMIC TRAITS IN SPRING WHEAT UNDER HEAT STRESS

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F_1 progenies of 7x7 diallel fashion crosses comprising four high temperatures tolerant and three susceptible spring wheat parental genotypes were evaluated under normal and heat stress conditions. The characters days to heading, spike index at anthesis, plant height, spikes per plant, spikelets per spike and grain yield per plant were studied under both conditions. Analysis of variance under both conditions indicated additive gene action with partial dominance suggesting that these traits might be useful for the development of terminal heat tolerant varieties by modified pedigree selection.. However over-dominance type of gene action was recorded for spikelets per spike suggesting that further improvement in this trait may be effected by biparental mating coupled with few cycles of recurrent selection.
Keywords: Spring wheat, terminal heat, genetic, diallel, dominance, gene action, spike index at anthesis

INTRODUCTION

Wheat is most important crop of the country comprising three times area and twice the value added share of next two crops i.e. cotton and rice Anonymous (2008). Wheat is also the staple food grain of Pakistan, supplying 72% of the calories and protein in the average diet. It occupies 70% of Rabi and 37% of the total cropped area in the country (Khan, 2004.) In Pakistan temperature usually exceeds over the optimum limits during grain filling period resulting instability in wheat yield. Grain filling proceeds steady and robust in the range of 25-28°C. The flowering and grain filling are routinely exposed to warming temperatures (maximum 28-38°C) during March/April. Yield reduction is higher especially in late planted crop or in high temperature during grain filling (Khan, 2004). A survey on substantial yield losses in wheat conducted in nineteen wheat producing developing countries reported that heat stress is one of the most important constraints on wheat production, affecting up to 57% of the entire wheat area in the surveyed countries (Kosina *et al*., 2007). Wheat production in India has always, been regarded as a gamble with seasonal temperatures (Tandon, 1994) and similar is the situation in Pakistan as highlighted by Khan (2006). Potential yield of present commercial cultivars is also limited by high temperatures at any stage of crop development (Ageeb, 1994). Wheat grain weight is decreased from 4 to 8% per degree rise in mean temperature over the range of 12-26^{o}C during grain filling period (Wiegand and Cuellar 1981). Similarly wheat yield is reduced by almost 4% for every 1°C rise in mean temperature over the range of 12.2-27.5°C (Grover *et al.* 2004). AbdElShafi and Ageeb (1994) reported grain yield reduction under heat stress in Upper Egypt in late planting in the range of 30-46% in comparison with optimal planting. In Punjab generally sowing is recommended up to the mid November in irrigated plains of the Punjab. However, these sowings are staggered from mid-November through late December or even into the January depending on cropping pattern in different ecological zones of wheat in Punjab. Late harvesting of sugarcane, rice and cotton crops does not allow the timely sowing of wheat (Khan, 2004). The crop is frequently exposed to temperatures higher than the tolerance limit during grain filling stage. Eighty percent wheat crop is sown late, which is ultimately exposed to high temperature combined with lack of water during grain filling and hence grain yields are reduced substantially (Annonymous, 2007; Hussain *et al*., 2010; Mahmood *et al*., 2011). Rajaram (1997) concluded that late planting is one of the most limiting factors reducing yield in India and neighboring countries (Pakistan) and it can cause reduction in yield as high as 50% on high yielding temperature sensitive genotypes while reduction is only 1/3 in case of thermo-tolerant varieties and suggested that our testing program must combine optimum and late planting based on the same genotypes. Sharrma *et al. (*2002) studied wheat heat tolerance through 10x10 diallel approach including reciprocals to evaluate various yield traits under heat stress and no stress environments and found both additive and dominance components of variance as significant for most of the traits in both environments.

Heat stress is a major yield limiting factor and genetic management is the most apposite solution. Diallel analysis of the genetic traits is a valuable aid in selection and development high yielding and wheat varieties. Information perceived in this study on various morphological traits and genetic aspects will give an insight for the development of thermo-tolerant wheat varieties for irrigated hot climate and late planting in Pakistan and this will pay good dividend to all stakeholders and would lead nation to wheat yield stability and self-sufficiency.

MATERIALS AND METHODS

Research work was conducted in the experimental area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad Pakistan (Latitude 31.26°N, Longitude 73.06°E, Altitude 184.4 m, soil pH 6.50, while photoperiod for wheat was 10 h in November 2007) during two spring wheat sowing dates from 2006-07 to 2007-08.The selected seven wheat genotypes viz. Bhakkar-2002, V00183, SH-2002, Chakwal-86, 3C001 93T347 and Punjab-96 were crossed in full diallel fashion during February 2007. F0 along with parents seed was harvested at maturity, threshed manually and preserved accordingly Two separate experiments were conducted during wheat crop seasons 2007-08 (November 2007 to April 2008). First under normal temperature condition (Timely planting), was laid-out on 10th November 2007 and second under high temperature stress situation (late planting) was sown on December 20, 2007**.** Forty two F_1 progenies along-with seven parents were laid out in each set according to randomized complete block design with three replications. Each entry consisted of five rows of 2.50 meter length with plant to plant and row to distance of 0.15m and 0.30 m respectively. A template was used to maintain the uniformity in distance and depth of seeds. Two seeds per hole were sown to ensure uniform population. After germination one healthy seedling was retained at each plant position through thinning, Gap filling if any, was executed at an earliest date possible with water imbibed seed of respective entry and skipping free populations were ensured. All the standard agronomic practices were adapted uniformly. As it was desirable to avoid water stress during evaluation of heat tolerance, therefore optimum irrigation regime was provided during the crop season. These experiments were laid out adjacently in field under similar soil conditions. The data were recorded on 10 randomly selected guarded plants of each genotype per replication per treatment for following different morphological traits. Most of the parameters studied were secondary traits, as indicator of high temperature tolerance.

Days to heading (N): Days to 50% heading was recorded from date of sowing to ½ of earing of each genotype by daily visiting the experiment.

Spike index at anthesis (%)

Ten guarded plants per genotype were harvested at anthesis, dried and weighed. Spikes were cut at ear base with a nursery cuter and weighed and finally spike index at anthesis was calculated as under.

SIA=Dry spike weight per plant at anthesis x 100/Dry biomass per plant at anthesis

SIA= Spike index at anthesis

Plant height (cm)

Plant height of each of ten randomly selected plants was measured from base of plant at the level of soil surface to the tip of main spike excluding awns. Average plant height of each test entry was calculated.

Spikes per plant (N)

Spikes of all selected plants of each genotype in each replication were counted and average value was computed.

Spikelets per spike (N)

Spikelets of main culm spike of all the selected plants of each genotype were counted individually and then average number of spikelets per spike was calculated.

Grain yield per plant (g)

Spikes of all individually selected plants were threshed manually and grains were weighed with electronic balance and finally average value for grain yield per plant was computed for each genotype in each replication Data recorded for various parameters were statistically analyzed using analysis of variance (ANOVA) procedures as described by Steel *et al.* (1997). Separate ANOVA for each environment was performed to determine, whether heat treatment significantly affected various parameters or not. On obtaining significant differences, data were subjected to diallel analysis as proposed by Mather and Jinks (1982) and Hayman (1954) and Jinks (1954) to derive information for other genetic parameters.

RESULTS AND DISCUSSION

Under normal planting 50% heading was achieved during third week of February 2008 and temperature remained within optimum limit during this period, while under stress 50% earing was recorded by mid-March when the temperature exceeded above the optimum range i.e. <28°C. Grand mean of heading date of both the environments is given in Table 2 and temperature data for both seasons are represented in graphical form as Fig. 1**.** Analysis of variance of all characters under both normal and heat stress conditions are presented in Table 1. Grand mean, COV%, LSD value and % reduction for plant trait under normal temperature and heat stress conditions are given in Table 2. Genotypic differences were found highly significant for all the traits under both temperature regimes.

A. Relation between traits tested and temperatures during different growth stages:

On over all mean basis days to heading showed a reduction of 18.26% under heat stress condition (Table 2). Among the parents maximum reduction of 23.59% was recorded in the genotype Punjab-96. Similarly, in case of F_1 hybrids the reduction in days to heading ranged from 9.59% (93T347 x V00183) to 22.46% (Punjab-96 x V00183). These results are

Table 1. Analysis of variance of seven wheat genotypes and their all possible F_1 progenies for various traits studied under normal and heat stress conditions.

Sr.No.	Traits	Genotypic mean squares (df=41)	
		Normal	Heat stress
1	Days to heading	117.70**	53.86**
2	Spike index at anthesis	74.77**	32.97**
3	Plant height	128.75**	109.38**
4	Spikes per plant	14.80**	10.39**
5	Spikelets per spike	21.48**	38.20**
6	Grain yield per plant	59.22**	43.88**

****=P≤0.01 *=P≤0.05**

Table 2. Grand mean, COV%, LSD value and % reduction for plant trait under normal temperature and heat stress conditions

Character	Condition	Grand mean	COV %	LSD (0.05)	% reduction		
					Parents	F_1 hybrid	Over all
Days to heading (N)	Normal temperature	103.58	0.93	1.56	14.81-23.59	9.59-22.46	-18.26
	Heat stress	84.66	0.68	0.92			
Spike index at anthesis (%)	Normal temperature	29.42	2.34	1.11	13.18-28.77	11.59-40.29	-22.40
	Heat stress	22.83	6.14	2.26			
Plant height (cm)	Normal temperature	100.76	0.75	1.22	6.21-14.16	7.05-14.76	-9.56
	Heat stress	91.13	1.40	2.05			
Spikes per plant (N)	Normal temperature	11.17	9.76	1.76	23.87-37.50	23.47-50.07	-31.87
	Heat stress	7.61	9.51	1.16			
Spi Spikelets per spike (N)	Normal temperature	21.72	6.04	21.22	4.65-30.20	4.63-32.17	-19.47
	Heat stress	17.49	9.29	2.62			
Grain_yield per plant (g)	Normal temperature	30.34	7.48	3.66	31.61-49.77	19.62-42.34	-37.01
	Heat stress	19.11	9.77	3.19			

Table 3. Estimates of components of variation for various traits under normal temperature and heat stress conditions

Character	Condition	D	H_1	H_2	F	h^ 2	E	$(H1/D)^{0.5}$	#	$h^2_{(n.s)}$
Days to heading	Normal	81.63*	21.94	19.43	5.02	2.20	0.32	0.51	1.12	0.88
	H. stress	21.21*	20.75*	19.19*	-7.8*	8.56*	0.14	0.98	0.68	0.75
Spike inex at anthesis	Normal	35.41*	19.31*	17.79*	-9.08	2.27	0.17	0.73	0.70	0.83
	H. stress	15.61*	8.85*	8.19*	-1.77	0.32	0.66	0.75	0.85	0.76
Plant height	Normal	104.88*	17.82	12.48	16.17	1.67	0.21	0.41	1.46	0.93
	H. stress	44.13*	20.27*	13.54*	-23*	0.94	0.55	0.67	0.43	0.90
Spikes per plant	Normal	8.92*	6.80*	5.88	2.65*	0.15	0.42*	0.87	1.41	0.65
	H. stress	4.92*	4.47*	4.13*	0.16	0.08	0.17	0.95	1.03	0.67
Spikelets per spike	Normal	6.32*	10.00*	9.46*	-2.53	0.14	0.62*	1.30	0.73	0.63
	H. stress	10.01*	22.77*	21.50*	-4.79	0.17	0.93	1.50	0.72	0.55
Grain yield/plant	Normal	36.78*	26.42*	22.99*	11.33	0.62	1.80*	0.84	1.44	0.65
	H. stress	20.66*	16.95*	15.45*	0.42	0.38	1.29*	0.90	1.02	0.67

*= Value is significant when it exceeds 1.96 after dividing with its standard error.
= $4DH_1^{0.5}+F/4DH_1^{0.5}-F$

in accordance with Shpiler and Blum (1991), AbdELshafi and Ageeb (1994), and Tewolde *et al*. (2006).
Grand mean reduction recorded for spike index at anthesis under heat stress condition was 22.40%. Among the parents maximum (28.77%) and minimum (13.18%) reductions were recorded in the genotype Punjab-96 and Bhakkar-2002 respectively. However, in case of hybrids the reduction in spike index at anthesis ranged from 11.59% (Bhakkar-02 x V00183) to 40.29% (3C001 x Punjab-96). Among the parents maximum spike index at anthesis was recorded

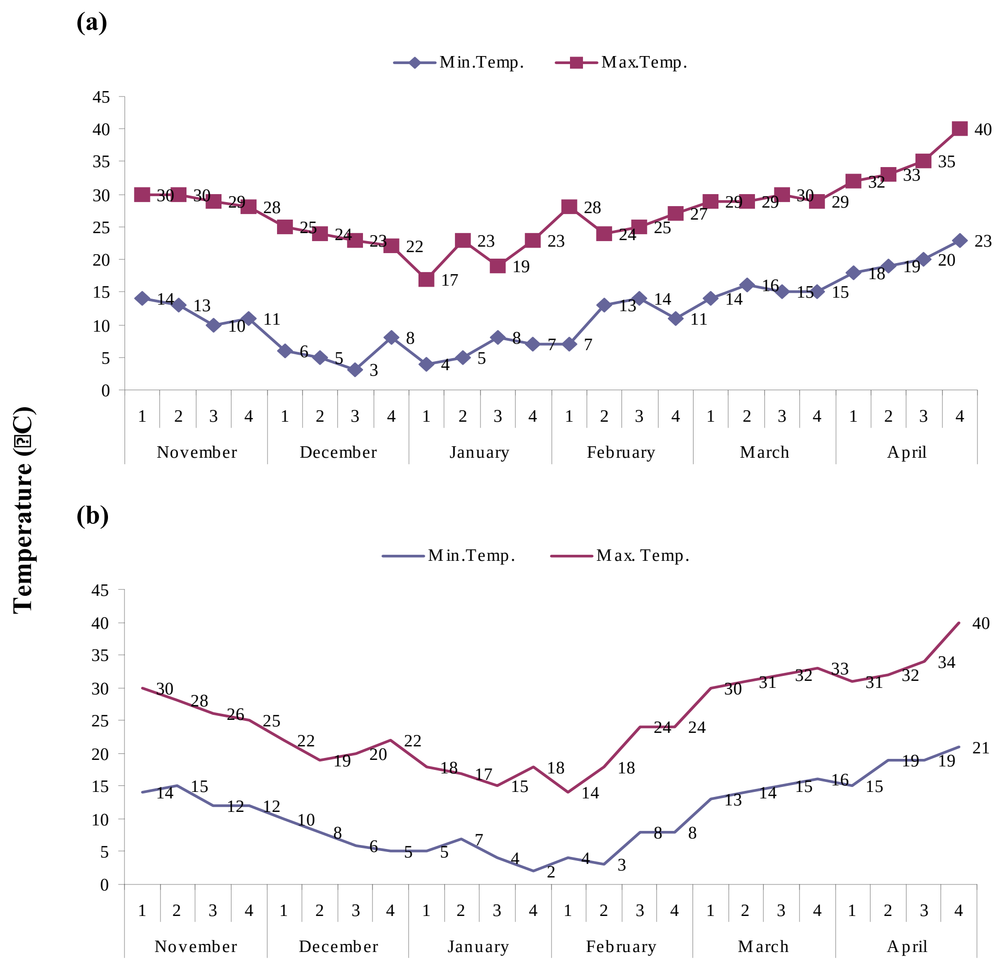

Figure 1. Graphical representation of the temparature data during the years (a) 2006-07 and (b) 2007-08. 1=first week, 2= second week, 3 = third week and 4 = fourth week

36.33% and 31.00% under normal and heat stress conditions respectively in genotype V00183. Findings are in agreement with Fischer (2001).

A reduction in the plant height with grand mean value of 9.56 % was recorded for all the genotypes including parents and F_1 hybrids under heat stress condition. Maximum reduction (14.16%) was recorded in 93T347. Parental genotype V00183 had the lowest plant height under late planting with a reduction of 7.90%. In case of hybrids maximum reduction (14.76%) in plant height was recorded in Bhakkar-02 x 3C001. These results are in accordance with Shpiler and Blum (1991), Bhatta (1994), AbdELshafi and Ageeb (1994) and Akbar *et al.* (2008).

Spikes per plant showed considerable reduction (31.87% on an average) under heat stress condition. Best cross combinations under normal temperature condition were Bhakkar-02 x SH-02 and Chakwal-86 x V00183. The best cross for this trait under heat stress condition was -02 x SH-02, however, this hybrid showed reduction of 25.53%. Reduction in spikes per plant under heat stress condition has also been reported by Hanchinal *et al.* (1994), Bhatta (1994) and, AbdElShafi and Ageeb (1994).

Grand mean reduction of 19.47% was recorded for spikelets per spike under heat stress condition. Considering the hybrids the greatest number of spikelets per spike (26.17) were observed in V00183 x SH-02 under normal temperature which showed reduction of 12.76% under heat stress. Spikelets per spike were maximum (23.50) in Bhakkar -02 x V00183 F_1 hybrid under heat stress with a reduction of (7.48%). These results are in accordance with Hanchinal *et al.* (1994)

Grand mean reduction of 37.01% was recorded for grain yield per plant under heat stress condition. The best parent under normal temperature condition (39.0 g) was Bhakkar -02. Parents showing maximum reduction in grain yield per plant under heat stress condition (49.77 and 43.03%) were Punjab-96 and 3C001 respectively. Best parent under heat stress was - Bhakkar 02 with a grain yield of 25.0 g per plant. The best cross under normal condition was Bhakkar -02 x SH-02 with a grain yield of 39.67 g per plant. Under heat stress condition F_1 hybrids Bhakkar -02 x SH-02 and its reciprocal had the highest grain yield per plant (28.00 and 27.33g) with a reduction of 29.42% and 26.78%, respectively. Highest reduction in grain yield per plant (48.31%) was recorded in hybrid Punjab-96 x V00183 which reduced from 24.67g under normal temperature to 12.75g under heat stress condition. These results get support from the findings of AbdELShafi and Ageeb (1994), Bhatta (1994), Rajaram (1998), Singh *et al.* (2005) Rasal *et al.* (2006), Mian *et al*. (2007), Akbar *et al*. (2008) and Prasad *et al.* (2008).

B. Genetic Analysis

Genetic component of variation were estimated according to Hayman (1954) and are presented in table 3. Genetic components of variations for days to heading revealed that both additive (D) and dominance variations were significant under both conditions. However, additive component (D) was greater than H components under both temperature regimes displaying predominance of additive effects. H_1 and H_2 values were necessarily equal in magnitude displaying uniformity of distribution of positive and negative alleles among the parents. F component under heat stress condition was negative and significant showing lower frequency of dominant genes supported by ratio of dominant to recessive genes (0.728) which was less than 1. Significant value of $h^{\wedge 2}$ under heat stress condition indicated the presence of overall dominance effect due to heterozygous loci affecting the expression of this trait. Average degrees of dominance (0.598 and 0.821) revealed the absence of dominance under both conditions. High narrow heritability estimates were also recorded indicating considerably large additive proportion in the total heritable genetic variation. Placement of array points displayed (Figure 2a) that genotypes 3C001, SH-02, V00183 and Ch-86 occupied the intermediary position displaying equal proportion of dominant and recessive genes in them. Genotypes Bhakkar -02 and 93T347 had the least dominant genes being placed farthest from the origin, while Punjjab-96 had maximum dominant genes. Figure 2b indicated that 3C001 had the maximum dominant genes, while maximum recessive genes were found in Bhakkar-02, V00183, Punjab-96, SH-02 and Chakwal-86 occupied intermediary position thus possessing equal proportion of dominant and recessive genes under heat stress condition.

When genetic components of variation for spike index at anthesis were computed it was revealed that both additive (D) and dominance effects (H) were significant under both conditions. H_1 and H_2 values were necessarily equal in magnitude displaying uniformity of distribution of positive and negative alleles among the parents. Average degrees of dominance under both conditions indicated the presence of partial dominance. High narrow sense heritability estimates were also recorded indicating considerably large additive proportion in the total heritable genetic variation. Placement of array points displayed (Figure 3a) that genotypes 93T347, 3C001, Bhakkar -02, SH-02 and Chakwal-86 occupied the intermediary position displaying equal proportion of dominant and recessive genes in them. Genotype V00183 had the least dominant genes being farthest from the origin. Punjab-96 had the maximum dominant genes being nearest to the origin. Figure 3b indicated that Punjab-96 and 93T347 had the maximum dominant genes, while maximum recessive genes were found in SH-02, along with intermediary position of Bhakkar -02, 3C001, V00183 and Chakwal-86 genotypes possessing equal proportion of dominant and recessive genes under heat stress condition.

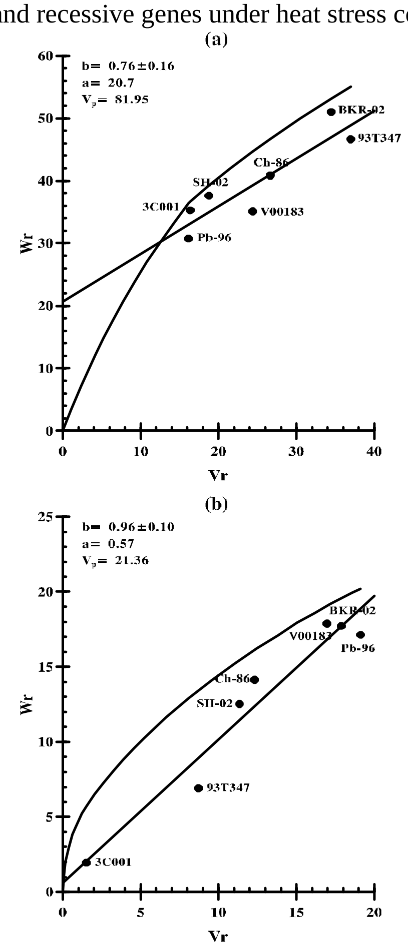

Figure 2. Wr/Vr graph for days to heading under (a) normal temperature, and (b) heat stress condition

Components of genetic variation for plant height depicted significant additive (D) variation while dominance was found absent under normal condition. Under heat stress condition however, significant additive (D) as well as dominance variations were detected. Unequal values of H_1 & H_2 indicated unequal distribution of positive and negative alleles in the parents under both conditions. F component

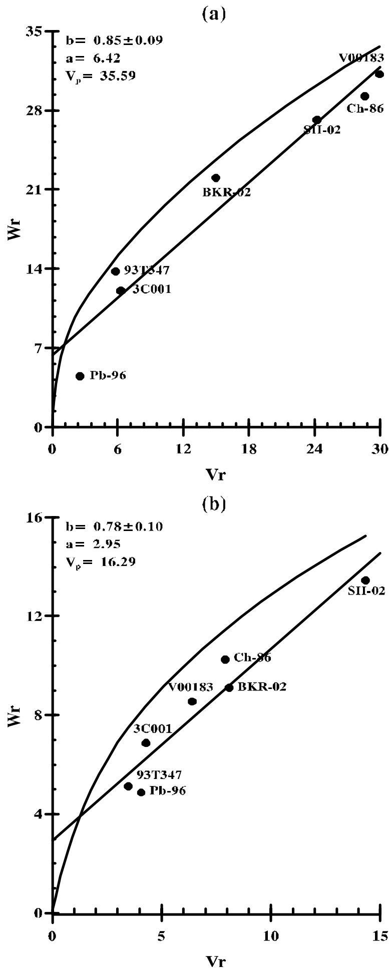

Figure 2. Wr/Vr graph for spike index at anthesis under (a) normal temperature, and (b) heat stress condition

under heat stress condition was negative and significant showing lower frequency of dominant genes supported by ratio of dominant to recessive genes (0.535) which was less than 1. Average degrees of dominance under both condition indicated the presence of partial dominance. Additive gene action with partial dominance for this trait has earlier been reported by Iqbal (2004) and Chandrashekhar and Kerketta (2004). High narrow sense heritability estimates were also recorded indicating considerably large additive proportion in the total heritable genetic variation. High heritability for this trait has been reported by Chandrashekhar and Kerketta (2004) and Khan *et al*. (2005). Placement of array points displayed (Figure 4a) that genotype Chakwal-86 occupied the intermediary position displaying equal proportion of dominant and recessive genes. Genotypes Bhakkar -02, V00183, Punjab-96, 3C001, SH-02 and 93T347 had the least dominant genes being farthest from the origin. Figure 4b indicated that maximum recessive genes were found in Bhakkar- 02 and 3C001 along with intermediary position of SH-02, V00183, 93T347 and Chakwal-86 genotypes possessing equal proportion of dominant and recessive genes, while Punjab- 96 had the maximum dominant genes, under heat stress condition.

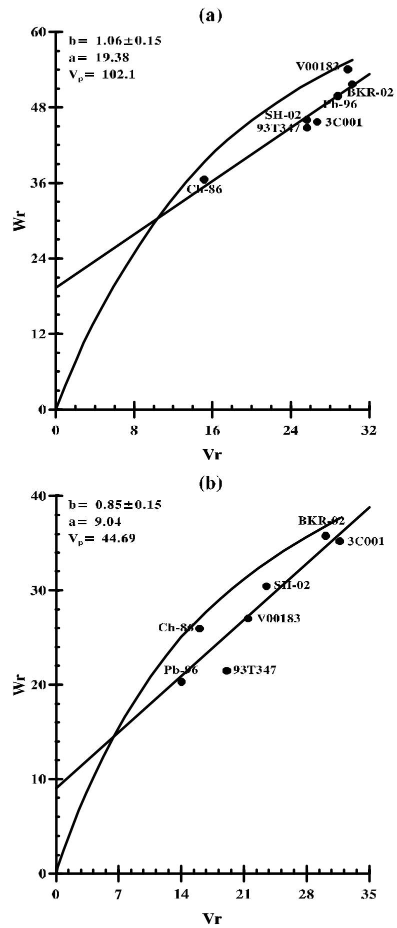

Figure 3. Wr/Vr graph for plant height under (a) normal temperature, and (b) heat stress condition

When the genetic components of variations for spikes per plant were computed it was revealed that both additive (D) and dominance effects (H) were significant under both conditions. Distribution of positive and negative alleles was unequal. Significant and positive F value under normal condition signified the important role of dominant genes. Ratio of dominant to recessive genes (1.410) also indicated that dominant genes were frequent than recessive genes in the parents. However significant value of E depicted the influence of environment in the expression of this trait under both temperature regimes. Average degrees of dominance (0.872 & 0.953) displayed the absence of complete dominance under both conditions respectively These results are in conformity with those of Joshi *et al.* (2004) and Chandrashekhar and Kerketta (2004) Placement of array points displayed (Figure 5a) that genotype Chakwal-86 occupied the intermediary position displaying equal proportion of dominant and recessive genes in them. Genotypes Bhakkar 02, V00183, Punjab-96, 3C001, SH-02 and 93T347 had the least dominant genes being farthest from the origin. Figure 5b indicated that maximum recessive genes were found in BKR-02 and 3C001 alongwith intermediary position of SH-02, V00183, 93T347 and Chakwal-86 genotypes possessing equal proportion of dominant and recessive genes, while Punjab-96 had the maximum dominant genes, under heat stress condition.

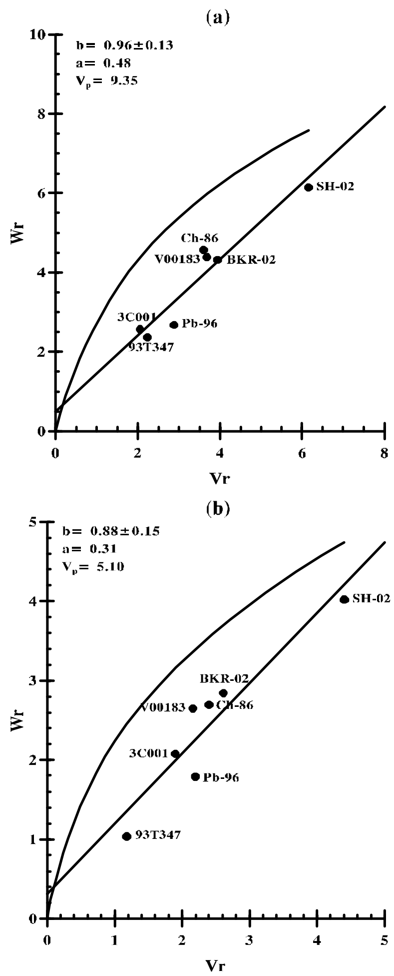

Figure 5. Wr/Vr graph for number of spikes per plant (a) normal temperature, and (b) heat stress condition

Genetic components of variations for spikelets per spike revealed that both additive (D) and dominance effects (H) were significant under both conditions. However, dominance components (H) were greater than additive (D) components under both conditions displaying predominance of dominance effects. Distribution of positive and negative alleles was unequal under both conditions. However, significant value of E depicted the influence of environment on the expression of this trait under normal temperature regimes. Average degrees of dominance (1.304 & 1.507) displayed an over dominance type of gene action under both conditions respectively. Over dominance type of gene action for spikelets per spike was also reported by Khan and Habib (2003) and Sharma *et al.* (2003). Moderately low narrow sense heritability estimates were also recorded indicating dominant variation was more profound than additive one in the inheritance of this trait under both conditions, while low heritability estimates for this trait has been reported by Khan *et al.* (2005). Placement of array points displayed (Figure 6a) that genotype Chakwal-86, Bhakkar 02, 3C001 and Punjab-96 occupied the intermediary position displaying equal proportion of dominant and recessive genes in them. Genotype V00183 had the least dominant genes being

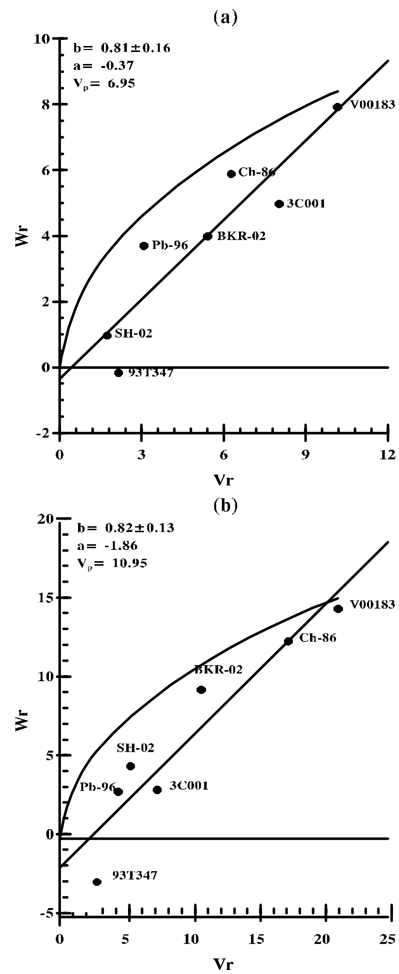

Figure 6. Wr/Vr graph for spikelets per spike under (a) normal temperature, and (b) heat stress condition

farthest from the origin. Figure 6a also indicated that maximum dominant genes were found in 93T347 and SH-02 strains being placed nearest to the origin. Figure 6b indicated that maximum dominant genes were found in genotype 93T347 and Punjab-96 along with intermediary position of Bhakkar -02, SH-02 and 3C001 genotypes possessing equal proportion of dominant and recessive genes under heat stress condition. Figure 6b also indicated that minimum dominant genes were found in Chakwal-86 and V00183 being placed farthest from the origin under high temperature stress condition.

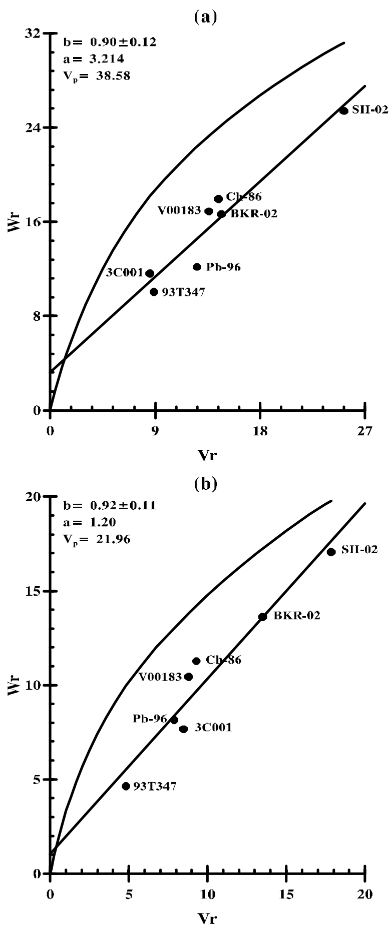

Figure 7. Wr/Vr graph for grain yield per plant under (a) normal temperature, and (b) heat stress condition

When the genetic components of variations for grain yield per plant were computed it was revealed that both additive (D) and dominance effects (H) were significant under both conditions. Unequal values of H_1 and H_2 under normal and heat stress conditions indicated the unequal distribution of positive and negative alleles among the parents. However significant value of E depicted the influence of environment on the expression of this trait in both regimes. Joshi *et al.* (2002) also reported that both gene actions (additive and non-additive) for grain yield were highly influenced by the environment. Average degrees of dominance (0.847 & 0.905) displayed the absence of complete dominance under both conditions respectively. Additive gene action with partial dominance for this trait has earlier been reported by, Hamada *et al.* (2002), Joshi *et al.* (2004) and Chandrashekhar and Kerketta (2004). High narrow sense heritability estimates were also recorded under normal and heat stress conditions indicating considerably large additive proportion in the total heritable genetic variation. High heritability estimates for this trait were reported by Hamada *et al.* (2002), Chandrasekhar and Kerketta (2004) and Khan *et al.* (2005). Placement of array point displayed (Figure 7a) that genotypes Chakwal-86, Bhakkar-02 and V00183 occupied the intermediary position displaying equal proportion of dominant and recessive genes in them. Genotype SH-02 had the least dominant genes being farthest from the origin, while 3C001, Punjab-96 and 93T347 had the maximum dominant genes being placed nearest to the origin. Figure 7b indicated that 93T347 had the maximum dominant genes, while maximum recessive genes were found in SH-02 along with intermediary position of 3C001, V00183, Bhakkar 02, Punjab-96 and Chakwal-86 genotypes possessing equal proportion of dominant and recessive genes under heat stress condition.

Thus the overall situation displayed the significant role of both additive and non-additive genetic variability suggesting the involvement of integrated heat stress breeding strategies which can potentially exploit the additive and non-additive genetic variability under normal temperature and heat stress conditions. Therefore, use of diallel mating with recurrent selection would be helpful for recombination and accumulation of desirable genes. Involvement of parental genotypes like SH-02, Ch-86 and Bhakkar-02 and specific combinations like Chakwal-86 x SH-02, Bhakkar-02 x SH-86 may be effective for developing wheat genotypes best suited for normal temperature condition. Similarly integrated use of pedigree method with recurrent selection by way of diallel crossing involving parents like Bhakkar-02, SH-02 and V00183 and use of specific crosses Bhakkar-02 x SH-02, V00183 x Chakwal-86 and Chakwal-86 x SH-02 would be more effective for evolving wheat varieties for the environments prone to terminal heat stress..

CONCLUSIONS

Additive gene action with partial dominance was observed for days to heading, spike index at anthesis, plant height, spikes per plant and grain yield per plant under both temperature conditions suggesting that these traits might be useful for the development of thermo tolerant varieties by modified pedigree selection.

Over-dominance type of gene action was recorded for spikelets per spike under both normal and heat stress conditions suggesting that further improvement in this trait may be effected by bi-parental mating coupled with few cycles of recurrent selection.

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