International Journal of Agriculture, Environment and Biotechnology
Citation: IJAEB: 10(3): 295-302, June 2017
DOI: 10.5958/2230-732X.2017.00037.7

GENETICS AND PLANT BREEDING

Evaluating the Performance of Bread Wheat (*Triticum aestivum* L.) Genotypes for Terminal Heat Tolerance

Neerja Sood*, G.S. Mavi, Akhil Malhotra, Ramandeep Kaur Jhinjer, Baldeep Singh, Binder Kaur and V.S. Sohu

Department of Plant Breeding and Genetics, Punjab Agricultural University, PAU, Ludhiana, Punjab, India

*Corresponding author: soodneerja@gmail.com

Paper No. 582 Received: 14-1-2017 Accepted: 4-5-2017

ABSTRACT

Terminal heat stress is a key yield-reducing factor in late sown wheat. Twenty-five bread wheat genotypes were evaluated for terminal heat tolerance by planting in normal (non-stress) and late (stress) environments. To check the tolerance level of genotypes to heat stress, indices namely mean performance of genotypes, heat susceptibility index, and heat susceptibility percent were studied. The analysis of variance revealed significant variation due to genotypes for all characters in two sowing dates except grain filling period. In heat stressed environment, genotypes DBW 107, HUW 688, UP 2883, K 1314, HD 3118, HI 1604 and HD 3159 had high per se performance for grain yield/m^2. Genotypes HD 3164, GW 463, PBW 718 and CG 1015 showed low heat susceptibility index (HSI<1) for grain yield/m^2 and were thus consider as heat tolerant genotypes. Reduction in grain yield/m^2 (14.97%) was mainly associated with a reduction in grain filling period (16.73%).

Highlights

- In heat stressed environment, genotypes DBW 107, HUW 688, UP 2883, K 1314, HD 3118, HI 1604 and HD 3159 had high per se performance for grain yield/m^2.
- Genotypes HD 3164, GW 463, PBW 718 and CG 1015 showed low heat susceptibility index (HSI<1) for grain yield/m^2 and were thus consider as heat tolerant genotypes.

Keywords: Wheat, heat tolerance, genotypic variation, morphological traits

Wheat (*Triticum aestivum* L.) has a prominent position among the cereals that supplement nearly one-third of the total world population's diet by providing half of the dietary protein and more than half of the calories (Kasana *et al.,* 2016). During the last four decades of the 20th century, the global wheat production is doubled from 3 to 6 billion and by the year 2020 demand for wheat imposed by growing population is forecasted around 950 million tonnes. This target will be achieved only if global wheat production is increased by 2.5% per annum (Singh *et al.,* 2011). This increase in wheat production is much more challenging due to a shortage of water and changing climate.

Seasonal fluctuations have a potential impact on the crop development and grain yield. The variation in temperature requirements and temperature extremes varies widely for different cultivars of the same species, among species and it varies widely for most crops. Kalra *et al.* (2008) emphasized the need of studying the response of crops to weather variations for evaluating the impact of seasonal temperature change and estimating yield dependence of temperature rise of crops. Too early sowing of crop produces weak plants with poor root system as the temperature is above optimum whereas delay in sowing leads to irregular germination which results in poor tillering and finally reduction in yield (Yajam and Madani 2013). Many authors have reported a reduced crop stand, shorter life cycle, reduced tillering, less biomass production, reduced fertilization and grain development, reduced head size, reduction in number of spikes per m^2, number of grains per spike and grain weight as the consequences of heat stress, and all these changes are translated in reduction of grain yield/m^2under heat stress conditions (Moshatati *et al.*, 2012).

Wheat is very sensitive to high temperature (Slafer and Satorre 1999) and trends in increasing growing season temperatures have already been reported for the major wheat-producing regions (Gaffen and Ross 1998; Alexander *et al.*, 2006; Hennessy *et al.*, 2008). Wheat experiences heat stress to varying degrees at different phenological stages, but heat stress during the reproductive phase is more pronounced than during the vegetative phase due to the direct effect on grain number and dry weight (Wollenweber *et al.*, 2013).

Yield and yield components in stress condition, are still the most effective tools for stress evaluation (Ozkan *et al.*, 1998). Selection of different genotypes under environmental stress conditions is one of the main tasks of plant breeders for exploiting genetic variations to improve stress tolerant cultivars (Khan and Kabir 2014). Several screening methods and selection criteria have been proposed by different researchers, but very few were reported for screening heat tolerant genotypes in wheat. Stress indices based on loss of yield under stress conditions in comparison to normal conditions have been used for screening stress tolerant genotypes. Fischer and Maurer (1978) proposed genotype stress susceptibility index (SSI) as a ratio of genotypic performance under stress and non-stress conditions. They suggested the SSI for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments. Bansal and Sinha (1991) proposed to use SSI and grain yield/m^2 as stability parameters to identify drought resistant genotypes of wheat. Clarke *et al.*, (1992) used Stress susceptibility index (SSI) to distinguish between wheat (*Triticum aestivum* L.) genotypes and suggested that an SSI > 1 indicated above average susceptibility to drought stress. With this in mind, it was felt imperative to evaluate some improved wheat genotypes (Table 5) facing high temperatures during and after anthesis under field conditions to identify genotypes that have high yield potential in both relatively favourable and high-temperature environments for using in a breeding program.

MATERIAL AND METHODS

The experimental material comprised of 25 bread wheat genotypes were planted in randomized block design with two replications for timely sown (TS) and late sown (LS) conditions during Rabi 2014-2015. Late sown planting was done 30 days after TS planting to subject the late sown experiment to terminal heat at grain filling stage. The two planting dates represented no-stress (10^{th} November, E_1) and heat stress (10^{th} December, E_2) environments. Each genotype was grown in a plot having 6 rows of 3m length. The trial was conducted in the experimental area of Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana. All the recommended cultural and agronomical practices were followed to raise the good crop. Data were recorded for yield and yield component traits viz., Grain filling period, plant height (cm), biomass (gm/m^2), productive tillers (spikes/m^2), test weight (gm/1000 grains), grain number (GN/5 spikes), grain weight (GW/ 5 spikes) and grain filling period for each genotype and performance of each genotype was compared over two environments.

Heat susceptibility index (HSI) was calculated for grain yield/m^2 and other attributes over high-temperature stress (late sown) and no-stress environment (timely sown) by using the formula as suggested by Fischer and Maurer (1978).

$$HSI = (1 - Xh/X)/1 - Yh/Y$$

where, Xh and X are the phenotypic means for each genotype under heat stress and no stress conditions, respectively, and Yh and Y are the phenotypic means for all the genotypes together under heat stress and control conditions, respectively. Besides that, heat susceptibility (percent) was worked out as a reduction in genotypic mean under stress environment from that under no-stress environment.

RESULTS AND DISCUSSION

The meteorological variations have a great impact on the production and yield factors, as said above the increasing temperature has caused a decline in the production during 2014-15. It has been seen that the mean maximum and minimum temperatures remained high during march and April (Fig. 1).

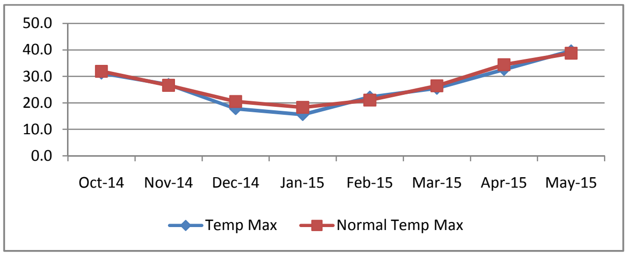

Fig. 1: Schematic representation of difference of maximum and minimum temperature during *rabi* season 2014-15

Analysis of Variance

The analyses of variance for grain yield/m^2 and other yield components in both timely and late sowing environments are given in Table 1. The results revealed highly significant differences among two dates of sowing for all the characters. The test of significance among the genotypes revealed highly significant differences for all the characters studied except grain filling period. This suggested that the magnitude of differences in genotypes was sufficient to provide some scope for selecting genotypes with improved heat stress tolerance and such genotypes can be used to create desirable genetic variability for heat stress tolerance. Similarly, the genotypes interacted highly significantly with dates of sowing for all the traits showing that genotypes performed differently in normal sown and late sown conditions thus indicating the influence of sowing condition on genotypes and traits. Kaur *et al.* (2013) confirmed that high-temperature stress, created by delayed sowing, caused significant stress conditions for the crop by affecting these traits. The results were also supported by the findings of Singh and Ahmad (1997) and Sharma *et al.* (2004).

Per Se Performance

For each genotype mean values of the replications were calculated under each thermal regime in order to identify genotypes excelling for each trait (Table 2). The genotypes showed wide ranges of variations with respect to per se performance for various traits studied. The results exhibited wide differences among genotypes for their sensitivity to heat stress. Genotypes with better per se performance were identified under each thermal regime. Genotypes viz., UAS 360, HD 3165, UAS 361, HI 1604, DBW 150, PBW 716 and UP 2883 had longer grain filling period under normal conditions. Genotype PBW 716 was able to maintain a longer grain filling period under late sown conditions and may possess heat tolerance for grain filling period. The data on plant height revealed that both the sowing dates and varieties affected the plant height significantly. PBW 718, WH 1179 and UAS 360 were tall genotypes, whereas IC 138852 and HUW 688 were dwarf genotypes under both environments. Under normal environment, maximum biomass was observed in PBW 709 followed by PBW 716, HD 3164, K 1312, HUW 688 and DBW 150 whereas; DBW 147 had more biomass under late sown environment. HUW 688, UAS 360, PBW 709, UP 2883, HI 1604 and K 1312 were genotypes with more productive tillers under normal conditions. In some cases the delayed sowing as the temperature was not favouring the tillering requirement, resulting in less number of tillers m^2. Differences in a number of tillers m^2 among varieties might be attributed to their genetic diversity. These results are in accordance with those of Aslam *et al.*, (2003); Shah *et al.*, (2006) for differences in a number of tillers m^2

Table 1: Analysis of variance for experimental design for various traits in bread wheat

Source of Variation	d.f.	Mean Squares							
		GFP	PH	Biomass	PT	TW	GN/5 spikes	GW/5 spikes	GY
Replications	1	7.30	0.97	900.16	1997.28	51.83	249.50	1.16	4.65
Dates (A)	1	2470.10**	4678.57**	10574.12**	28730.08**	15.99*	1339.42**	15.99**	82.35**
Genotypes (B)	24	1.66	40.93*	30658.33**	3764.63**	45.71**	1761.04**	2.84*	2.35*
AB	24	28.07*	28.73**	17925.49**	3661.29**	13.10**	2808.46**	3.86**	1.40*

GFP = Grain filling period; PH = Plant height; PT = Productive tillers; TW = Test weight; GN/ 5 spikes = Grain number per five spikes; GW/ 5 spikes = Grain weight per five spikes and GY = Grain yield

** ,** are significant at 5% and 1% level of significance, respectively*

Table 2: Mean performance of genotypes for various characters over two sowing dates (E1 and E2)

Entry	GFP		Plant height		Biomass		Productive tillers		Grain yield/ m^2		Test wt		GN/ 5 spikes		GW/5 spikes	
	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2	E1	E2
DBW 147	58.5	52.0	102.0	84.7	1261.5	1153.0	344.5	378.8	447.0	373.0	35.5	34.3	157.0	228.5	7.95	9.50
DBW 148	56.5	52.5	102.0	91.2	1237.5	1026.5	395.3	351.3	445.0	364.5	34.7	31.5	211.5	199.0	8.15	9.15
DBW 150	61.0	51.5	106.0	84.8	1351.5	974.5	353.0	257.3	445.0	335.5	31.5	34.0	186.0	172.5	6.85	7.32
DBW 107	53.5	54.0	98.0	85.7	1324.0	1339.0	400.5	412.3	420.0	427.5	39.8	39.8	187.0	194.5	7.50	8.93
WH 1179	57.0	46.0	104.5	92.0	1007.5	1001.5	395.8	375.8	393.0	288.0	30.0	29.5	225.0	223.0	8.95	9.37
PBW 716	61.0	54.5	102.5	88.3	1423.5	1052.5	371.0	314.2	424.5	398.5	35.9	33.3	314.0	307.0	10.55	9.09
PBW 718	56.0	49.0	107.0	99.5	1206.0	933.0	359.5	358.8	389.5	388.0	41.1	41.2	181.5	187.5	7.26	8.20
PBW 719	59.0	49.0	101.0	89.3	1152.0	1075.0	335.0	317.5	337.0	343.0	31.1	33.1	154.0	273.0	6.20	11.94
PBW 707	58.0	54.0	104.5	89.3	940.0	842.0	322.5	325.8	449.0	357.0	33.0	30.5	189.0	181.0	8.05	7.80
PBW 709	58.5	47.0	106.5	88.8	1428.5	1006.0	439.0	316.7	431.0	345.0	39.0	32.5	174.0	151.0	6.96	6.70
HD 3165	62.0	42.5	103.0	86.2	999.0	931.5	350.5	384.0	441.0	357.0	36.0	29.4	227.5	200.0	8.30	8.87
HD 3164	58.5	46.0	104.0	83.2	1398.5	1039.0	333.0	362.3	353.0	325.0	37.6	35.4	194.0	172.0	8.00	7.92
HD 3159	59.0	49.0	102.0	86.5	1305.5	989.0	351.5	351.0	408.0	417.0	30.0	31.7	184.0	227.0	8.90	9.75
HD 3118	60.0	43.0	100.5	86.3	1063.5	1005.5	359.5	349.8	418.5	429.0	29.5	34.7	179.0	205.0	6.65	7.28
HI 1604	61.5	48.0	96.5	96.8	1186.0	968.0	427.7	343.3	406.0	410.5	40.9	39.8	173.5	178.5	9.20	8.26
IC 138852	55.0	43.0	96.0	82.5	1074.5	1025.0	371.5	394.2	395.0	342.0	40.1	31.0	242.5	168.5	9.60	7.80
HUW 688	57.0	52.0	94.5	83.0	1377.5	1085.0	470.3	365.8	378.0	399.5	33.3	31.0	170.5	173.0	8.75	7.50
UP 2883	61.0	47.5	99.0	84.5	1275.5	1020.0	428.0	244.2	407.0	408.0	31.7	31.8	197.5	200.0	7.30	8.93
K 1312	60.0	50.0	103.0	84.3	1398.5	913.0	406.7	278.5	416.0	321.0	36.5	31.0	192.5	194.0	8.05	9.85
K 1313	56.0	53.0	97.0	86.5	1196.0	1080.0	327.5	302.7	398.5	332.5	38.2	31.0	171.5	159.0	6.55	7.28
K 1314	54.5	46.5	101.5	85.5	1245.0	1125.0	295.0	374.0	409.0	410.0	43.0	43.4	190.0	202.0	7.30	8.04
CG 1015	58.5	45.0	97.5	91.8	1196.5	1125.0	345.5	311.0	391.0	385.5	33.1	32.1	230.0	174.0	8.25	7.48
GW 463	54.0	50.0	106.5	80.8	1186.0	1087.5	395.5	363.0	377.0	380.5	30.1	33.0	224.5	172.5	9.10	7.50
UAS 360	64.0	46.0	106.0	95.5	1289.5	986.5	445.7	388.3	473.0	365.5	35.3	34.6	225.5	236.5	8.80	9.73
UAS 361	62.0	42.5	99.0	90.0	1186.5	985.5	359.5	314.2	420.5	321.0	37.5	33.0	184.5	182.0	7.55	8.55
Mean	58.5	48.5	101.6	87.9	1228.4	1030.7	375.3	341.4	410.9	369.0	35.4	33.7	198.6	198.4	8.0	8.5
CD (5%)	NS		6.5		117.9		74.7		1.1		3.1		25.0		0.8	
SE(m)	2.6		2.7		70.5		30.2		23.7		1.7		19.3		0.8	
SE(d)	3.7		3.8		99.7		42.8		33.5		2.4		27.3		1.1	
C.V.	7.0		4.0		8.8		11.9		8.6		7.1		13.8		13.0	

Significant at 0.05 and 0.01%

as attributed to genetic diversity. For test weight, K 1314, PBW 718, HI 1604 possessed more weight in both the environments. A Number of grains per spike is an important yield contributing parameter and has a direct effect on the final grain yield/m^2 of wheat. IC 138852 and UP 2883 were desirable genotypes for grain number and grain weight per five spikes under normal environment whereas under late sown conditions PBW 716 and PBW 719 showed more grains/ 5 spikes and grain weight/ 5 spikes. Grain yield/m^2 of wheat crop is the result of combined effect of various yield contributing components. It is evident from the data that delayed sowing significantly affected the grain yield. HUW 688 and UP 2883 gave higher grain yield/m^2 under normal conditions, whereas HD 3118 performed better under late sown conditions. Yajam and Madani (2013) stated that wheat cultivars responded to delay sowing date with a reduction in grain yield. Other authors (Sial *et al.*, 2005; Tahir *et al.*, 2009) reported low grain yield/m^2 in late sowing. Genotypes identified for both the environments were not common and these results were confirmed with the findings of Kaur *et al.* (2009).

Heat Susceptibility Index

The heat tolerance as measured by heat susceptibility index reflects the stability of performance of genotypes under no-stress, and heat stress environment. The heat susceptibility of various genotypes was estimated and expressed in the form of heat susceptibility index (Table 3). The reduction in performance when sown under heat-stress conditions from that of the no-stress environment was calculated. HSI <1 indicates the tolerance of genotype to heat stress whereas HSI >1 indicates susceptibility of the genotypes under stress. The comparison of these values was used to identify genotypes with least susceptibility to thermal stress. The heat tolerance as measured by heat susceptibility index reflects the stability of performance of genotypes under -no-stress and heat stress environments and does not take into account the actual yield obtained under heat stress (Kaur *et al.*, 2009). Grain filling duration contributes to the final yield of a plant that is a product of the rate of grain filling and duration of the grain filling period. For grain filling period DBW 107 was least affected by high temperature followed by K 1313, PBW 707, DBW 148 and GW 463 which also maintained longer grain filling period and were less affected by high temperature. Regarding plant height, HI 1604 had minimum heat-stress sensitivity followed by CG 1015 and PBW 718. In the case of test weight, minimum heat susceptibility was observed in HD 3118 which was followed by HD 3165, PBW 707, GW 463, DBW 150, PBW 719 and HD 3159. Genotypes UP 2883, IC 138852, CG 1015, HI 1604, GW 463, HUW 688 and PBW 709 are associated with negative values of HSI revealing low heat-stress sensitivity under heat-stress condition than in normal sown condition. A heat-tolerant genotype can have a low mean yield and consequently will be of no commercial value but will have a good academic

Table 3: Heat susceptibility index for various characters in bread wheat (E_1 vs E_2)

Entry	GFP	PH	GN/5 spikes	GW/5 spikes	Test wt (g)	Grain yield/m²
DBW 147	0.65	1.26	12.18	1.94	1.50	1.08
DBW 148	0.42	0.79	-1.58	1.22	3.92	1.18
DBW 150	0.92	1.48	-1.94	0.68	-3.39	1.60
DBW 107	-0.05	0.93	9.65	4.55	0.02	1.45
WH 1179	1.14	0.89	-0.24	0.47	-1.45	1.74
PBW 716	0.63	1.02	11.62	2.64	3.17	0.83
PBW 718	0.74	0.52	0.88	1.29	-0.11	0.03
PBW 719	1.00	0.86	20.66	9.19	-2.77	1.40
PBW 707	0.41	1.08	0.30	-0.31	-5.07	1.33
PBW 709	1.16	1.23	-3.53	-0.37	7.29	1.30
HD 3165	1.85	1.21	1.61	0.68	-6.41	1.24
HD 3164	1.26	1.48	2.77	-0.10	-0.95	-0.22
HD 3159	1.00	1.13	10.27	4.10	-2.44	0.45
HD 3118	1.67	1.04	3.88	3.93	-7.70	0.28
HI 1604	1.29	-0.03	-6.30	-2.09	1.09	0.59
IC 138852	1.28	1.04	-8.16	-1.86	9.84	0.87
HUW 688	0.52	0.90	-5.47	-1.42	3.05	1.45
UP 2883	1.30	1.09	-8.16	-2.53	-0.25	1.71
K 1312	0.98	1.34	0.21	2.22	6.57	1.48
K 1313	0.32	0.80	1.24	1.10	8.19	1.08
K 1314	0.86	1.17	16.40	5.89	-0.49	0.44
CG 1015	1.36	0.43	-6.51	-0.93	1.31	0.09
GW 463	0.44	1.79	-6.19	-1.75	-4.25	-0.06
UAS 360	1.65	0.73	1.30	1.05	0.89	1.48
UAS 361	1.85	0.67	-0.36	1.31	5.20	1.54

Table 4: Heat susceptibility (%) for various characters in bread wheat

Character	Heat susceptibility (%)
Grain filling period	16.73
Plant height	13.42
GN/5spikes	-6.66
GW/5 spikes	-12.45
Test weight (g)	1.54
Grain yield/m^2	14.97

Table 5: Pedigree list of Different wheat genotypes

Sl. No.	Genotypes	Pedigree
1	DBW 147	PBN142/DBW30
2	DBW 148	BHRIKUTI/35thIBWSN325
3	DBW 150	DBW16/GW322
4	DBW 107	TUKURU/INQALAB91
5	WH 1179	OASIS/SKAUZ//4*BCN/3/3*PASTOR
6	PBW 716	HD2967/7/CAL/NH//H567.71/3/SERI/4/CAL/NH//H567.71/5/2*KAUZ/6/PASTOR
7	PBW 718	HD2855/PBW550//PBW548
8	PBW 719	UP2556/PBW543
9	PBW 707	FRET2/TUKURU//FRET2/3/MUNIA/CHTO//AMSEL/4/FRET2/TUKURU/FRET2
10	PBW 709	PBW621/HD2967
11	HD 3165	HD2824/CBW14
12	HD 3164	DL711/DBW31
13	HD 3159	WBLL1*2/BRAMBLING/5/BABAX/LR42//BABAX*2/4/SNI/TRAP#1/3/KAUZ*2/TRAP//KAUZ
14	HD 3118	ATTILA*2/PBW65//WBLL1*2/TUKURU
15	HI 1604	PFAU/SERI.1B//AMAD/3/WAXWING/4/BABAX/LR42//BABAX*2/3/KUKURU
16	HUW 688	ATTILA/PASTOR//HP1731
17	UP 2883	KAUZ//ALTAR84/AOS/3/MILAN/KAUZ/4/HUITES/5/PBW502
18	K 1312	PBW343/K0402
19	K 1313	HUW468/K9107
20	K 1314	HD2402/K8565
21	CG 1015	NI908/BL1986
22	GW 463	GW496/KLP010
23	UAS 360	BAU/KAUZ//PASTOR/GW322
24	UAS 361	RAJ4037//PARUS/PASTOR

value, whereas, a heat susceptible but exceptionally higher yielding genotype can still give better under stress environment.

As low HSI is synonymous with high-stress tolerance, the genotypes HD 3164, GW 463, PBW 718 and CG 1015 had lowest HSI value for grain yield, therefore, these genotypes had low heat susceptibility indicating their specific suitability under late sowing condition. These results are in conformity with those of Khan *et al.* (2007) concurred that some genotypes have potential to produce high yield even under high temperature. In contrast, genotype WH 1179, followed by UP 2883 and DBW 150 with the highest HSI values could be identified as highly susceptible to heat. Several authors (Khanna-Chopra, Viswanathan 1999; Singh *et al.*, 2011; Sharma *et al.*, 2013) evaluated stress susceptibility indices of yield and its different components of wheat genotypes for heat stress tolerance and grouped them into highly tolerant, tolerant and susceptible genotypes based on their stress susceptibility indices values.

Heat Susceptibility (percent reduction)

The overall comparison of percentage reduction of group means of all genotypes under heat stress over no-stress environment indicated that the most sensitive trait to heat stress was grain filling period (16.73%) followed by grain yield/m^2 (14.97%), plant height (13.42%). Sohail *et al.* (2014) reported that late sowing reduced the wheat grain upto 29%Percentage reduction in grain number and grain weight per 5 spikes was not observed under heat stress environment indicating that the genotypes evaluated in this study were more tolerant to heat stress for these traits.

The study revealed that grain yield/m^2 was significantly affected by high temperature. Considering grain yield/m^2 as the final product of different physiological processes, the two entries viz., HD 3164 and GW 463 displayed the uppermost grain yield/m^2 under the heat stress and were identified as superior genotypes. These genotypes can be utilized in breeding programs for development of wheat varieties having heat tolerance at the terminal growth stage.

ACKNOWLEDGMENTS

Thanks to IIWBR, Karnal for providing material for the study.

CONCLUSION

Heat stress is a complex trait. A thermotolerant genotype needs adaptation for all physiological traits at all plant developmental stages. Hence from the present study, it was concluded that genotypes viz., DBW 107, HUW 688, UP 2883, K 1314, HD 3118, HI 1604 and HD 3159 had high per se performance for grain yield. Genotypes HD 3164, GW 463, PBW 718 and CG 1015 showed low heat susceptibility index (HSI<1) for grain yield/m^2 and were thus consider as heat tolerant genotypes. Thus the genotypes identified on the basis of both these criteria could be of immense use for further exploitation in a breeding programme.

REFERENCES

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Tank, A., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Kumar, K.R., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. and Vazquez-Aguirre, J.L. 2006. Global observed changes in daily climate extremes of temperature and precipitation. *J Geophysical Research: Atmospheres*, **111**: 1–22.

Aslam, M., Hussain, M., Akhtar, M., Cheema, M.S. and Ali, L. 2003. Response of wheat varieties to sowing dates. *Pakistan Journal of Agronomy*, **2**(4): 190-94.

Bansal, K.C. and Sinha, S.K. 1991. Assessment of drought resistance in 20 accessions of Triticum aestivum and related species Total dry matter and grain yield stability. *Euphytica* **56**: 7-14.

Clarke, J.M.D., Pauw, R.M. and Townley-Smith, T.M. 1992. Evaluation of methods for quantification of drought tolerance in wheat. *Crop Science*, **32**: 728-732.

Fischer, R.A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield response. *Australian Journal of Agricultural Research*, **29**: 897-907.

Gaffen, D.J. and Ross, R.J. 1998. Increased summertime heat stress in the US. *Nature*, **396**: 529–530.

Hennessy, K., Fawcett, R., Kirono, D., Mpelasoka, F., Jones, D., Bathols, J., Whetton, P., Stafford Smith, M., Howden, M., Mitchell, C. and Plummer, N. 2008. An assessment of the impact of climate change on the nature and frequency of exceptional climatic events. CSIRO and Bureau of Meteorology, http://www.daff.gov.au/ data/assets/pdf file/0007/721285/csirobom-report-future-droughts.pdf

Kalra, N.D., Chakraborty, A., Sharma, H.K., Rai, M., Jolly, S., Chander, P.R., Kumar, S., Bhadraray, D., Barman, R.B., Mittal M Lal and Sehgal, M. 2008. Effect of increasing temperature on yield of some winter crops in northwest India. *Current Science*, **94**(1): 82-88.

Kasana, B.S., Singh, A.K., Tomar, R.K.S. and Rikhari, Y.C. 2016. Evaluating the performance of wheat varieties under late sown irrigated condition in Bundelkhand zone. *International Journal of Applied and Pure Science and Agriculture*, **1**(7).

Kaur Simarjit, Sohu, V.S. and Mavi, G.S. 2009. Physiological response of wheat genotypes to post anthesis hyperthermal stress. *Crop Improvement*, **36**(2): 83-90.

Kaur Simarjit, Sohu, V.S. and Mavi, G.S. 2013. Climate change resilience in a set of diverse Indian and exotic genotypes of bread wheat. *Crop Improvement*, **40**(1): 50-57.

Khan, A.A. and Kabir, M.R. 2014. Evaluation of spring wheat genotypes (*Triticum aestivum* L.) for heat stress tolerance using different stress tolerance indices. *Cercetari Agronomice în Moldova*, **160**(4): 49-63.

Khan, M.I., Tila, M., Subhan, F., Amin, M. and Shah, S.T. 2007. Agronomic evaluation of different bread wheat (*Triticum aestivum* L.) genotypes for terminal heat stress. *Pakistan Journal of Botany*, **39**(7): 2415-25.

Khanna-Chopra, R. and Viswanathan, C. 1999. Evaluation of heat stress tolerance in irrigated environment of *T. aestivum* and related species. I. Stability in yield and yield components. *Euphytica*, **106**: 169-180.

Moshatati, A., Siadat, S.A., Alami Saeid, K., Bakhshandeh, A.M. and Jalal Kamali, M.R. 2012. Effect of terminal heat stress on yield and yield components of spring bread wheat cultivars in ahwaz. *Iran Intl J Agric: Res & Rev.*, **2**(6): 844-49.

Ozkan, H., Yagbasanlar, T. and Genc, T. 1998. Tolerance and stability studies on durum wheat under drought and heat stress conditions. *Cereal Research Communication*, **26**: 405– 12.

Shah, W.A., Bakht, J., Ullah, T., Khan, A.W., Zubair, M. and Khakwani, A. 2006. Effect of sowing dates on yield and yield components of different wheat varieties. *Journal of Agronomy*, **5**(1): 106-10.

Sharma, A., Rawat, R.S., Verma, J.S. and Jaiswal, J.P. 2013. Correlation and heat susceptibility index analysis for terminal heat tolerance in bread wheat. *Journal of Central European Agriculture*, **14**(2): 57-66.

Sharma, S., Sohu, V.S. and Mavi, G.S. 2004. Evaluation of elite wheat genotypes to high temperature stress in bread wheat (*Triticum aestivum* L). *Crop Improvement*, **31**: 141-48.

Sial, M.A., Arain, M.A., Mazhar, S.K., Naqvi, H., Dahot, M.U. and Nizamani, N.A. 2005. Yield and quality parameters of wheat genotypes as affected by sowing dates and high temperature stress. *Pakistan Journal of Botany*, **37**(3): 575-84.

Singh, K., Sharma, S.N. and Sharma, Y. 2011. Effect of high temperature on yield attributing traits in bread wheat. *Bangladesh Journal of Agricultural Research*, **36**(3): 415-26.

Singh, N.B. Ahmad. 1997. Response of wheat (*Triticum aestivum*) varieties to different dates of sowing. *Indian Journal of Agricultural Science*, **67**: 208-11.

Slafer, G.A. and Satorre, E.H. 1999. Wheat: Ecology and Physiology of Yield Determination. Haworth Press Technology and Industrial, ISBN 1560228741.

Sohail, M., Hussain, I., Riaz-ud-Din, S.K., Tanveer, M., Qamar and Abbas, S.H. 2014. Evaluation of advance wheat lines for agronomic traits in rainfed environment. *Pak. J. Agric. Res.*, **27**(2): 79-88.

Tahir, M., Ali, A., Nadeem, M.A., Hussain, A. and Khalid, F. 2009. Effect of different sowing dates on growth and yield of wheat (*Triticum aestivum* L.) genotypes in District Jhang, Pakistan. *Pakistan Journal of Life Social Science*, **7**(1): 66-69.

Wollenweber, B., Porter, J.R. and Schellberg, J. 2013. Lack of interaction between extreme high-temperature events at vegetative and reproductive growth stages in wheat. *Journal of Agronomy Crop Science*, **189**: 142–150.

Yajam, S. and Madani, H. 2013. Delay sowing date and its effect on Iranian winter wheat cultivars yield and yield components. *Annals of Biological Research*, **4**(6): 270-75.