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CHARACTERIZATION OF WHEAT GENOTYPES USING MORPHO-PHYSIOLOGICAL TRAITS FOR HEAT TOLERANCE

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ABSTRACT

Constant or transitory high temperatures affect plant growth and development inducing diverse morphological and physiological changes in plants which ultimately causes yield decrease. The traits like relative injury (RI%), chlorophyll content, canopy temperature depression (CTD), heat susceptibility index (HSI), 1000-kernel weight (TKW), grain filling duration (GFD) were used in present study to assess the capability of plants to tolerate heat stress. The study revealed that the evaluated wheat genotypes showed variable degree of tolerance against heat for different traits. On the basis of morpho-physiological traits such as RI, chlorophyll content at 15 days after anthesis (DAA), CTD at 15 DAA, HSI, TKW, GFD, genotypes HD2329 x HD2967 (19.2%), WH1021 (-21.7%), JOB666 X WH1105 (-37.5%), WH1124 X HD2967 (0.55), HD2891 (2.1%) and WAXWING X HD2967 (-2.15%) were identified as the most heat tolerant genotypes for respective characters. For grain yield out of 54 wheat genotypes, DBW90, HD2329, UP2843 × HD2967, WH1124 × HD3059, WH1124 × HD2967, MACS6272 × WH1105, MACS6272 × HD2967, HD2891 × WH1105 and UP2338 were classified as heat tolerant.

Key words: Characterization, wheat genotype, morpho-physiological traits, heat tolerance, grain yield

INTRODUCTION

Wheat (*Triticum aestivum)*, a cereal grass of *Graminae* (Poaceae) family, is one of the world's largest grown cereal crops raised under wide climatic conditions (Kumar *et al*., 2015a). It is agronomically and nutritionally most important cereal, essential for food security, poverty alleviation and improved livelihoods. It is world's most widely adapted crop, supplying 1/3rd of the world population with around half of their calories and protein (Kumar *et al*., 2015b). The low level of productivity is mainly due to the difficulty in availability of improved varieties and occurrence of diseases that pose severe threat to wheat production. The major and foremost aspect in increasing production and productivity in wheat is adoption of high yielding, disease resistant, photo-thermo-tolerant and fertilizers responsive varieties and to minimize yield losses due to effect of high temperature on its growth and development (Reynolds and Borlaug, 2006). In view of global warming and changing environmental scenario, a heat tolerant variety is an urgent requirement. Heat stress adversely affects wheat production and is particularly detrimental during reproductive development and grain filling stage. Manifestation of wheat yield fluctuates widely as a result of its interaction with environment because grain yield in wheat is a complex inherited character and is the product of several contributing factors affecting yield directly or indirectly (Kumar *et al*., 2015c). Wheat crop requires favorable winter for about 100-110 days for producing its potential yield. Wheat has optimum temperature regimen of 21.3±1.27°C during grain filling stage (Farooq *et al*., 2011). In India, incidences of high temperatures at the time of grain-filling are more pronounced when sowing of wheat is delayed (Rane *et al*., 2007; Joshi *et al*., 2007). A 2˚C increase above long-term averages shortens the growing season by a critical 9 days and reduces total yield by upto 50% (Lobell *et al*., 2012).

The relationship between morpho-physiological traits associated with heat tolerance is important in forming selection criteria for heat tolerance. Available genetic diversity in wheat offers opportunity for breeders to develop genotypes with wider adaptability having resistance to biotic and abiotic stresses by hybridization and recombination of desired genes (Prasad *et al*., 2012; Kumar *et al*., 2015d). It is difficult to make progress for grain yield and yield components under heat stress conditions as these are complex characters and largely influenced by environmental factors. Canopy temperature depression (Shefazadeh *et al*., 2012), cell membrane stability (Dhanda and Munjal, 2006) and chlorophyll content (Dhyani *et al*., 2013) have been used as physiological screening techniques for heat tolerance. High temperature causes modifications of membrane fluidity, permeability and stability and electrolyte loss resulting from heat-induced cell membrane leakage is considered a measure of stress cellular damage (Fokar *et al*., 1998). Photosynthesis may be disrupted under heat stress mainly due to damage of the components of photo-system II located in thylakoid membranes of chloroplast and membrane proteins (Al-Khatib and Paulsen, 1984). Therefore, the heat tolerant wheat variety is still one of the priorities in agricultural research, because above the optimum temperature (21.3±1.27˚C) wheat yield is drastically affected. Therefore, there is a dire need to develop/identify heat tolerant genotype and present study was focused to screen heat tolerant genotype on the basis of morpho-physiological characters to terminal heat stress or may mature early without appreciable yield losses.

MATERIALS AND METHODS

The present study was conducted at Norman E. Borlaug, Crop Research Centre, GBPUAT, Pantnagar, India. The material was developed through line x tester mating during *rabi* 2013-14 and the progenies were evaluated in *rabi* 2014-15. Thirteen genetically diverse heat tolerant wheat varieties *viz*., HD3091, DBW90, UP2843, WH1124, HPW211, WH1021, CBW12, MASC6272, JOB666, HD2329, WAXWING, HD2891 and HD2961; and three testers HD2967, WH1105 and HD3059, procured from Wheat Breeding Research Unit, Department of Genetics and Plant Breeding, GBPUAT, Pantnagar (India), crossed in line x tester mating design excluding reciprocals. Complete set of 39 F_1s, 13 lines and 3 testers along with 2 standard checks (DPW 621-50 and UP 2338) were evaluated in a randomized block design with three replications during *rabi* 2014-15. Each plot consisted of 2 rows of 1 m length with plant spacing of 10 x 20 cm. To estimate the level of heat tolerance for different genotypes with respect to morphological characters under study included grains spike^{-1}, grain weight spike^{-1}, grain filling duration (duration between the anthesis stage and physiological maturity), 1000-grain weight, grain yield plant^{-1} and heat susceptibility index (HSI) for yield which was calculated using the following formula as described 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 stressed and control conditions, respectively, and Yh and Y are the phenotypic means for all genotypes under heat stressed and control conditions, respectively. Physiological characters contributing to heat tolerance for various genotypes of bread wheat were estimated. Canopy temperature depression (CTD) was measured by hand held infrared thermometer (model AG-42, Tele Temp Crop, Fullerton CA) for instantaneous measurement of canopy minus air temperature as canopy temperature depression at anthesis and 15 days after anthesis at an angle of 30^o, 50 cm above the canopy from horizontal and at 1 m distance from the edge of the plot end and data recorded between 12:00 to 14:00 h. Relative injury (%) was estimated by following the procedure and formula of Blum and Ebercon (1981):

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

Where, T and C refer to treatment and control, respectively, and 1 and 2 refer to the initial and final conductance readings, respectively. Chlorophyll content was recorded in flag leaves, using a self-calibrating SPAD chlorophyll meter (Minolta) and data recorded at anthesis and 15 days after anthesis. Percent increase or decrease in mean values for different morpho-physiological traits associated with heat tolerance over control under late sown environment was used for analysis and interpretation. SAS (2003) and EXCEL software were used for these analyses.

RESULTS AND DISCUSSION

Among the morpho-physiological characters, percent increase or decrease in traits like grain filling duration (GFD), grain weight spike^{-1}, 1000-grain weight (TGW), grains spike^{-1} (GS) and grain yield and CTD at anthesis and 15 days after anthesis were taken into consideration for genotype characterization for terminal heat tolerance in addition to heat susceptibility index for grain yield (HSI), relative injury and grain yield under late sown over timely sown condition. The physiology of heat tolerance in crop plants has utilized the relative injury assay as a measure of relative heat tolerance and is negatively correlated. Maximum RI value (94.23%) was found for WAXWING and lowest injury (19.25%) for cross HD2329 x HD2967, followed by WAXWING x WH1105 (24.18%) [Table1]. Thirty five genotypes showed <60% injury, hence can be grouped as tolerant or moderately tolerant (Table 2). A substantial genetic variability for relative injury has been reported by Munjal and Dhanda (2004) in wheat genotypes with less relative injury possessed greater thermo-tolerance for plant growth and grain yield, possibly through maintaining their cellular membrane integrity under high temperature conditions. Reddy *et al*. (2008) reported the cross PBW 452 x Lok 54 as the most heat tolerant with RI value of 26.26% which was less severe than either of the parents.

Decline in chlorophyll was found adversely correlated with heat tolerance and minimum decline (-15.66%) was noted in cross WH1124 X HD3059, followed by genotype JOB666 (-13.94%); however, highest value was observed in UP2338 (14.2%) at anthesis. While, a range of -21.69 (WH1021) to 26.98% (WH1021 X HD3059) genotypes were observed for chlorophyll content at 15 days after anthesis . Forty seven wheat genotypes showed marginal decrease in chlorophyll content at anthesis so can be grouped as tolerant or moderately tolerant for anthesis stage, while twenty genotypes showed marginal decrease in chlorophyll content at 15 days after anthesis (Table 2). Dhyani *et al*. (2013) reported that heat stress drastically affects chlorophyll content and were higher in tolerant genotypes under late sown conditions in wheat. Such type of comparative physiological changes in wheat genotypes was in conformity with Almeselmani *et al.* (2012).

CTD is a direct function of transpiration rate, determined by number of physiological and metabolic processes including stomatal conductance, photosynthetic rate, vascular capacity, etc. The percent decrease in CTD at anthesis was highest (87.57%) for genotype UP2338, followed by JOB666 (83.03%) indicating these to be susceptible genotypes for heat tolerance; however lowest CTD (-30.67%) was observed for variety HD2967 at anthesis. The most tolerant genotype against heat stress with regard to CTD (-37.5%) was cross JOB666 X WH1105 and greatest value (85.7%)

Table 1: Increase or decrease (-) in various morpho-physiological traits in wheat over control under late sown condition alongwith heat susceptibility index

Genotypes	RI (%)	Chlorophyll content		CTD		HIS	TKW	GWS^{-1}	GFD	GS^{-1}	GY
		At anthesis	15DAA	At anthesis	15DAA						
HD3091	70.03	1.95	19.64	31.67	33.71	1.08	31.61	52.10	22.31	3.97	65.12
DBW90	64.43	4.04	15.16	53.15	12.47	0.69	24.45	53.40	23.58	11.92	41.29
UP2843	67.41	-4.71	6.70	57.11	50.44	0.84	11.97	43.39	12.61	2.50	50.50
WH1124	65.26	3.98	20.57	42.36	39.62	0.91	33.50	45.78	23.38	13.64	54.72
HPW211	80.11	-3.50	4.01	59.85	1.79	0.91	33.86	64.61	21.62	19.05	54.58
WH1021	74.92	9.85	-21.69	71.15	57.06	0.90	40.20	35.31	21.31	10.55	54.75
CBW12	61.94	-0.77	26.54	53.86	74.86	1.20	25.59	40.08	6.82	15.87	72.65
MASC6272	76.90	3.22	-7.23	61.67	5.17	0.95	18.03	43.56	15.23	3.68	57.07
JOB666	51.86	-13.94	2.67	83.03	-16.61	0.93	26.60	44.63	23.43	20.85	55.96
HD2329	61.03	-0.74	5.56	0.00	16.51	1.11	27.90	19.55	9.38	3.00	66.94
WAXWING	94.23	9.51	7.78	58.06	63.64	1.00	7.22	56.19	4.11	9.14	60.17
HD2891	87.37	2.01	-1.58	68.58	42.50	0.92	2.10	37.50	15.15	10.91	55.09
HD2961	77.02	9.26	0.35	41.44	32.50	0.94	25.04	46.43	15.86	-2.48	56.57
HD3059	80.30	-0.44	18.96	82.67	57.67	0.59	44.49	52.98	18.92	13.88	35.58
WH1105	88.49	-4.33	8.02	14.23	47.19	1.20	43.63	54.78	15.40	15.00	72.07
HD2967	55.89	6.81	0.06	-30.67	54.67	1.09	39.64	50.65	10.22	8.95	65.48
HD3091 × HD3059	62.08	-8.89	17.67	72.70	51.05	0.90	23.40	50.97	21.05	13.70	54.21
HD3091 × WH1105	85.57	-6.28	11.66	74.95	27.48	0.94	19.82	44.71	18.09	20.11	56.81
DBW90 × HD3059	75.06	5.24	20.79	57.65	38.76	0.96	19.70	49.85	9.92	7.19	57.72
DBW90 × WH1105	26.99	0.00	2.63	-5.71	26.35	0.95	26.46	38.96	21.08	10.78	57.06
DBW90 × HD2967	45.41	2.31	13.39	26.67	45.63	1.24	35.85	56.31	19.44	21.05	74.59
UP2843 × HD3059	26.92	3.59	2.22	72.34	68.40	0.86	32.01	38.46	26.74	3.05	51.57
UP2843 × WH1105	73.24	1.81	4.90	45.67	22.66	1.34	26.05	53.17	18.79	21.70	80.92
UP2843 × HD2967	38.59	2.12	-6.55	54.25	3.33	0.82	20.86	48.75	12.89	12.07	49.28
WH1124 × HD3059	29.72	-15.66	5.58	57.17	1.12	0.76	21.40	38.19	20.58	14.55	45.76
WH1124 × WH1105	26.78	2.87	5.89	37.11	41.37	1.06	17.46	52.12	14.97	6.80	63.57
WH1124 × HD2967	35.96	4.39	13.98	52.12	29.72	0.55	22.77	40.58	21.50	5.17	32.86
HPW211 × HD3059	32.75	9.70	13.55	35.00	67.83	1.11	45.91	41.99	20.52	17.14	66.77
HPW211 × WH1105	41.64	4.29	-1.87	77.30	31.33	0.94	35.31	61.43	19.27	13.36	56.70
HPW211 × HD2967	31.44	-10.97	0.89	40.35	49.63	0.84	31.58	49.75	24.99	25.79	50.39
WH1021 × HD3059	30.53	3.23	26.98	70.25	16.67	0.99	28.66	53.40	19.27	8.19	59.82
WH1021 × WH1105	38.39	-0.43	6.48	64.77	67.87	1.20	37.03	49.69	12.99	11.70	72.01
CBW12 × HD3059	30.66	-5.36	18.65	77.10	-4.03	1.13	31.66	55.22	21.08	14.04	68.21
CBW12 × WH1105	42.47	-2.72	7.65	67.67	85.75	1.01	35.76	46.46	20.94	14.53	60.51
CBW12 × HD2967	47.48	-1.18	21.22	72.46	27.46	1.18	42.93	55.31	15.30	10.45	70.83
MACS6272 × HD3059	36.36	-6.38	-7.01	57.17	-34.68	1.15	32.43	44.48	2.18	6.71	69.44
MASC6272 x WH1105	46.09	6.68	19.11	38.79	10.38	0.82	30.08	36.36	10.90	11.19	49.36
MASC6272 x HD2967	45.40	3.20	6.51	30.87	41.46	0.47	32.43	43.44	16.02	12.07	28.45
JOB666 × HD3059	40.19	4.34	-9.08	41.13	28.33	1.33	35.97	55.94	22.69	16.00	80.31
JOB666 × WH1105	28.34	5.81	2.98	68.79	-37.50	1.29	45.84	43.18	21.36	15.06	77.70
HD2329 × HD3059	48.22	-2.36	21.19	5.35	41.03	0.86	26.52	34.44	21.24	1.79	51.62
HD2329 × WH1105	82.77	-1.95	9.67	48.13	60.24	0.85	24.70	33.67	16.15	8.05	51.04
HD2329 × HD2967	19.25	-0.06	2.27	63.65	74.66	1.33	32.59	47.90	13.98	12.78	79.81
WAXWING xHD3059	39.69	-2.91	-6.00	54.00	68.79	1.10	44.29	69.02	8.57	17.94	66.19
WAXWING x H1105	24.18	13.58	5.74	68.22	-2.09	0.91	38.88	49.24	8.82	11.60	54.59
WAXWING x D2967	25.16	12.11	14.51	73.41	43.22	1.42	31.21	44.48	-2.15	7.36	85.57
HD2891 × HD3059	30.94	4.95	9.91	21.34	33.88	1.01	29.35	40.45	16.98	-0.60	61.05
HD2891 × WH1105	25.73	6.21	7.78	69.23	62.10	0.71	28.22	46.21	22.43	17.27	42.68
HD2891 × HD2967	27.77	7.70	1.50	53.86	8.68	0.96	24.30	26.22	11.59	10.91	57.84
HD2961 × HD3059	34.61	3.81	13.93	38.63	18.32	1.15	55.79	55.52	21.68	1.25	69.38
HD2961 × WH1105	28.04	4.71	4.68	37.28	57.07	0.86	36.34	52.63	18.70	10.55	51.50
HD2961 x HD2967	27.73	-1.41	11.52	47.23	55.18	0.96	14.34	49.68	13.57	-7.92	57.75
UP2338	31.80	14.20	19.15	87.57	84.13	0.80	32.52	50.00	25.22	-0.64	48.04
DPW621-50	35.87	5.61	6.10	11.94	34.62	0.92	29.00	47.25	3.19	1.71	55.40

RI= Relative injury, CTD = Canopy temperature depression, DAA = Days after anthesis, HSI = Heat susceptibility index, TKW = 1000-kernel weight, GWS^{-1} = Grain weight spike^{-1}, GFD = Grain filling duration, GS^{-1} = Grains spike^{-1}, GY = Grain yield

Table 2: Classification of wheat genotypes for heat tolerance on morpho-physiological trait basis

Parameters	Tolerant genotypes
Morphological	
Grain filling duration (GFD) (<10%)	WAXWING, CBW12, HD2329, DBW90 × HD3059, MACS6272 × WH1105, WAXWING × HD3059, WAXWING × WH1105, WAXWING × HD2967 and DPW621-50
Grain weight spike^{-1} (<25%)	HD2329
1000-grain weight (<25%)	DBW90, UP2843, MACS6272, WAXWING, HD2891, HD3091 × HD3059, HD3091 × WH1105, HD3091 × HD2961, DBW90 × HD3059, UP2843, HD2967, WH1124 × HD3059, WH1124 × WH1105, WH1124 × HD2967, HD2329 × WH1105, HD2891 × HD2967 and HD2961 × HD2967
Grains spike^{-1} (<10%)	HD3091 , UP2843, MACS6272, HD2329, WAXWING, HD2961, HD2967, DBW90 × HD3059, UP2843 × HD3059, WH1124 × WH1105, WH1124 × HD2967, WH1021 × HD3059, MACS6272 × HD3059, HD2329 × HD3059, HD2329 × WH1105, WAXWING × HD2967, HD2891 × HD3059, HD2961 × HD3059, HD2961 × HD2967, UP 2328 and DPW621-50
HSI (<1)	DBW90, UP2843, WH1124, HPW211, WH1021, MACS6272, JOB666, HD2891, HD2961, HD3059, HD3091 × HD3059, HD3091 × WH1105, DBW90 × HD3059, DBW90 × WH1105, UP2843 × HD3059, UP2843 × HD2967, WH1124 × HD3059, WH1124 × HD2967, HPW211 × WH1105, HPW211 × HD2967, WH1021 × HD3059, MACS6272 × WH1105, MACS6272 × HD2967, HD2329 × HD3059, HD2329 × WH1105, WAXWING × WH1105, HD2891 × WH1105, HD2891 × HD2967, HD2961 × WH1105, HD2961 x HD2967, UP2338 and DPW621-50
Physiological	
Canopy temperature depression at anthesis (<25%)	WH1105, HD2329, HD2967, DBW90 × WH1105, HD2329 × HD3059, HD2891 × HD3059, UP2338 and DPW621-50
Canopy temperature depression at 15 DAA (<25%)	DBW90, HPW211, MACS6272, JOB666, HD2329, UP2843 × WH1105, UP2843 × HD2967, WH1124 × HD3059, WH1021 × HD3059, CBW12 × HD3059, MACS6272 × HD3059, MACS6272 × WH1105, JOB666 × WH1105, WA×WING x WH1105, HD2891 × HD2967 and HD2961 × HD3059
Chlorophyll content at anthesis (<5%)	HD3091, DBW90, UP2843, WH1124, HPW211, CBW12, MACS6272, JOB666, HD2329, HD2891, HD3059, WH1105, HD3091 × HD3059, HD3091 × WH1105, DBW90 × HD3059, DBW90 × WH1105, UP2843 × HD3059, UP2843 × WH1105, UP2843 × HD2967, WH1124 × HD3059, WH1124 × WH1105, WH1124 × HD2967, HPW211 × WH1105, HPW211 × HD2967, WH1021 × HD3059, WH1021 × WH1105, CBW12 × HD3059, CBW12 × WH1105, CBW12 × HD2967, MACS6272 × HD3059, MACS6272 × HD2967, JOB666 × HD3059, HD2329 × HD3059, HD2329 × WH1105, HD2329 × HD2967, WA×WING x HD3059, HD2891 × HD3059, HD2961 × HD3059, HD2961 × WH1105 and HD2961 x HD2967
Chlorophyll content at 15 days after anthesis (<5%)	HPW211, WH1021, MACS6272, JOB666, HD2891, HD2961, HD2967, DBW90 × WH1105, UP2843 × HD3059, UP2843 × WH1105, UP2843 × HD2967, HPW211 × WH1105, HPW211 × HD2967, MACS6272 × HD3059, JOB666 × HD3059, JOB666 × WH1105, HD2329 × HD2967, WA×WING x HD3059, HD2891 × HD2967, HD2961 × WH1105
Relative injury (<50%)	JOB666, HD2967, DBW90 × WH1105, DBW90 × HD2967, UP2843 × HD3059, UP2843 × HD2967, WH1124 × HD3059, WH1124 × WH1105, WH1124 × HD2967, HPW211 × HD3059, HPW211 × WH1105, HPW211 × HD2967, WH1021 × HD3059, WH1021 × WH1105, CBW12 × HD3059, CBW12 × WH1105, CBW12 × HD2967, MACS6272 × HD3059, MACS6272 × WH1105, MACS6272 × HD2967, JOB666 × HD3059, JOB666 × WH1105, HD2329 × HD3059, HD2329 × HD2967, WA×WING x HD3059, WA×WING x WH1105, WA×WING x HD2967, HD2891 × HD3059, HD2891 × WH1105, HD2891 × HD2967, HD2961 × HD3059, HD2961 × WH1105, HD2961 x HD2967, UP2338 and DPW621-50
Grain yield (<50%)	DBW90, HD2329, UP2843 × HD2967, WH1124 × HD3059, WH1124 × HD2967, MACS6272 × WH1105, MACS6272 × HD2967, HD2891 × WH1105 and UP2338

was reflected for cross CBW12 X WH1105 at 15 days after anthesis (Table 2). Eight and sixteen genotypes exhibited <25% decrease in CTD at anthesis and 15 days after anthesis, respectively, and have considerable limit of heat tolerance. High CTD may indicate high demand for photo assimilation caused by rapidly filling kernels (i.e. sink strength) in physiologically adapted lines and is indicative of good vascular system capable of meeting evaporative demand and positively associated with yield under heat stress (Gutierrez *et al*., 2010; Bahar *et al.*, 2011).

Heat susceptibility index (HSI) is used to measure stress tolerance based on minimization of yield and its components, losses under late sowing compared to optimum sowing date. Low HSI (<1) is synonymous with higher stress tolerance. Lowest value (0.55) was estimated for cross WH1124 X HD2967 and maximum (1.42) for cross WAXWING X HD2967, showing that these were most tolerant and susceptible. In present study thirty two genotypes had less than 1 HSI, hence were adjudged as tolerant ones. A wide range of response to late sowing tolerance in wheat genotypes has been investigated by several workers (Nour *et al.*, 2011; Kushwaha *et al.*, 2011).

High temperature stress during reproductive stage of wheat has detrimental effect on 1000-kernel weight, grain weight spike^{-1} and number of grains spike^{-1}. Temperature stress on above traits was greater in susceptible genotypes while tolerant genotypes showed somewhat lower influence. The decrease in 1000-grain weight was less (2.10) for HD2891 so was considered most tolerant genotype and the highest percent detrimental effect (55.79) was for cross HD2961 X HD3059 so was considered most susceptible line for this trait. Sixteen genotypes had <25% reduction for it (Table 2). However, percent decrease in grain weight spike^{-1} varied from 19.55 (in HD2329) to 69.02 (in WAXWING X HD3059) adjudged as the most heat tolerant and susceptible genotypes, respectively. Peculiarly only one genotype HD2329 showed <25% reduction for this important trait.

The number of grains spike^{-1} is one of the most important morphological traits to assess tolerant and susceptible genotype with respect to heat stress and it showed similar trend. Temperature stress was found detrimental but the degree of influence was variable depending upon the genetic makeup of genotypes. Ironically only four genotypes *viz.*, HD2961 x HD2967 (-7.92%), HD2961 (-2.48%), UP2338 (-0.64%) and HD2891 x HD3059 (-0.60%) showed higher number of grain spike^{-1} under control conditions. Whereas, HPW211 X HD2967 was most susceptible genotypes having 25.79% reduction in grains spike^{-1}. However, 21 genotypes reflected less than 10% reduction in late sown over timely sown condition (Table 2). Similar results were reported by Cao *et al*. (2015) in reduction in 1000-kernel weight (TKW), grain weight spike^{-1} (GWS) and grain number spike^{-1} in Chinese wheat accessions under high-temperature conditions. Mohammadi (2012) also justified the same trend for these characters for bread wheat genotypes.

Heat stress during grain-filling stage is a major constraint in wheat yield and accelerates the rate of grain filling; whereas grain filling duration is shortened with resultant reduction in grain yield. However, in our study only one cross WAXWING x HD2967 had a negative association with stress (-2.15) and was considered as most tolerant against high temperature. Maximum percent decrease (26.74) in grain filling duration was found in UP2843 x HD3059, so was considered as most susceptible genotype. Genotypes WAXWING, CBW12, HD2329, DBW90 × HD3059, MACS6272 × WH1105, WAXWING × HD3059, WAXWING × WH1105, WAXWING × HD2967 and DPW6 21-50 had less reduction in grain filling duration than their counterparts under timely sown conditions.

Decrease in grain yield due to heat stress was from 28.4 (MASC6272) to 85.6% for WAXWING x HD2967 (identified as the most susceptible genotype). Nine genotypes namely, DBW90, HD2329, UP2843 × HD2967, WH1124 × HD3059, WH1124 × HD2967, MACS6272 × WH1105, MACS6272 × HD2967, HD2891 × WH1105 and UP2338 showed <50% decrease in grain yield so can be grouped as tolerant. Our findings are support earlier reports about high temperatures significantly shortening the grain filling period in different bread wheat genotypes owing to the interaction of each genotype with temperature (Dias and Lidon, 2009), grain yield, 1000-kernel weight and grain filling duration (Bala *et al*., 2014; Cao *et al*., 2015).

Conclusion: Even after several years of research on developing heat tolerant varieties in cereals, there is no direct selection criteria for heat tolerant plants. During recent years, new parameters for heat stress tolerance e.g., relative injury, chlorophyll content, CTD, heat susceptibility index, TKW, GFD, etc. have been developed. These parameters allow selection of best heat tolerant plant/lines in combination with morpho-physiological traits and these tools may assist conventional breeders to develop heat tolerant cultivars. On the basis of above traits it may be concluded that out of 54 wheat genotypes many genotypes showed tolerance against heat for different traits. However, the prime and ultimate objective of a breeding program is yield advantage. On the basis of grain yield DBW90, HD2329, UP2843 × HD2967, WH1124 × HD3059, WH1124 × HD2967, MACS6272 × WH1105, MACS6272 × HD2967, HD2891 × WH1105 and UP2338 wheat genotypes were identified as heat tolerant. Further investigation may be required to evaluate these tolerant lines at different locations for confirmation against heat tolerance and material may be utilized in further breeding program for crop improvement.

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