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RESEARCH ARTICLE

Evaluation of Selected Indian Wheat Cultivars for Identification of Tolerant Lines under Terminal Heat Stress

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In the present study, 102 Indian wheat cultivars were evaluated against terminal heat tolerance under normal and late sowing conditions at the ICAR-NBPGR Farm, New Delhi for two consecutive years in augmented block design. Observations were recorded for ten characters including phenological, yield and yield component traits. Genotype, season, and genotype by season interaction on grain yield and other traits were highly significant. Six genotypes, IC75240(C306); IC75215(PBW34); IC252632(HD2687); IC303070(HD2781); IC75226(WG377); IC75191(DL153-2) were common among the 30 top yielding genotypes across the environments. The Relative Heat Tolerance (RHT) ranged from 0.09% in genotype RAJ3765 (38) to -57.19% in genotype RAJ2184(70). Grain yield was positively correlated with days to spike emergence, days to physiological maturity, biological yield, tillers per plant, grains per spike and harvest index under normal sown condition, whereas it was associated additionally with thousand grain weight under late sown condition. The sufficient genetic variability recorded in the cultivars warrants for improving heat tolerance using combination breeding among these lines and further search for novel variation in untapped genepool.

Key Words: Cultivar, Grain yield, Heat tolerance, Terminal heat, Wheat

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops of the world, occupying 17% of crop acreage worldwide, feeding about 40% of the world population and providing 20% of total food calories and protein in human nutrition (Gupta *et al.,* 2008). India has witnessed a significant increase in total food grain production to the tune of 277.49 m tones with a major contribution of wheat 98.61 MT and productivity of 3172 kg/ha (2017). On the other hand, India is also the second largest wheat consumer after China. Global reports indicated a loss of 10-40% in crop production by 21st century because of the impact of climate change (Dutta *et al.,* 2013). Continual heat stress is a problem in about 7 m ha while terminal heat stress is a problem in about 40% of the irrigated wheat growing areas of the world (Joshi *et al.,* 2007). High temperature during grain filling stage in wheat is a major constraint and reduces the number of grains per ear, grain weight and subsequently the harvest index, resulting in reduced grain yield (Bansal *et al.,* 2013). The wheat crop in the northern plains are exposed to higher ambient temperatures at the time of grain filling, which significantly reduces the productivity. Modern wheat varieties are well adapted to controlled cultural practices, but they are generally not highly tolerant to extreme environmental stresses such as high temperature (Morgunov,1994). Heat tolerance thus should be essential characteristic of wheat cultivars to be developed. In general, photosynthetic rate is maximum at 20-22^{o}C and decrease abruptly at 30-32^{o}C. Heat stress injuries of the photosynthetic apparatus during reproductive growth of wheat diminish source activity and sink capacity which results in reduced productivity.

Late planting of wheat in India is common due to the intensive cropping system, which often delays the sowing of the wheat crop up to the middle of January, particularly in North East India where it is generally sown after harvest of paddy. As a result, a portion of maturity period of the crop is pushed forward and thus has to face higher temperature of the summer with hot spells often occurring at the time of maturity (Abrol *et al.,*1991). Wheat is a sink limited crop and high temperature during grain filling causes the production

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of shrivelled grains due to forced maturity (Savin and Slafer, 1991). Late sown crop gets exposed to mean maximum temperature of about 35°C during grain growth and causes yield reduction of 270 kg ha^{-1} per degree rise in temperature (Rane *et al.,* 2000). Higher temperatures affect all phases of crop growth, accelerate floral initiation, reduce the period of spike development, resulting in shorter spike with lower number of spikelet and adversely affecting pollen development. The duration of grain growth in the post-anthesis period is considered the most significant determinant of yield in wheat (Evans *et al.,* 1975). Both the day and night temperatures have a pronounced effect on the duration of grain filling. It could extend to over 80 days at 15 to 10 °C day/night temperature and is reduced to less than 40 days at 30/25°C. Higher temperatures further associated with limitation of water cause rapid shrinkage of grain volume. The knowledge from the germplasm evaluation will be of great significance for selection of heat tolerant genotypes and also for improving grain yield under high temperature. Keeping in view the above points an experiment was conducted to evaluate the yield potential of wheat cultivars under terminal heat stress.

Materials and Methods

The experiment was conducted at ICAR-NBPGR, Farm IARI, New Delhi during 2010-2011 and 2011-2012 with 102 wheat accessions (Indian cultivars) alongwith three checks (C306, HDR77 and WR544) in augmented block design under natural field conditions. The detail of the material is given in Table 1. The crop was sown on 20th November (normal sown) and 20th December (late sown) in both the years. Each accession was sown in three rows of 2 m row length and row to row distance was 25 cm. Recommended fertilizer dose (120 kg N: 60 kg P_2O_5: 40 kg K_2O in per hector area) were applied in field. Standard agronomic practices were followed for raising the crop. Observations were recorded for different phenophases, yield and yield attributes under normal and late sown conditions. The relative heat tolerance was calculated by the formula $(Yh - Yc)/Yc) \times 100\%$ as described by Haque *et al.* (2009), where Yh is grain yield in the heat stressed condition (late season), Yc is grain yield in the control (normal season). Augmented design analysis was performed using SAS 9.3 software and Pearson's correlation coefficients of the traits were obtained using SPSS version 16 software (SPSS, Chicago, Illinois, USA).

Results and Discussion

Effects of genotype, stress condition, year and their interaction

The effect of genotype was highly significant for all the traits except for biomass, spike length and grains per spike (Table 2). The effect of sowing condition was consistently highly significant for all the traits, whereas year was not significant for plant height. The effects (mean squares) of genotype and stress condition interaction and genotype × year × sowing condition were significant for days to physiological maturity and 1000 grain weight whereas genotype and year interaction was significant for biomass, tillers per plant and 1000 grain weight. Significant effects of genotype, environment and genotype × environment obtained are similar to the findings of Tadesse *et al.* (2012), Degewione *et al.* (2013) and Mohamed (2013). The effect of sowing condition (SC) was consistently much greater than its corresponding effects due to genotype, year and other interaction on each of the traits which revealed that most of the observed variations are mainly due to environmental effects, in this case high temperature during grain filling. Moreover, the effect of G was constantly greater than its corresponding effect of G×S except in biomass, spike length, grains per spike and 1000 grain weight (Table 2). Furthermore, the significant genotype by year interaction showed that each genotype responded differently to the two seasons in respect to biomass, tillers per plant and thousand grain weight. Sharma *et al.* (2010) also explained that wheat grain yield (GY) is highly influenced by production environments. More importantly, the significant genotypic effect obtained on GY and other traits revealed the existence of sufficient genetic variability among the wheat germplasm that can be exploited in the heat tolerance breeding programs.

Grain yield and other traits' performance of the wheat genotypes under normal and late sown condition

The mean performance of wheat genotypes for all the traits was significantly ($p \leq 0.05$) higher in the normal season than in the late season (Table 3) which is similar to numerous reports on impact of heat stress on wheat (Singh *et al.,* 2007; Rahman *et al.,* 2009). Exposure to higher temperatures can significantly reduce grain yield (Tewolde *et al.,* 2006). Kushwaha *et al.* (2006) recorded significantly less tillers/m^2, spike length and spikelets/ear under late planting in wheat. Singh

Table 1. List of wheat varieties studied for terminal heat tolerance

S.N.	Acc. ID	Variety	S.N.	Acc. ID	Variety	S.N.	Acc. ID	Variety
1	IC75240	C306 C	37	IC128152	CPAN1676	73	IC252927	RW346
2	IC128184	HDR77 C	38	IC443766	RAJ3765	74	IC75219	SKML1
3	IC296383	WR544 C	39	IC443767	RS31-1	75	IC393885	SONAK
4	IC536265	UP262	40	IC443769	UP115	76	IC145735	SONORA64
5	IC536269	UP368	41	IC443768	Utkalika	77	IC145753	UP2121
6	IC535622	WL1562	42	IC528119	DBW16	78	IC252954	UP2425
7	IC112258	VL401	43	IC116274	AJANTA	79	IC445595	UP2338
8	IC128150	BW11	44	IC144904	AKW381	80	IC75223	WL2265
9	IC128157	DL784-3	45	IC128155	SANGAM	81	IC113722	MOTIA
10	IC128175	HD2327	46	IC145280	HD1925	82	IC547563	DBW17
11	IC128180	HD2428	47	IC145283	HD1941	83	IC128167	HD2189
12	IC128195	HS240	48	IC145971	HD1949	84	IC443725	HD2285
13	IC128206	J24	49	IC145286	HD1981	85	IC75242	HD2329
14	IC128210	JU12	50	IC128209	HD1982	86	IC252612	HD2402
15	IC128213	K7410	51	IC252611	HD2177	87	IC443727	HD2643
16	IC128228	HI385	52	IC128168	HD2204	88	IC252632	HD2687
17	IC128261	VL404	53	IC128169	HD2236	89	IC290174	HD2733
18	IC128266	WH157	54	IC128170	HD2270	90	IC303070	HD2781
19	IC128267	WH283	55	IC128171	HD2278	91	IC443728	HD2824
20	IC128268	WH291	56	IC128172	HD2281	92	IC540910	HD2894
21	IC128270	WH416	57	IC128174	HD2307	93	IC574476	HD2967
22	IC128272	WH410	58	IC128178	HD2385	94	IC574388	HD2987
23	IC128273	WL711	59	IC128181	HD2501	95	IC296299	DBW14
24	IC252742	HW2004	60	IC122726	HUW468	96	IC75191	DL 153-2
25	IC252818	Lal Bahadur	61	IC252732	HUW510	97	IC138631	DL788-2
26	IC252951	UP2382	62	IC128211	K65	98	IC443722	DL803-3
27	IC290230	K9644	63	IC128212	K68	99	IC402064	HD2851
28	IC335540	Kharchia 65	64	IC128235	Narmada4	100	IC437081	HD2864
29	IC75234	HD2009	65	IC128244	PBW154	101	IC528118	HD2888
30	IC75212	PBW12	66	IC128666	PBW222	102	IC519900	HD2932
31	IC75226	WG377	67	IC420923	PBW226	103	IC309874	PBW343
32	IC144903	AKW1071	68	IC420925	PBW299	104	IC240798	PBW373
33	IC128177	HD2380	69	IC75215	PBW34	105	IC565811	PBW590
34	IC145420	HUW213	70	IC75389	RAJ2184			
35	IC443729	HD2833	71	IC410028	RAJ4037			
36	IC282300	K7903	72	IC252929	RW3016			

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Table 2. Combined analysis of variance of agronomical traits of 105 wheat varieties as influenced by date of sowing and year

Source	DSE	DPM	PH	BM	TP	SL	GS	GYP	TGW	**HI**
Gen	54.41*	60.61**	976.29**	6.30	25.49**	2.97	73.44	40.93**	529.80**	1470.38**
Yr	2460.56**	1541.33**	18.75	4318.27**	271.54**	33.78**	7458.39**	853.50**	579.61**	383.08**
SC	8225.06**	33849.48**	2862.37**	2255.71**	176.97**	184.61**	1764.19**	456.53**	18207.96**	212.02**
Gen*Yr	42.76	0.03	2.75	146.36**	6.21**	4.16	32.71	5.92	996.67**	28.17
Gen*SC	0.61	16.87*	73.73	1.38	4.54	1.79	83.25	0.02	456.47**	30.38
Gen*Yr*SC	34.98	40.35**	59.04	10.46	2.58	0.92	62.04	0.11	44.05*	11.06

Days to spike emergence (DSE); days to physiological maturity (DPM); plant height (PH); biological yield per plant (BYP); tillers per plant(TP); spike length(SL); grains per spike (GS); grain yield (GYP) 1000-grain weight (TGW); and harvest index (HI).

Table 3. Mean performance of wheat cultivars for agronomical traits under timely and late sown conditions averaged across years

Traits	Mean performance		CV(%)		% Reduction
	Timely sown	Late Sown	Timely sown	Late Sown	
DSE	91.48±0.31	82.74±0.27	5.11	4.83	9.56
DPM	136.65±0.23	118.95±0.14	2.47	1.82	12.95
PH	96.57±0.80	91.59±0.81	12.23	13.06	5.16
BYP	21.87±0.39	17.41±0.42	26.26	35.31	20.40
TP	6.35±0.10	5.09±0.09	23.29	27.88	20.00
SL	12.92±0.11	11.61±0.09	12.61	12.15	10.14
GS	56.18±0.81	52.20±0.69	21.40	19.63	7.09
GYP	8.74±0.17	6.71±0.17	29.76	39.01	23.20
TGW	43.33±0.47	30.53±0.49	15.97	23.85	29.54
HI	39.84±0.38	38.43±0.42	14.33	16.16	3.55

Days to spike emergence (DSE); days to physiological maturity (DPM); plant height (PH); biological yield per plant; g(BYP); tillers per plant (TP); spike length, cm (SL); grains per spike (GS); grain yield; g (GYP) 1000-grain weight; g (TGW); and harvest index % (HI).

et al. (2016) reported general reduction in the values of all traits under late planting condition as compared to normal planting due to temperature stress. The higher temperature associated with the late season as evidently reported in the meteorological data (Fig. 2) impacted heat stress on the crop leading to the greater significant reduction in all the traits especially on thousand grain weight (29.54%) and grain yield (23.50%). In late season 1, grain yield ranged from 2.1 in genotype Lal Bahadur and PBW12 to 10.3 g in genotype HD2687, while in late season 2 it extended from 4.3 in genotype Lal Bahadur to 15.3 g in genotype HD2687. It ranged from 2.8 g in genotype Lal Bahadur to 13.2 g in genotype HD2189 in the normal season 1, whereas it stretched from 5.0 g in genotype Lal Bahadur to17.9 g in genotype HD2687 in the normal season 2. Prasad *et al*. (1999) confirmed that heat stress also imparts to the decreased seed filling duration thus resulting in production of smaller seed size. Mitchell and Jones (2005) found five climatic variables available which included cloud cover, diurnal temperature range, precipitation, temperature and vapour pressure. Janjua *et al.* (2010) analyzed the impact of climate change on wheat production and concluded that higher temperature affected the growth process of wheat negatively thus resulting in severely hampered productivity. A considerable decrease in the number of grains was observed on exposure of floral initiation stage and spikelet development to high temperature conditions thus adversely impacting the maximum yield potential. Sink strength and source capacity are considered two vital factors in modifying the grain yield and quality of wheat genotypes exposed to chronic heat as well as a heat shock reported by Yang *et al.* (1996). Kumar *et al.* (2013) recorded reduction in biomass, grain growth and grain yield are the consequence of impaired biological processes at cellular, molecular and organ level under thermal stress.

Table 4. Thirty top yielding genotypes in each of the environment (L1: late sown-first year; N1: normal sown-first year; L2: late sown-second year; N2: normal sown-second year). Genotypes in Bold indicates stable genotypes across the environments

Sl. No.	Gen (L1)	GYP (g)	Sl. No.	Gen (N1)	GYP (g)	Sl. No.	Gen (L2)	GYP (g)	Sl. No.	Gen (N2)	GYP (g)
88	**IC252632, HD2687**	10.30	83	IC128167, HD2189	13.20	**88**	**IC252632, HD2687**	15.33	**88**	**IC252632, HD2687**	17.93
84	IC443725, HD2285	9.90	**88**	**IC252632, HD2687**	13.10	**69**	**IC75215, PBW34**	15.14	**69**	**IC75215, PBW34**	15.97
54	IC128170, HD2270	9.50	70	IC75389, RAJ2184	12.70	64	IC128235, Narmada4	13.16	64	IC128235, Narmada4	15.44
69	**IC75215, PBW34**	9.50	103	IC309874, PBW343	12.50	102	IC51990, HD2932	11.89	10	IC128175, HD2327	15.24
83	IC128167, HD2189	9.30	64	IC128235, Narmada4	11.75	2	IC128184, HDR77	11.87	92	IC540910, HD2894	14.52
85	IC75242, HD2329	9.20	101	IC528118, HD2888	11.30	10	IC128175, HD2327	11.45	70	IC75389, RAJ2184	14.33
74	IC75219, SKML1	9.00	86	IC252612, HD2402	11.25	**96**	**IC75191, DL153-2**	11.43	9	IC128157, DL784-3	14.04
90	**IC303070, HD2781**	8.60	**31**	**IC75226, WG377**	11.00	104	IC240798, PBW373	11.27	103	IC309874, PBW343	13.49
1	**IC75240, C306**	8.20	92	IC540910, HD2894	10.90	92	IC540910, HD2894	11.14	91	IC443728, HD2824	13.39
17	IC128261, VL404	7.55	**69**	**IC752215, PBW34**	10.83	36	IC282300, K7903	11.08	**90**	**IC303070, HD2781**	13.21
27	IC290230, K9644	7.00	2	IC128184, HDR77	10.75	53	IC128169, HD2236	11.06	36	IC282300, K7903	12.99
31	**IC75226, WG377**	7.00	9	IC128157, DL784-3	10.65	17	IC128261, VL404	11.01	17	IC128261, VL404	12.37
46	IC145280, HD1925	6.85	15	IC128123, K7410	10.50	87	IC443727, HD2643	10.90	11	IC128180, HD2428	12.21
96	**IC75191, DL153-2**	6.85	**96**	**IC75191, DL153-2**	10.50	97	IC138631, DL788-2	10.80	101	IC528118, HD2888	12.20
53	IC128169, HD2236	6.80	36	IC282300, K7903	10.30	5	IC536269, UP368	10.74	53	IC128169, HD2236	12.07
35	IC443729, HD2833	6.65	102	IC519900, HD2932	10.30	89	IC290174, HD2733	10.69	102	IC519900, HD2932	11.99
77	IC145753, UP2121	6.50	**90**	**IC303070, HD2781**	10.25	**31**	**IC75226, WG377**	10.65	78	IC252954, UP2425	11.83
82	IC547563, DBW17	6.50	54	IC128170, HD2270	10.20	**90**	**IC303070, HD2781**	10.64	104	IC240798, PBW373	11.82
5	IC536269, UP368	6.45	74	IC75219, SKML1	10.20	15	IC128213, K7410	10.61	**31**	**IC75226, WG377**	11.81
68	IC420925, PBW299	6.40	24	IC252742, HW2004	10.05	**1**	**IC75240, C306**	10.42	89	IC290174, HD2733	11.81

Sl. No.	Gen (L1)	GYP (g)	Sl. No.	Gen (N1)	GYP (g)	Sl. No.	Gen (L2)	GYP (g)	Sl. No.	Gen (N2)	GYP (g)
75	IC393885, SONAK	6.25	87	IC443727, HD2643	9.90	54	IC128170, HD2270	10.33	**1**	**IC75240, C306**	11.61
60	IC122726, HUW468	6.05	85	IC75242, HD2329	9.85	78	IC252954, UP2425	10.21	2	IC128184, HDR77	11.60
104	IC240798, PBW373	6.00	93	IC574476, HD2967	9.70	39	IC443767, RS311	10.10	63	IC128212, K68	11.51
95	IC296299, DBW14	5.95	45	IC128155, SANGAM	9.50	65	IC128244, PBW154	10.00	20	IC128268, WH291	11.48
50	IC128209, HD1982	5.90	63	IC128212, K68	9.40	103	IC309874, PBW343	9.83	**96**	**IC75191, DL153-2**	11.46
43	IC116274, AJANTA	5.80	84	IC443735, HD2285	9.25	83	IC128167, HD2189	9.76	19	IC128267, WH283	11.43
52	IC128168, HD2204	5.75	10	IC128175, HD2327	8.95	20	IC128268, WH291	9.51	87	IC443727, HD2643	11.37
89	IC290174, HD2733	5.75	11	IC128180, HD2428	8.95	27	IC290230, K9644	9.46	8	IC128150, BW11	11.34
67	IC420923, PBW226	5.70	**1**	IC75240, C306	8.90	19	IC128267, WH283	9.41	15	IC128213, K7410	11.31
39	IC443767, RS311	5.65	82	IC547563, DBW17	8.80	46	IC145280, HD1925	9.24	24	IC252742, HW2004	11.26

Table 4 showed the top thirty high yielding genotypes in each of the four environments (late season 1, late season 2, normal season 1, and normal season 2) with mean grain yield of 5.1, 8.4, 7.7, and 9.9 g in the four environments, respectively. These genotypes yielded above 5.65 g per plant under late planted condition and above 9.24 g under non stress condition. Among them, six genotypes viz.,1-IC75240 (C306), 69- IC75215(PBW34), 88-IC 252632(HD2687), 90-IC303070 (HD2781), 31-IC75226(WG377), 96-IC75191(DL153-2) were stable for grain yield in all the environments, hence recommended for both heat favourable and heat stressed environments. The stability of these six genotypes were due to stability in different yield components. For example, genotype 1-IC75240 (C306) was stable in terms of plant height, tillers per plant, spike length, grains per spike and harvest index as evident by % reduction less than 10% for these traits (Table 5). Genotype 31-IC75226(WG377) had stable spike length and thousand grain weight and harvest index, whereas genotypes 69-IC75215(PBW34) had moderate reduction for all the traits except thousand grain weight. Genotypes 88-IC252632(HD2687), 90-IC303070 (HD2781) and 96-IC75191(DL153-2) had less reduction for plant height, spike length and grains per spike. The combination breeding can be opted for suitably combining the component traits. Gavhane *et al.* (2016) identified genotypes NIAW2972, NIAW34 and HI977 as terminal heat tolerant to be used in the crossing programme for developing terminal heat tolerant variety/line. Similarly, tolerant genotypes like DBW14, RAJ3765, HD2643 and HALNA performed physiologically better in terms of higher membrane stability index (MSI), chlorophyll content, photosynthesis rate (Pn), harvest index under heat stress conditions by Nagar *et al.,* 2015. Al-Otayk (2010) argued that a genotype with stable and high yield across different environments would be a more suitable cultivar and perhaps a donor parent for further breeding for heat tolerance. Specifically, genotypes 69- IC75215(PBW34); 88-IC252632(HD2687) were consistently among the top five yielding genotypes in the two late seasons will be ideal for heat stressed environments, while genotypes 88-IC252632(HD2687) and 64-IC128235(NARMADA4) that were consistent in the two normal seasons are recommended for heat favourable (non-stressed) condition only. The genotype

Table 5. Percent reduction of stable wheat cultivars under terminal heat stress condition over the years for agronomical traits

Acc No	1	31	69	88	90	96
Acc ID/Cultivar	IC75240 (C-306)	IC75226 (WG377)	(IC75215) PBW34	IC252632 (HD2687)	IC303070 (HD2781)	IC75191 (DL1532)
Source/ Pedigree	UP, RGN/CSK3//2*C591/3/ C217/N14//C281	UP (WG 143 x USA-255) x PV 18	PAU, Anhinga S x Flamingo S	Delhi CPAN 2009/HD-2329 (CPAN 2009 =KVZ/TO-RIM//POTAM/ANA)	Delhi BOW/C 306//C 591/HW 2004	UP TANORI 71/NP 890
Traits	**Percent reduction**					
DSE	10	7.1	11.68	9.28	11.83	12.17
DPM	12.83	14.65	14.64	10.7	12.22	14.03
PH	6.6	-3.65	8.65	2.34	1.08	-1.68
BYP	15.74	17.87	9.19	20.84	17.35	29.05
TP	25.37	34.48	5.56	4.35	8.33	22.22
SL	8.66	9.71	10.66	7.66	9.81	5.68
GS	2.49	11.04	-3.23	6.8	3.33	-5.38
GYP	10.09	22.62	8.06	17.4	17.99	16.76
TGW	26.4	9.93	21.11	35.96	30.5	50
HI	-7.12	6.39	-1.14	11.09	0.73	-16.45

Days to spike emergence (DSE); days to physiological maturity(DPM); plant height(PH); biological yield per plant; g(BYP); tillers per plant(TP); spike length; cm(SL); grains per spike (GS); grain yield; g (GYP) 1000-grain weight; g (TGW); and harvest index,% (HI).

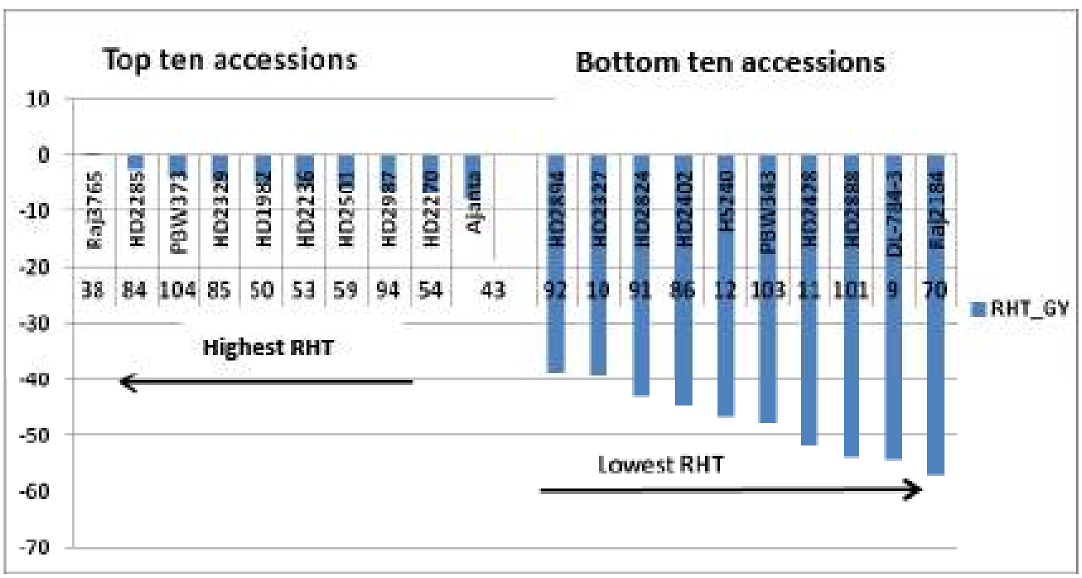

Fig. 1. Relative heat tolerance for grain yield (%) of the wheat germplasm under late sown condition with respect to normal sown

88-IC252632(HD2687) can be recommended for both heat stressed environments and heat favourable (non-stressed) conditions.

Relative heat tolerance (RHT) of wheat germplasm

Figure 1 showed the grain yield plasticity/stability of the genotypes in the late seasons (heat stressed environments) with respect to their corresponding normal seasons (control/heat favourable environments). The RHT ranged from 0.09% in genotype RAJ3765(38) to -57.19% in genotype RAJ2184(70). None of the top ten and bottom genotypes were found among six stable and common genotypes high yielding genotypes under timely and late sown conditions. However, genotype no. 104-IC240798(PBW373), 53-IC128169(HD2236) and 54-IC128170(HD2270) were among top thirty

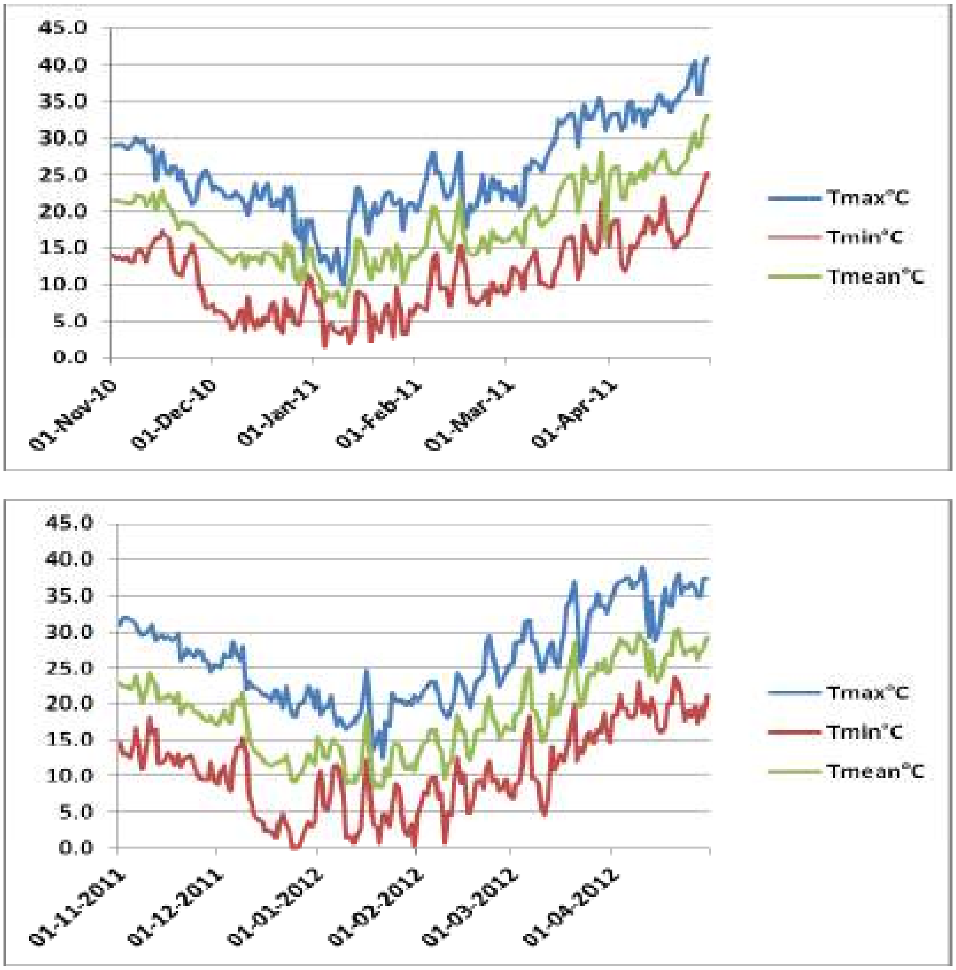

Fig. 2. Minimum, maximum and mean temperature(°C) during 1st and 2nd years of screenin

under three environments. 104-IC240798(PBW373) and 53-IC128169(HD2236) were superior under all environments except non-stress condition during first year. 54-IC128170(HD2270) was superior under all environments except non-stress condition during second year. 84-IC443725 (HD2285) and 85-IC75242(HD2329) were superior during first year evaluation only. Rehman *et al.* (2009) previously reported that wheat planted in the late season suffered drastic yield loss which exceeded 50%. Top ten tolerant genotypes could be genetic sources for heat tolerance breeding program. Wheat has the tendency to adopt diverse types of responses to temperature stress as well as a heat shock by developing thermo-tolerance for the enhancement of the grain quality and yield (Iqbal *et al.,* 2017). End-of-season or 'terminal' heat stress is also likely to increase for wheat in the near future (Semenov, 2009) due to increase in global warming. Therefore, breeding for heat tolerance in wheat is a major global concern (Paliwal *et al.,* 2012).

Association of the grain yield with other traits

Days to spike emergence (DSE) was significantly positively correlated with days to physiological maturity (DM), biological yield per plant, tillers per plant, spike length, grains per spike, grain yield per plant under normal sown condition, whereas under late sown condition, association was found with days to physiological maturity, biological yield per plant, tillers per plant, grains per spike, grain yield per plant and harvest index. Plant height was correlated with biomass under normal sown condition. Grain yield was positively correlated with days to spike emergence, days to physiological maturity, biological yield, tillers per plant, grains per spike and harvest index under normal sown condition, whereas it was associated additionally with thousand grain weight under late sown condition (Table 6). Thousand grain weight was positively correlated with grain yield under late sown condition. Grain yield

Table 6. Pearson correlation of grain yield and other studied traits of wheat cultivars under normal (below diagonal) and late sown conditions (above diagonal)

	DSE	DPM	PH	BYP	TP	SL	GS	GYP	TGW	HI
DSE	1	0.67**	0.18	0.30**	0.26**	-0.01	0.32**	0.37**	0.09	0.25*
DPM	0.59**	1	0.31**	0.27**	0.38**	0.04	0.38**	0.33**	0.08	0.21*
PH	-0.02	0.10	1	0.26**	0.24*	-0.16	-0.02	0.19	0.06	-0.03
BYP	0.39**	0.43**	0.05	1	0.54**	0.00	0.36**	0.89**	0.34**	0.10
TP	0.32**	0.38**	-0.05	0.66**	1	0.04	0.20*	0.48**	0.17	0.08
SL	0.21*	0.09	-0.14	0.17	0.08	1	0.43**	-0.02	-0.10	-0.06
GS	0.31**	0.18	-0.10	0.31**	0.07	0.41**	1	0.41**	-0.05	0.24*
GYP	0.36**	0.35**	0.00	0.91**	0.56**	0.07	0.29**	1	0.37**	0.53**
TGW	-0.25	-0.11	0.11	-0.23	-0.24	-0.35	-0.29	-0.14	1	0.19
HI	0.00	-0.06	-0.10	0.05	-0.06	-0.19	0.04	0.44**	0.20*	1

Days to spike emergence (DSE); days to physiological maturity (DPM); plant height (PH); biological yield per plant; g(BYP); tillers per plant (TP); spike length; cm(SL); grains per spike (GS); grain yield; g (GYP) 1000-grain weight; g (TGW); and harvest index % (HI).

(GY) significantly correlated positively with DSE, and DM indicating that longer the maturation of the crop especially if the grain filling duration is prolonged, the more the increase in the GY. Although early maturing germplasm escape heat stress and ideally suitable for heat stressed conditions (Mondal *et al.,* 2015), but based on this study these genotypes may not produce more seed yield in comparison to medium to late maturing germplasm. This suggests that days to maturity could be favourably selected for enhanced grain yield, except under intense and protracted heat stress especially during the late growing season. Menshawy (2007) also indicated that early maturing cultivars are preferable to escape heat stress injury that occurs at the end of the growing season. The correlation showed that medium maturing genotypes are ideal for heat stressed as well as heat favourable environments (non-stressed condition). These early maturing genotypes possess earliness *per se* genes that hasten the developmental and flowering time under heat stressed environments as soon as vernalization and photoperiod requirements have been fulfilled. Gavhane *et al.* (2016) reported positive correlation of yield under stress environment (<0.05) ($r=0.95$) association with that of non stress environment.

The significant impact of the heat stress on yield performance of the wheat genotypes underlines the urgent need for breeding for heat tolerance. The improved and released cultivars certainly have the good amount of genetic variability for heat tolerance that can be harnessed for yield improvement of wheat. Further significant genotypic variation present in cultivars will also guide for search of novel genotypes in unexplored germplasm that can be exploited in the heat tolerance breeding programs. Based on this study, genotypes with stable yield performance under stressed as well as non-stressed environments; 1- IC75240(C306); 69-IC75215(PBW34); 88-IC252632(HD2687); 90-IC303070(HD2781); 31-IC75226(WG377); 96-IC75191(DL153-2) are recommended for both heat favourable (non-stressed condition) /normal sown) and heat stressed (late sown) environments. Also, genotypes 104- IC40798, (PBW373); 53-IC128169(HD2236) and 54-IC128170(HD2270) that were among the 10 heat tolerant genotypes based on relative heat tolerance were among top thirty high yielders under three environments, therefore could be suggested as donor lines for heat tolerance breeding program.

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