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EVALUATION OF EXOTIC SPRING WHEAT (*TRITICUM AESTIVUM* L.) GENOTYPES FOR HEAT STRESS TOLERANCE

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ABSTRACT

Present research was carried out at Wheat and Barley Research Institute, Tandojam during 2017-18. The experiment was set on two different sowings dates viz., 19th November (Normal) and 19th December (Late) for ten exotic spring wheat lines. The analysis of variance for normal sowing for genotypes, treatments and genotype x interaction revealed highly significant differences at 0.01% probability level for all the attributes. The mean performance displayed that under normal conditions, HTWYT/1 produced the most dwarf plants and maximum chlorophyll content. Maximum spike length, spikelets/spike, biological yield/plant and harvest index were seen in local check (Sindhu) and 1000 grain weight (g) was recorded in HTWYT/06. Whereas more tillers/plant, number of spikelets/spike, grain yield/plant, biological yield/plant and relative water content were noticed in HTWYT/9 at normal sowing date. HTWYT/8 demonstrated more grains/spike; however, more biological yield/plant and harvest index was measured in HTWYT/7 under timely sowing conditions. In case of heat stress conditions, HTWYT/1 produced the shortest plants, maximum grain yield/plant and chlorophyll content. HTWYT/9 revealed the most number of fertile tillers/plant, biological yield plant^{-1} and relative water content, HTWYT/3 showed the longest spikes, Sindhu expressed maximum spikelets/spike, HTWYT/4 manifested number of grains per spike, HYWYT/6 showed the most grain yield/plant, 1000-grain weight, HTWYT/2 produced maximum harvest index in high temperature conditions. In case of correlation, almost all traits exhibited positive and highly significant associations with one another. The genotypes (HYWYT/1, HYWYT/6 and HYWYT/9) performed best in both heat stress and non-stress conditions were observed to be heat insusceptible for most of the traits.

KEYWORDS: *Triticum aestivum*; harvest index; relative water content; biological yield; Pakistan

INTRODUCTION

Hexaploid wheat (*Triticum aestivum* L.) is extremely sensitive to high temperature resulting in a lot of losses in yield at all stages because of being metabolic pathways affected (Akter and Islam, 2017). Hexaploid wheat is the most vital crop in the world in terms of area harvested. It gives about 20% of the total dietary calories and proteins world-wide (FAO, 2018). It was guessed by FAO that annual cereal production has to be grown by approximately 1 billion tonnes in order to feed 9.1 billion people by 2050 (Poudel and Poudel, 2020). Because of its versatility in adaptation and utility of various ways, wheat is grown in more than 44 countries at global level (Mecha *et al.,* 2017). Wheat has a unique position among cereal crops, mostly attributable to the reason that grains retain protein with exceptionally good chemical and physical properties (Bhandari *et al.*, 2016).

This grain crop is the leading food crop of the worldly farming and occupies the second most important place in staple food next to rice, consumed by nearly 35% of the people of the globe. The crop ranks first in terms of harvested area covering 223.67 million hectares and is the second most produced crop with a global production of 735.3 million tons per year (USDA, 2017). It has been predicted that the population of the world would rise to over 9 billion by the year of 2050 (United Nations, 2015). This growth in population will increase the demand of this crop by 60% compared with current years. China is the largest producer of wheat with 17.6% production in the world having planted about 222 million hectares under wheat cultivation (CIMMYT, 2016).

A recent investigation predicted that the yield of wheat will decline by 4.1% to 6.4% due to each global rise of 1ºC in the presence of a progressive climate change

(Liu *et al.*, 2016). It is urgent to increase the wheat crop in Pakistan as well as in the globe by increasing the number of heat tolerant varieties. It is cultivated in almost in all parts of our country under irrigated conditions with 70% and rainfed conditions with 30%, respectively**.** Pakistan is mainly an agricultural country, where 70% of the population is directly dependent on agriculture, 16% of the population is indirectly dependent on agriculture. It shares 9.6% with the value addition in agriculture and 1.9% with national GDP (GoP, 2017).

Heat stress is one of the main abiotic stresses which limit yield in the bread wheat. Thus, selection, improvement and development of heat stress tolerant genotypes with high grain yield has been one of the most chief objectives in the wheat genetic breeding science (Kaushal *et al.*, 2016). It has been reported by a several researchers and scientists about high temperatures being some major problems in the form of negative effects on the crop wheat (Kumari *et al.*, 2013; Akter and Islam, 2017) and unexpected changes in time and space can lead to reduced plant growth and productivity. Genetic analysis provides a guideline to the breeder in evaluating and selecting the elite and desirable parents to be used in the formulation of systemic breeding program for improving quantitative traits such as yield and yield components (Morgan *et al.*, 2018). Therefore, the success of a breeding program largely depends on the choice and exploitation of potential parental genotypes for hybridization, followed by selection for favourable gene combinations (Naimat-Ullah *et al.*, 2018). Keeping in view the above discussion current study was conducted to evaluate exotic spring wheat genotypes for heat stress tolerance.

MATERIALS AND METHODS

This study was performed at normal sowing date and late sowing date during rabi season 2017-18 at Wheat and Barley Research Institute, Tandojam. The experiment was conducted in Randomized Complete Block Design with four replications. The trial was consisted of four rows with 11 feet length for each genotype per replication. The plants were kept from each other at the distance of 20 cm, whereas 30 cm distance was maintained between row to row. Ten exotic spring wheat genotypes including one local check were put into practice i.e. HTWYT/1, HTWYT/2, HTWYT/3, HTWYT/4, HTWYT/5, HTWYT/6, HTWYT/7, HTWYT/8, HTWYT/9 and Sindhu (Local check). The evaluated morphological and physiological attributes were plant height (cm), Tillers / plant, spike length (cm), spikelets / spike, grain / spike, grain yield / plant (g), seed index (1000-grain weight g), biological yield/plan (g), Harvest index (%), relative water content (%) and chlorophyll content (%) were taken by standard procedures.

Statistical analysis

The collected data were subjected to the statistical analysis as suggested by Gomez and Gomez (1984). The means of genotypes for all the traits were compared by using the least significant difference (LSD) test at 5% probability level as suggested by Steel *et al.* (1997). Correlation studies were determined according to Snedecor and Cochran (1980).

RESULTS AND DISCUSSION

Analysis of variance

The mean squares from analysis of variance for two sowing dates viz, normal and late for ten advanced lines are depicted in (Table 1). The analysis for genotypes in the conditions of normal sowing date showed highly significant at $p \leq 0.01$ for plant height, number of tillers/ plant, number of grains/spike, number of spikelets/ spike,1000-grain weight (g), biological yield/plant (g),

Table 1. Mean squares from analysis of variance for various morpho-physiological traits of advance wheat lines grown under normal and late sowing dates

Traits	Source of variation				
	Replication (D.F = 3)	Genotype (G) (D.F = 09)	Treatment (T) (D.F = 1)	G x T (D.F = 09)	Error (D.F = 54)
Plant height	17.36	99.55**	1442.45**	11.44**	2.84
No. of tillers/plant	2.28	2.08**	30.28**	0.33 N.S	0.33
Spike length	0.19	0.18*	13.53*	0.19*	0.23
No. of spikelets/spike	0.22	2.14**	69.61*	0.91**	0.3
No. of grains/spike	78.06	23.06**	2531.25**	82.82**	3.20
1000-grain weight	14.57	53.76**	114.91**	0.30*	3.51
Grain yield	1.30	5.02**	1415.82**	0.48*	0.50
Biological yield	2.08	15.76**	1362.74**	1.98*	1.63
Harvest index	0.60	2.63*	692.25**	2.07*	1.06
Relative water content	50.70	255.12**	121.45**	0.73*	4.11
Chlorophyll content	15.23	52.46**	332.19**	1.68*	2.32

** = Highly significant at 1%

grain yield/plant (g), relative water content (%) and chlorophyll content (%). Whereas, spike length (cm) and harvest index (%) revealed significant differences at p≤0.05 probability level. For the treatment all the traits were highly significant at p≤0.01probobility level except spike/length and spikelets/spike which were significant. In case of the interaction, all the traits were highly significant at p≤0.01 probability level for plant height (cm), number of spikelets/ spike and number of grains/spike and the rest of the traits were significant at p≤0.05 probability level. However, number of tillers/ plant was non-significant. The use of morphological and physiological traits were also reported by Pooja and Munjal (2019) to improve wheat grain yield in diverse environmental conditions. Thapa *et al.* (2019) obtained highly significant results due to treatments for all the traits in normal as well as late environments. Ribeiro *et al.* (2019) developed a study with an objective of identifying thirty-six promising populations for tolerance to heat stress in which he sought genetic variability for heat tolerance among the wheat populations demonstrating the possibility of selecting heat stress-tolerant lines of wheat for the coming breeding in the world.

Mean performance of wheat genotypes grown under normal sowing and late sowing

Plant height (cm): Under normal sowing date, plant height (cm) ranged from 85.00 to 97.95 cm, whereas in late sowing, it ranged from 78.75 to 87.50 cm. The undesirable maximum plant height was recorded under normal conditions in HTWYT/7 (97.95 cm) while the minimum height and desirable height was recorded in genotype HTWYT/1(85 cm). In terms of late sowing, the maximum undesirable plant height was exhibited in HTWYT/7 (87.5 cm), however the minimum and desirable plant height was recorded in the HTWYT/1 (78.75 cm). Check genotype, Sindhu expressed 87.47 and 82.15 cm height under normal and late sowing conditions, respectively (Table-2.). It has been suggested by Irfan and Ali (2018) that heat stress tolerant varieties should have been used in plant breeding programs for developing different wheat varieties having heat stress tolerance at different stages of plant growth. It was also found by Noorka *et al.* (2018) that the development of short stature varieties has been desired due to lodging problems. By introducing short stature varieties, grain yield was increased as a result of shorter vegetative phase and longer reproductive phase during past green revolution under both normal and late sowing conditions. Bala and Sikder (2018) found the decrease in plant height due to short period of growth and photosynthesis imposed by heat stress in a late sown environment.

Tillers/plant: Under timely sowing conditions, the range of tillers/plant were recorded from 8.50 to 6.50, while in heat stress environments, it was observed from 6.90 to 5.45 tillers/plant (Table 2). On an average, the genotypes produced 7.71 tillers/plant on the date of normal sowing and 5.94 tillers/plant on the date of late sowing. The reduction of 17.03% was noticed among the genotypes due to heat stress. The lowest decline in tillers/plant was observed in Sindhu (Local check) with the mean values of 10.49% followed by HTWYT/5 (12.23%), respectively, under non-stress conditions. The highest reduction nonetheless was recorded in HTWYT/8 (27.33%) followed by HTWYT/2 (21.12%) under stress conditions. The maximum tillers/ plant was expressed in HTWYT/9 (8.50) and the least number of tillers was manifested in HTWYT/4 (6.50) in

Table 2. Mean performance of plant height (cm) and tillers/plant of advance wheat lines grown under normal and late sowing dates

Genotypes	Plant height (cm)		R.D.%	Tillers/plant		R.D.%
	Normal sowing	Late sowing		Normal sowing	Late sowing	
HTWYT/1	85.00	78.75	7.35	7.55	6.10	19.20
HTWYT/2	95.65	86.65	9.40	7.10	5.60	21.12
HTWYT/3	97.45	87.45	10.26	6.75	5.60	17.03
HTWYT/4	95.15	85.15	10.50	6.50	5.45	16.15
HTWYT/5	96.12	86.55	9.95	6.95	6.10	12.23
HTWYT/6	93.60	83.95	10.30	6.80	5.75	15.44
HTWYT/7	97.95	87.50	10.66	6.63	5.80	12.51
HTWYT/8	96.60	85.90	11.07	7.50	5.45	27.33
HTWYT/9	89.62	85.65	4.42	8.50	6.90	18.82
SINDHU (Check)	87.47	82.15	6.08	7.43	6.65	10.49
Mean	93.46	85.07	17.45	7.71	5.94	17.03
LSD (5%) (G)	1.77			0.58		
LSD (5%) (T)	0.79			0.25		
LSD (5%) (G x T)	2.50			0.82		

R.D = Relative difference between normal and late sowing treatments, Late sowing means heat stress

normal environments. Yet in abnormal environments, the maximum tillers/ plant was recorded in HTWYT/9 (6.90) and minimum tillers per plant in HTWYT/8 (5.45). Bheemanahalli *et al*. (2020) also experimented with wheat genotypes which contrasting phenotypes in their study. Sharma *et al.* (2019) concluded that the main cause of reduction in yield and yield-related traits during stress was the production of sterile tillers under different environmental conditions like timely and late sowing conditions.

Spike length (cm): Variable response of wheat genotypes was observed for spike length under heat stress in natural field conditions. The range of spike length was measured from 12.90 to 12.28 cm under normal sowing, while the range of 12.30 cm to 11.50 cm for spike length was noted in late sowing (Table 3). The lowest decline in HTWYT/9 (3.39 %) and the highest reduction in HTWYT/7 (9.44%) appeared in heat stress condition. The longest and the shortest spikes were recorded in Sindhu (Local check) (12.90) and HTWYT/6 (12.28) under normal sowing. However, in high temperature environmental conditions, HTWYT/2 (12.30) and HTWYT/7 (11.50) were the only genotypes to produce the longest and shortest spikes for the character spike length. Low reduction under heat stress was in spike length was also observed by Saha *et al*. (2020). These results were in paradox with Asmaa *et al.* (2019) who suggested that enhancing heat tolerance could be approached by increasing the assimilating area of the plant after anthesis and grains per spike. Iqbal *et al.* (2017) further added that first approach could be implemented through selection for spike length since the spike is the only organ that lasts greener than the leaves for longer duration after anthesis.

Spikelets/spike: The results for different sowing dates for the number of spikelets/spike are presented in Table 3. The range of spikelets/spike assorted from 20.50 to 18.05 and 17.74 to 16.60 under both normal and late sowing conditions (Table 5). The average production of this trait was 19.03in normal sowing and 17.18under late sowing. The reduction of 9.65% averagely was noticed among the genotypes due to heat stress. The lowest and highest drop in spikelets/spike was observed in HTWYT/4 (5.04%) and HTWYT/7 (14.35%) in heat stress conditions. The maximum and minimum spikelets/spike were counted in Sindhu (Local check) (20.50 %) and HTWYT/1 (18.05 %) under normal sowing, yet under late sowing, genotypes HTWYT/9 (17.74%) and HTWYT/2 (16.60%) manifested more and less number of spikelets per spike at late sowing conditions. Such results were reported by Singh *et al.* (2020) in which they informed that grain yield increased due to increase in spikelets/spike. For spikelets/spike, reduction at high level had also been expressed by Perdomo *et al.* (2017) in high temperature and added.

Grains/spike: Under normal sowing, the range of grains/spike was between 73.38 and 62.25 kernels, while at late sowing it was from 61.30 to 48.85 grains/ spike (Table 4) with the average of 66.71 and 55.46 grains/spike. The average reduction of 16.54 % was noticed among the genotypes due to late sowing. The lowest decrease in HTWYT/4 (1.52 %) and HTWYT/5 (9.63 %) was observed respectively, under late sowing. The highest reduction nonetheless was recorded in HTWYT/8 (33.42 %) followed by HTWYT-9 (23.64 %) in late sowing. The highest grain number was counted in HTWYT/8 (73.38) and the lowest grains were counted in HTWYT/4 (62.25) under normal sowing. While at late sowing, maximum grains/spike was recorded in line HTWYT/4 (61.30) and minimum

Table 3. Mean performance of spike length (cm) and spikelets/spike of advance wheat lines grown under normal and late sowing dates

Genotypes	Spike length (cm)		R.D.%	Spikelets/spike		R.D.%
	Normal sowing	Late sowing		Normal sowing	Late sowing	
HTWYT/1	12.63	11.65	7.75	18.05	17.00	5.81
HTWYT/2	12.80	12.30	3.90	18.85	16.60	11.93
HTWYT/3	12.65	11.95	5.53	18.50	17.10	7.56
HTWYT/4	12.80	11.70	8.59	18.43	17.50	5.04
HTWYT/5	12.60	11.90	5.55	19.58	17.40	11.13
HTWYT/6	12.28	11.85	3.50	18.48	17.20	6.92
HTWYT/7	12.70	11.50	9.44	19.50	16.70	14.35
HTWYT/8	12.70	11.70	7.87	18.60	16.90	9.13
HTWYT/9	12.68	12.25	3.39	19.90	17.74	11.05
SINDHU (Check)	12.90	11.70	9.30	20.50	17.70	13.65
Mean	12.67	11.85	5.70	19.03	17.18	9.65
LSD (5%) (G)	0.51			0.69		
LSD (5%) (T)	0.22			0.30		
LSD (5%) (G x T)	0.72			0.97		

R.D. = Relative difference between normal and late sowing treatments, Late sowing means heat stress

number of grains in HTWYT/8 (48.85). Hence, Thomas *et al. (*2017) and Singh *et al*. (2020) achieved some reductions in grain yield of wheat and stated that heat stress was an alarming threat that significantly reduced yield. Kumar *et al.* (2016) also reported the reduction in grains per spike in response to high temperature in their experiments with wheat.

Grain yield/plant (g): Grain yield ranged from 19.10 to 16.95g and 10.83 to 8.04 g under both normal and late sowing conditions (Table 4). The mean performance of all the genotypes at normal sowing was 18.22 g. However, at late sowing it was 9.80 g. On an average, 46.23% loss in grain yield occurred due to late sowing. The greatest performance was observed in HTWYT/6 with minimum reduction of 42.72% followed by HTWYT/5 and Sindhu (Local check) 43.10 and 43.74%, respectively under late sowing. The highest relative decrease percentage was shown by HTWYT/3 (52.56 %) followed by HTWYT/4 (48.63%) in late sowing. The maximum grain yield (g) was obtained by HTWYT/9 (19.10 g) and the minimum by HTWYT/3 (16.95 g) in normal sowing, while in late sowing, the highest grain yield (g) was presented by HTYWT/6 (10.83 g) and the lowest by HTWYT/3 (8.04 g)**.** Saha *et al*. (2020) evaluated wheat genotypes under heat stress conditions in order to identify suitable cultivars to develop heat tolerant genotypes resistant to future global warming in which they articulated some degree of reduction grain yield due to the effect of high temperature. Qaseem *et al.* (2019) made an investigation and aimed to quantify the effects on wheat yield for the identification of tolerance of wheat under stressful conditions with the reductions of 56.47%, 53.05% and 44.66% in his experiment.

1000–grain weight (g): Weight of a single grain in wheat has also a great importance. If the weight of grains decreases, the yield also decreases. The highest 1000-grain weight were recorded in genotype HTWYT/6 (54.58 g) and the lowest in HTWYT/3 (45.50 g) under normal sowing, while in late sowing, the maximum 1000-grain weight was observed in genotype HTWYT/6 (52.50 g) and minimum in HTWYT/3 (42.95 g) (Table 5). The average 1000-grain weight of all the genotypes grown under normal sowing conditions was 50.51 g and the genotypes grown at late sowing conditions showed the mean value of 48.11g for 1000-grain weight. However, late sowing caused a decline of 4.74% on an average for 1000-grain weight. The minimum relative decrease in genotype HTWYT/6 (3.81%) under late sowing, yet the highest decrease in HTWYT/9 (6.15%) under late sowing was exhibited. Therefore, the genetics of tolerance is having a prime importance for genetic improvement of wheat which has been tried in this study. Higher 1000 grain weight in parental lines was also observed by Kumar *et al.* (2016); Shrief *et al.* (2017) and Dwivedi *et al.* (2018) under heat stress conditions. Kumar *et al*. (2020) experimented with some genotypes of wheat for knowing the effect of heat which results in less than 15% in seed index in high temperature.

Biological yield/plant (g): Under normal and late sowing, biological yield (g) segregated from 29.15 to 26.52 g and 21.64 to 16.25 g. The average biological yields of all the genotypes in both were 27.88 g and 19.63 g, thus, average 29.69% reduction was caused by late sowing (Table-5). The lowest and the highest loss of decrease percentage however was recorded by HTWYT/9 (25.48%) and HTWYT/3 (39.09%) in both

Table 4. Mean performance of grains/spike and grain yield/plant (g) of advance wheat lines grown under normal and late sowing dates

Genotypes	Grains/spike		R.D.%	Grain yield/plant (g)		R.D.%
	Normal sowing	Late sowing		Normal sowing	Late sowing	
HTWYT/1	62.30	55.10	11.55	17.55	9.14	47.92
HTWYT/2	68.00	58.00	14.70	17.25	9.52	44.81
HTWYT/3	65.40	56.50	13.60	16.95	8.04	52.56
HTWYT/4	62.25	61.30	1.52	19.10	9.81	48.63
HTWYT/5	66.45	60.05	9.63	18.05	10.27	43.10
HTWYT/6	68.15	53.95	20.83	18.91	10.83	42.72
HTWYT/7	69.25	54.20	22.08	17.77	9.40	47.10
HTWYT/8	73.38	48.85	33.42	18.61	9.82	47.23
HTWYT/9	65.55	50.05	23.64	19.10	10.60	44.50
SINDHU (Check)	66.43	56.65	14.72	18.95	10.66	43.74
Mean	66.71	55.46	16.54	18.22	9.80	46.23
LSD (5%) (G)	2.02			0.71		
LSD (5%) (T)	0.90			0.32		
LSD (5%) (G x T)	2.85			1.01		

R.D. = Relative difference between normal and late sowing treatments, Late sowing means heat stress

sowing dates. The genotypes like HTWYT/6 (29.15 g) and HTWYT/7 (26.52 g) produced the most and the least biological yield in normal sowing, while in late sowing, the greater biological yield was obtained in HTWYT/9 (21.64 g) and the less in HTWYT/3(16.25 g) (Table 5). In the same way, the mean performance of biological yield plant^{-1} was on the top in the experiment of Shrief *et al.* (2017) and Tounsi *et al.* (2019) in high temperature because of the presence of resistance in the genotypes for this character.

Harvest index (%): Results of harvest index in wheat genotypes presented noteworthy variations under the impact of heat stress, yet some varieties demonstrated higher reductions in harvest index than the others because of heat stress. The highest harvest index was observed in genotype HTWYT/7 (56.32%) and the lowest in HTWYT/5 (53.50%) at normal sowing, nevertheless under late sowing, the maximum harvest index was recorded by HTWYT/1 (51.21%) and minimum (48.97%) by HTWYT/9 (Table-6). The overall average of all the genotypes in normal sowing was 55.62 % and in late sowing was 49.73 %. Heat stress caused the decrement of 10.55% averagely in all the genotypes grown under late sowing conditions. HTWYT/9 with a decrease of 12.88% and HTWYT/5 with the drop of 7.86% presented the maximum and minimum values for reduction, respectively. Selection preferentially for harvest index to accumulate favourable alleles in the selected entries for future uses had been suggested by Mansouri *et al.* (2018).

Table 5. Mean performance of 1000-grain weight (g) and biological yield/plant (g) of advance wheat lines grown under normal and late sowing dates

Genotypes	1000-grain weight (g)			Biological yield plant (g)		
	Normal sowing	Late sowing	R.D.%	Normal sowing	Late sowing	R.D.%
HTWYT/1	50.56	48.53	4.01	26.70	18.08	32.28
HTWYT/2	47.80	45.50	4.81	27.04	18.14	32.91
HTWYT/3	45.50	42.95	5.60	26.68	16.25	39.09
HTWYT/4	49.23	47.23	4.06	28.34	19.43	31.43
HTWYT/5	53.00	50.73	4.28	28.10	20.80	25.97
HTWYT/6	54.58	52.50	3.81	29.15	21.63	25.79
HTWYT/7	50.70	47.78	5.75	26.52	19.00	28.35
HTWYT/8	51.10	48.53	5.02	28.18	19.83	29.63
HTWYT/9	51.02	47.88	6.15	29.04	21.64	25.48
SINDHU (Check)	51.65	49.55	4.06	29.14	21.56	26.01
Mean	50.51	48.11	4.74	27.88	19.63	29.69
LSD (5%) (G)	1.82			1.26		
LSD (5%) (T)	0.81			0.56		
LSD (5%) (G x T)	2.58			1.79		

R.D = Relative difference between normal and late sowing treatments, Late sowing means heat stress

Table 6. Mean performance of harvest index (%) and relative water content (%) of advance wheat lines grown under normal and late sowing dates

Genotypes	Harvest index (%)			Relative water content (%)		
	Normal sowing	Late sowing	R.D.%	Normal sowing	Late sowing	R.D.%
HTWYT/1	55.73	51.21	8.11	85.41	83.14	2.65
HTWYT/2	55.69	50.71	8.94	71.49	68.44	4.26
HTWYT/3	55.22	49.60	10.17	74.60	71.04	4.77
HTWYT/4	56.07	50.01	10.80	77.86	75.54	2.97
HTWYT/5	53.50	49.29	7.86	82.62	81.09	1.85
HTWYT/6	55.48	49.14	11.42	82.63	80.57	2.49
HTWYT/7	56.32	49.47	12.16	74.89	71.84	4.07
HTWYT/8	56.02	49.58	11.49	82.90	80.31	3.12
HTWYT/9	56.21	48.97	12.88	88.95	86.85	2.36
SINDHU (Check)	55.97	49.40	11.73	81.21	79.12	2.57
Mean	55.62	49.73	10.55	80.25	77.79	3.11
LSD (5%) (G)	1.02			1.99		
LSD (5%) (T)	0.45			0.89		
LSD (5%) (G x T)	1.44			2.81		

R.D = Relative difference between normal and late sowing treatments, Late sowing means heat stress

Relative water content (%): The relative water content of bread wheat genotypes was extensively influenced under heat stress. The range of relative water content was 88.95 to 71.49% under the early sowing dates, whereas in late sowing dates, it ranged from 86.85 to 68.44% in (Table 6). The mean performance of all the genotypes grown under normal sowing was 80.25%, while in late sowing; it was 77.79%. The best performance for relative water content under the heat stress condition was given by genotype HTWYT/5 with the lowest decrement percentage of 1.85%. The maximum reduction (4.77%) was observed in HTWYT/3. In normal sowing, the greatest value was noted in genotype HTWYT/9 (88.95 %) and the lowest value was expressed by HTWYT/2 (71.49%), while in late sowing, the highest percentage of decline was recorded in HTWYT/9 (86.85%) and the lowest in HTWYT/2 (68.44%). Dwivedi *et al.* (2017) showed a reduction in RWC across the cultivars as compared to the normal sown condition. The high variability under heat stress obtained in the germplasm underlies sufficient genetic variability for improving heat tolerance in bread wheat (Cao *et al.*, 2015).

Chlorophyll content (%): Loss in chlorophyll content during heat stress associated with yield loss has been testified. The chlorophyll content (%) was recorded from 58.47 to 50.09 under normal sowing and 53.91 to 45.39 in late sowing (Table 7). Nonetheless, the average of all the genotypes was 54.89 in normal sowing and 50.81 under late sowing. On an average, heat stress caused 7.45% decline chlorophyll content. The highest loss in chlorophyll content was observed in HTWYT/2 (10.80%) closely followed by HTWYT/4 (9.38%) under heat stress conditions and the lowest decline in HTWYT/8 (5.31%) in heat stress condition, respectively. The maximum chlorophyll content was found in HTWYT/1 (58.47%) and minimum in HTWYT/4 (50.09%) under normal sowing. The maximum chlorophyll content was noted in HTWYT/1 (53.91) and the lowest in HTWYT/4 (45.39) due to late sowing. These results were in close conformation with the observation of Cao *et al.* (2015) for chlorophyll content. The current findings are also in conformity with the findings of Khan *et al.* (2015) in which heat stress significantly reduced chlorophyll-a and chlorophyll-b content of wheat genotypes.

Table 7. Mean performance of chlorophyll content of advance wheat lines grown under normal and late sowing dates

Genotypes	Chlorophyll content (%)		R.D.%
	Normal sowing	Late sowing	
HTWYT/1	58.47	53.91	7.89
HTWYT/2	53.10	47.36	10.80
HTWYT/3	56.90	53.12	6.64
HTWYT/4	50.09	45.39	9.38
HTWYT/5	54.40	50.63	6.93
HTWYT/6	55.69	51.15	8.15
HTWYT/7	53.45	48.80	8.69
HTWYT/8	56.78	53.76	5.31
HTWYT/9	54.75	51.79	5.40
SINDHU (Check)	55.27	52.24	5.48
Mean	54.89	50.81	7.45
LSD (5%) (G)	1.56		
LSD (5%) (T)	0.69		
LSD (5%) (G x T)	2.20		

R.D = Relative difference between normal and late sowing treatments, Late sowing means heat stress

Table 8. Correlation coefficient (r) of spring wheat genotypes for various traits in non-stress and heat stress conditions grown under normal and late sowing dates

Trait	Plant height	Tillers/ plant	Spike length	Spikelets/ spike	Grains/ spike	1000-grain weight	Grain Yield/ plant	Biological yield/ plant	Harvest index (%)	Chlorophyll content (%)
Tillers/plant	0.29^{ns}	-								
Spike length	0.53**	0.40**	-							
Spikelets/spike	0.47**	0.59**	0.67**	-						
Grains/spike	0.72**	0.46**	0.62**	0.69**	-					
1000-grain weight	0.19^{ns}	0.19^{ns}	0.26^{ns}	0.42**	0.38**	-				
Grain yield/plant	0.67**	0.61**	0.68**	0.80**	0.82**	0.49**	-			
Biological yield/plant	0.61**	0.60**	0.70**	0.79**	0.78**	0.54**	0.96**	-		
Harvest index (%)	0.68**	0.57**	0.61**	0.74**	0.81**	0.34**	0.93**	0.86**	-	
Chlorophyll content (%)	0.35^{ns}	0.45**	0.44**	0.42**	0.47**	0.34**	0.59**	0.59**	0.54**	-
Relative water content (%)	-0.01^{ns}	0.53**	0.24**	0.33**	0.11^{ns}	0.38**	0.31**	0.40**	0.17ns	0.40**

** = Highly significant at 0.01% probability level, * = Significant at 0.05% probability level, NS = Non-significant at 0.05% probability level

Correlation coefficients

Plant height was positively and highly significantly associated with spike length, spikelets/spike, grains/ spike, grain yield/plant, biological yield/plant and harvest index, but non significantly with tillers per plant. Tillers per plant expressed positive and highly significant relationship with all the attributes except one seed index with which it showed non-significant. Spike length also manifested the same association as tillers per plant. Spikelets/spike demonstrated only positive and highly significant associations with all characters. Grains per spike was positive highly significantly with all traits as well as non-significantly with relative water content. Seed index exhibited only positive and highly significant correlations with all characters. Grain yield also displayed the same correlations as seed index. Other traits like biological yield per plant, harvest index and chlorophyll content expressed both significant and non-significant positive associations with their traits (Table 8).

Bhutto *et al.* (2016) reported positive correlations of plant height with these above described traits. Regarding correlation with grain yield traits, Mohanty *et al.* (2016) showed a constructive association between spikelets per spike and grain yield while observing forty-nine wheat genotypes in the experiment. Consequently, selection can be based on these traits in both environments for breeding of bread wheat under heat stress condition according to Anzer-ul-Islam *et al.* (2017) who got positive correlation between productive tillers per plant and grain yield per plant in heat stress. Moreover, Desheva (2016); Desheva and Kyosev (2017) and Neeru *et al.* (2017) indicated highly significant positive association between grain yield and grains/ spike. Mohamed *et al.* (2019) told that grain yield per plant was strongly correlated with spike length under the favourable conditions. Schittenhelm *et al*. (2020) articulated nonsignificant linkages between yield and some other yield traits. Seed index is an important selection criterion in breeding programs as it has a positive correlation with grain yield in wheat (Thomas *et al.,* 2017). The investigation of Qaseem *et al.* (2019) showed a strong correlation of chlorophyll content before and after anthesis with the other studied agronomic and physiological traits with grain yield under stressful conditions.

CONCLUSION

It was concluded from the present research that the temperature from November to March was relatively favorable for wheat crop planted in normal conditions. Low and high temperature during grain formation stage was not suitable as crop planted in late December 19th. The genotypes HTWYT/1, HTWYT/06, HTWYT/7, HTWYT/8 and HTWYT/9 performed better under timely sowing conditions for all traits. In case of heat stress conditions, HTWYT/1, HTWYT/2, HTWYT/3, HTWYT/4, HYWYT/6 and HTWYT/9 showed better results for all attributes. In case of correlation, almost all traits exhibited positive and highly significant associations with one another. The genotypes which performed best in both heat stress and non-stress conditions were observed to be heat insusceptible for most of the traits.

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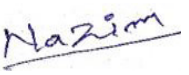
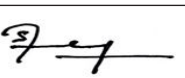
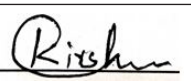
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