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Screening of Wheat Genotypes Under Terminal Heat Stress Conditions for the Morpho-Physiological and Yield Related Traits

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Abstract. Late sowing of wheat crop is associated with high temperatures. Thus temperature is one of the main limiting factors that influences yield production of wheat especially during the grain filling period. Heat tolerance is a complex phenomenon, which is very difficult to make a reliable assessment about it. High temperature stress is a chief ecological constraint hampering productivity of hexaploid wheat in most parts of the globe. Present research were carried out at Nuclear Institute of Agriculture Research Tandojam Sindh, which is located at approximately 25.4299° N latitude and 68.5426° E longitude, during the rabi season 2017-2018, in this context, a set of 22 bread wheat genotypes was evaluated against heat stress tolerance in glasshouse and as well as natural field conditions. A similar experiment of screening was also conducted in normal and late sowing conditions so as to expose the material under heat stress. The variances due to mean squares of both the screening experiments revealed significant differences for genotypes, treatments and treatment x genotypes interactions for studied traits. Such results indicated that genetic resources under present study are worth to be included in future breeding schemes. Based on mean performance and lower declines/reduction levels under heat stress, six out of 22 genotypes like TD-1, Benazir, TJ-83, Kiran-95, NIA-Sarang and AS-2002 were identified as heat stress tolerant for most of studied traits.

Keywords: heat stress, screening, wheat, physiological, yield traits

Introduction

Wheat (*Triticum aestivum* L.) belongs to the family Gramineae and is grown worldwide for its edible grains. Among cereals, wheat holds a major place as it is the staple food for more than 36% of the world's population. In 2024, global wheat production was estimated at 787-796 Million tons, while global consumption reached nearly 800 Million tons, reflecting the continuous demand for this staple crop (FAOSTAT, 2024). In Pakistan, wheat is the most important food grain, occupying about 9 Million hectares of cultivated land annually. During 2024, the country's wheat production was recorded at 31.4-31.8 Million tons with an average yield of around 3.2 tonnes per hectare, whereas domestic consumption was estimated at 29-30 Million tons (Government of Pakistan, 2024). To feed the increasing population, an increase in the per-unit yield of wheat is a necessity to meet the food requirements of the world population. A marginal increase has occurred in wheat productivity under favorable growth conditions. However, large scope for further improvement in wheat productivity under undesirable environments is still distantly characterized by abiotic constraints like high-temperature stresses (Bhanu *et al*., 2018; Bouslama and Schapaugh, 1984). There are several factors like diseases, insect pests, drought, high temperature, salinity, water logging and other biotic and abiotic stresses that are responsible for wheat limting yield, however, terminal heat stress is very important. The rise in temperature during the grain filling period is referred to as terminal heat stress. Heat stress due to late planting is the main reason for the lower yield per unit area in wheat (Tahir *et al*., 2022; Hura, 2020). In the present era, the breeding for heat tolerance in wheat is one of the major threats for breeders. To resolve this problem, plant breeders work on the selection of heat tolerant genotypes under targeted environments. Therefore, to fulfill the diversified goals of plant breeding, the development of heat-tolerant genotypes is essential for enhancement in grain yield, improvement in quality traits and wider adaptation to

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varied environments, to meet the food demand of the population (Van, 2020; Schmidt *et al*., 2020). Conventional wheat genotypes that accurately respond to diverse planting and environmental conditions become favorable for farmers by their consistency in production (Tahir *et al*., 2022; Janni *et al*., 2020). The information on genotype by environment interaction is key in determining the stability and proficiency of the selection in breeding. The confirmation of genotype by environment interaction is a substantial feature for any breeding scheme and the identification of superior wheat genotypes for yield stability (Khalil *et al*., 2016). In this regard, the present study was carried out with the aim to identify the wheat genotypes with tolerance to late planting heat stress by using glasshouse and natural field experiments among the morphological and yield traits under different planting regimes.

Materials and Methods

The current study was carried out to determine the genetic basis of heat tolerance in bread wheat genotypes. In this regard, 22 wheat genotypes from various origins were evaluated for maturity, growth, physiological and yield traits under heat stress conditions. This study focused primarily on isolating heat stress tolerant genotypes. The experiment was laid out in a glasshouse on cement embedded beds (size 3.75x9.75 m), filled with coarse gravel (up to 30 cm depth) and a thin layer of river sand having 2.5 cm depth (Shirazi *et al*., 2018). The initial research related to screening of bread wheat genotypes was carried out under glasshouse conditions of the Nuclear Institute of Agriculture, Tandojam during the wheat growing season 2015-16. The trial was laid out in a randomized complete block design (Factorial) with four replications and 22 wheat genotypes were grown for screening under optimum sowing date on 15th November, 2015. One set of 22 genotypes were planted in nearby field to glasshouse, whereas another set of the same 22 genotypes was gown on same sowing date in natural field. It was assumed that glasshouse would raise 2 to 3 °C temperature, which would provide heat stress to wheat genotypes for screening purposes.

Another experiment was conducted similar to previous, same twenty two varieties/lines were sown in two sets (optimum sowing date on 15th November and late sowing date on 15th December, 2015-16) in a plot size of 20x15 m. The experiment was sown in field conditions rather than in glasshouse in a randomized complete block design (Factorial) and four replicates were used for optimum sowing date (hereafter may be called as under non-stress, normal temperature or normal sowing time or early sowing) and late sowing date experiments (hereafter may be called as heat stress conditions, delayed sowing date). Recommended fertilizer dose was also applied i.e. nitrogen @ 120 Kg/ha (in two splits) in the form of ammonium sulphate $(NH_4)_2 SO_4$; phosphorus @ 90 Kg/ha (full dose at the time of sowing) in the form of single superphosphate Ca $(H_2PO_4)_2$ and potassium @ 60 Kg/ha (full dose) in the form of potassium sulphate (K_2SO_4).

Results and Discussion

The results from analysis of variance under glasshouse conditions for grain yield and other measured morpho-physiological traits indicated significant effects for treatments and genotypes both in normal and heat stress conditions. The interaction of treatments with genotypes was significant for most of the characters under heat stress conditions except grain filling duration which was non-significant. However, mean squares for natural field conditions indicated that characters such as days to 50% heading, days to 75% maturity, biomass/plant, leaf area, chlorophyll content and grain filling duration were significantly influenced by heat stress conditions as revealed by the mean squares from the analysis of variance. The genotypes also responded variably as indicated by the significant genotype x treatment interactions for all the studied traits (Table 1). A changeable response of genotypes to heat stress conditions may offer an opportunity to choose the reliable and stable ones which are able to perform well in both heat stress and non-stress environments.

Results revealed that all the traits were significantly influenced by heat stress which revealed substantial decline in yield and its related traits in wheat genotypes. Genotype x treatment interactions for all the studied traits further suggested differential response of genotypes to high temperature in which some of them were more tolerant than the other genotypes. Significant differences allowed looking at the mean performance of genotypes under heat stress (Table 2). Significant differences among wheat genotypes for days to 50% heading, plant height, grains/spike and spikelets/spike was also noted by Ali *et al*. (2016). Thapa *et al*. (2019) observed significant declines in biological yield/plant, grain yield/plant, productive tiller/plant and 1000 grain weight. Highly significant differences among the genotypes for days to maturity and leaf area were also identified by Ishaq

Table 1. Mean temperature data for the wheat growing period during November 2015 to March 2016 minimum, maximum and average for both experimental sites glasshouse and natural field

Month	Mini °C (Glasshouse)	Maxi °C (Glasshouse)	Average °C (Glasshouse)	Mini °C (Natural field)	Maxi °C (Natural field)	Average °C field
Nov	17.75	36.12	26.93	14.52	23.88	19.20
Dec	11.55	29.55	20.55	8.35	25.79	17.07
Jan	12.00	29.61	20.80	10.26	25.40	17.83
Feb	14.44	32.88	23.66	9.24	28.36	18.80
Mar	15.35	36.71	26.03	17.15	34.16	25.66

et al. (2018). Significant differences in spike length and cell membrane stability in our study are in harmony with Islam *et al.* (2017). Rani *et al*. (2017) reported highly significant differences among genotypes for peduncle length, grain filling duration, harvest index and chlorophyll content as well.

Days to 50% heading. The wheat genotypes for days to 50% heading under normal and heat stress conditions under glasshouse. The reduction under stress conditions for this character ranged between -4.13 to -13.55 days. The minimum reduction (-4.13 days) due to heat stress were seen in Benazir and AS-2002. Under normal conditions, days to heading ranged from 59.50 to 62.75 days with the mean value of 61.00 days and the genotypes such as Tatara, NRC-1236, NIA-5B and Bathoor-08 took maximum days to heading, whereas the minimum days to heading was observed in the genotype NIA-AS-9 for existing trait. Similarly in heat stress conditions the maximum days to heading was taken by the genotype Benazir, followed by TD-1 and TJ-83 days respectively, however the minimum days to heading was reported in genotype NIA-AS-9 with days to 50% heading. Manel *et al.* (2015) found appreciable variability for several wheat traits such as days to heading, grain yield and yield components under heat stress environment (Table 3).

In natural field experiment comparison with non-stress conditions, heat stress substantially reduced the days to 50% heading of wheat genotypes ranging from -2.40 (SRN-09) to -7.20% (AS-2002). The maximum heat induced reduction in days to 50% heading, therefore was noted in cultivars, AS-2002, NIA-5B and Bathoor-08 (Table 4). In heat stress, days to 50% heading of NRL-1236 followed by SRN-11 took relatively maximum days. These findings are also supported by Poudel *et al.* (2020). The genotypes which showed greater tolerance to heat stress were SRN- 87, NIA-6 and Hamal under heat stress conditions. Thapa *et al.* (2020) and Khajuria *et al.* (2016) found that the performances under late sowing revealed significant effects of heat stress on days to 50% heading and delayed flowering suggesting their ability to withstand heat stress. Based

Table 2. Mean square from analysis of variance of wheat genotypes for yield and physiological traits in glasshouse and natural field conditions for heat stress

Mean square (field and glasshouse)	Days to 50% Heading	Days to 75% maturity	Total biomass/ plant	Leaf area (cm^2) 4	SPAD chlorophyll	Grain filling duration
Replication D.F.=3	0.45	1.17	0.05	4.69	0.74	0.19
Treatment (T) D.F.=1	1320.02**	56.90**	1220.11**	67.92**	219.17**	245.81**
Genotypes (G) D.F.=21	4.67**	1852.51**	131.70**	119.88**	785.42**	13.09**
T x G D.F.=21	4.86**	6.47**	17.49**	0.41*	1.68**	0.69^{ns}
Error D.F.=129	0.52	0.67	0.44	0.31	0.50	0.51
Mean square normal and late sowing dates (Natural field)						
Replication D.F.=3	1.43	0.13	0.25	0.05	0.08	0.31
Treatment (T) D.F.=1	311.11**	5052.55**	1220.11**	1363.26**	1911.23**	2784.09**
Genotypes (G) D.F.=21	5.99**	4.52**	131.70**	37.64**	226.99**	34.04**
T x G D.F.=21	1.32*	5.13**	17.49**	12.87**	4.53**	16.52**
Error D.F.=129	0.75	0.41	0.44	0.03	0.15	0.33

**,* = Significant at 1 and 5% probability levels respectively.

Table 3. Mean performance and reduction% of days to 50% heading and days to 75% maturity of wheat grown, in field and glasshouse conditions

Genotypes	Days to 50% heading		Reduction %	Days to 75% maturity		Reduction %
	Field	Glasshouse		Field	Glasshouse	
NIA-Sundar	60.75	55.75	-8.23	90.00	84.25	-6.39
NIA-Sarang	61.00	56.25	-7.79	97.75	90.75	-7.16
NIA-AS-14	60.50	54.50	-9.92	94.75	87.50	-7.65
NIA-AS-9	59.50	53.50	-10.08	93.50	87.75	-6.15
NIA-AS-10	60.50	56.00	-7.44	91.50	86.50	-5.46
NIA-2B	60.50	54.25	-10.33	94.25	85.50	-9.28
Hamal	60.75	54.75	-9.88	92.50	85.00	-8.11
NIA- 5B	62.50	56.00	-10.40	93.50	87.25	-6.68
NIA-6	61.00	56.00	-8.20	94.00	85.75	-8.78
SRN-87	60.50	54.50	-9.92	94.75	86.50	-8.71
SRN-11	61.50	54.25	-11.79	93.00	85.25	-8.33
CT-49	60.25	54.00	-10.37	91.00	85.00	-6.59
NRC-1236	62.50	55.25	-11.60	91.25	85.75	-6.03
Bathoor-08	62.25	55.25	-11.24	94.50	85.25	-9.79
Tatara	62.75	54.25	-13.55	93.25	83.50	-10.46
TJ-83	61.50	56.75	-7.72	96.00	91.00	-5.21
TD-1	60.50	57.50	-4.96	96.25	92.25	-4.16
Benazir	60.50	58.00	-4.13	97.25	92.50	-4.88
Sehar	60.50	55.00	-9.09	89.00	82.00	-7.87
Kiran–95	60.50	56.75	-6.20	95.50	92.50	-3.14
LU-26s	61.25	55.00	-10.20	90.50	83.50	-7.73
AS-2002	60.50	58.00	-4.13	95.50	91.50	-4.19
Mean	61.00	55.52	-8.96	93.61	87.13	-6.94
LSD (5%) (T)	0.2144			0.2439		
LSD (5%) (G)	0.7111			0.8088		
LSD (5%) (T × G)	1.0057			1.1438		

on the overall performance in late sowing conditions for days to heading, six cultivars were found to be resistant to heat stress.

Days to 75% maturity. It is now well understood that days to 75% maturity is essential for heat stress tolerance. Performance of bread wheat genotypes for the character days to 75% maturity under normal and heat stress conditions (glasshouse conditions) was depicted in Table 3. The reduction in this trait under glasshouse stress conditions ranged between -3.14 and -10.46 days. Variety Kiran-95 gave the minimum reduction due to glasshouse imposed heat stress. Days to maturity ranged from 89.00 to 97.75 days with an average mean of 93.61 days in normal field conditions and the genotypes such as NIA-Sarang, Benazir, TD-1 and Sehar manifested the maximum days to maturity, whereas the minimum days to maturity was observed in the genotype Sehar. Under glasshouse sowing conditions, the days to 75% maturity varied between 82.00 and 92.50 with the mean decline of 87.13 days. The maximum days to maturity was expressed by the genotype Benazir (92.50), followed by TD-1 and AS-2002 (92.25 and 91.50 days), however the minimum days to maturity was observed in the genotype Sehar (82.00 days).

In natural field conditions heat stress reduced the days to maturity of varieties NIA-AS-9, SRN-87, NIA-6 and NIA-5B, yet cultivars NIA-AS-9 and SRN-87 were found more susceptible to heat stress because these cultivars recorded higher reductions in days to 75% maturity. Contrary to above finding, days to maturity of varieties like NIA-Sarang, TJ-83, TD-1, Benazir and SRN-11 were increased rather declined under heat stress indicating their high temperature tolerance (Table 4). Thapa *et al.* (2020) and Durr-e-Nayab *et al*. (2017) suggested that maturity is an important physiological trait in wheat and early maturing cultivars are desirable to avoid terminal stress due to sudden rise in temperature during late grain filling stage. Arain *et al*. (2022) also reported the likewise findings.

Table 4. Mean performance and reduction% of days to 50% heading and days to 75% maturity of wheat grown, in normal and late sowing conditions (Field)

Genotypes	Days to 50% heading		Reduction %	Days to 75% maturity		Reduction %
	Normal sowing	Late sowing		Normal sowing	Late sowing	
NIA-Sundar	62.75	60.00	-4.38	106.75	95.75	-10.30
NIA-Sarang	63.00	60.50	-3.97	105.50	97.75	-7.35
NIA-AS-14	62.50	59.25	-5.20	107.00	95.50	-10.75
NIA-AS-9	61.50	58.50	-4.88	108.25	94.50	-12.70
NIA-AS-10	62.75	60.25	-3.98	107.50	95.75	-10.93
NIA-2B	62.50	60.00	-4.00	105.50	94.50	-10.43
Hamal	62.75	61.00	-2.79	105.75	94.50	-10.64
NIA- 5B	64.50	60.25	-6.59	106.50	94.25	-11.50
NIA-6	62.75	61.00	-2.79	107.25	94.75	-11.66
SRN-87	62.50	61.00	-2.40	108.25	95.50	-11.78
SRN-11	63.50	61.50	-3.15	104.75	95.50	-8.83
CT-49	61.25	59.50	-2.86	105.75	94.25	-10.87
NRC-1236	64.75	62.00	-4.25	105.00	94.50	-10.00
Bathoor-08	64.25	60.50	-5.84	106.00	94.75	-10.61
Tatara	64.50	61.00	-5.43	105.25	93.75	-10.93
TJ-83	61.75	59.25	-4.05	103.75	96.00	-7.47
TD-1	62.50	59.75	-4.40	104.50	96.00	-8.13
Benazir	62.50	60.25	-3.60	105.50	96.50	-8.53
Sehar	62.50	59.50	-4.80	107.50	96.25	-10.47
Kiran–95	62.50	60.25	-3.60	105.50	96.50	-8.53
LU-26s	61.50	59.75	-2.85	105.25	94.50	-10.21
AS-2002	62.50	58.00	-7.20	106.25	96.25	-9.41
Mean	62.80	60.14	-4.23	106.06	95.34	-10.09
LSD (5%) (T)	0.2583			0.1919		
LSD (5%) (G)	0.8565			0.6363		
LSD (5%) (T x G)	1.2113			0.8999		

Total biomass/plant (g). Biomass/plant remained as one of the most important grain yield influencing traits (Mansouri *et al*., 2018). Understanding the underlying mechanisms of heat tolerance in wheat is crucial to effectively address as how much heat stress affects wheat production and to provide useful genes for genetic improvement (Tounsi *et al*., 2019). In comparison with non-stress conditions, heat stress reduced the biomass/plant of wheat genotypes. The response of hexaploid wheat genotypes for total biomass/plant under normal field and in glasshouse heat conditions is described in Table 5. Under heat stress conditions, the total biomass/plant extended between 11.69 and 17.08 g with the mean biomass of 13.78 g. The maximum total biomass/plant was obtained from the genotypes TD-1 (17.08 g), followed by Kiran-95 and NIA-Sarang (16.84 and 16.83 g respectively), however the minimum total biomass/plant was reported in the genotype NIA-5B (11.69 g). The reduction under high temperature conditions for this character fluctuated between -1.50 and -11.72 g. The minimum reduction (-1.50 g) due to heat stress was seen in NIA- AS-9. Under normal field conditions, total biomass/plant ranged from 13.02 to 17.78 g with the mean of 14.61 g and the genotypes such as TD-1, NIA-Sarang, Kiran-95 and AS-2002 (17.78, 17.55, 17.40 and 17.20 g respectively) gave maximum total biomass/plant, whereas the minimum total biomass/plant was obtained from the genotype NRC-1236 (13.02 g). The average total biomass in field was 13.78 g and the same value in glasshouse was 14.61 g, thus heat stress reduced the biomass by 5.68%.

However, in case of natural field conditions heat stress significantly changed the total biomass/plant shown in Table 6. The highest biomass/plant was produced by genotype TD-1 (9741.67 g) followed by Kiran-95 (9458.33 g) and NIA-Sarang (9008.33 g) under controlled conditions yet minimum biomass/plant was attained by CT-49 (7416.67 g). However, average biomass/plant of 33.93 g was noted under controlled

Table 5. Mean performance and reduction% of Total biomass/plant and Leaf area (cm^2)^4 of wheat grown, in field and glasshouse conditions

Genotypes	Days to 50% heading		Reduction %	Days to 75% maturity		Reduction %
	Field	Glasshouse		Field	Glasshouse	
NIA-Sundar	13.70	12.68	-7.49	16.55	15.00	-9.37
NIA-Sarang	17.55	16.83	-4.10	24.88	23.32	-6.25
NIA-AS-14	14.89	13.17	-11.52	16.45	14.04	-14.64
NIA-AS-9	13.25	13.06	-1.50	17.03	15.11	-11.26
NIA-AS-10	13.08	12.17	-6.98	16.65	14.44	-13.30
NIA-2B	13.52	12.50	-7.53	14.75	12.41	-15.86
Hamal	13.54	13.10	-3.20	14.95	12.76	-14.65
NIA- 5B	13.24	11.69	-11.72	18.60	16.23	-12.74
NIA-6	13.17	12.11	-8.05	16.45	14.34	-12.83
SRN-87	13.31	12.58	-5.55	15.58	14.21	-8.76
SRN-11	13.60	12.88	-5.35	17.38	15.45	-11.08
CT-49	13.73	12.78	-6.92	17.30	15.76	-8.90
NRC-1236	13.02	12.36	-5.07	15.65	14.00	-10.54
Bathoor-08	14.18	13.16	-7.20	18.18	16.11	-11.38
Tatara	13.64	12.95	-5.12	16.55	14.00	-15.41
TJ-83	16.88	16.23	-3.85	21.55	19.56	-9.23
TD-1	17.78	17.08	-3.90	25.75	23.33	-9.40
Benazir	17.09	16.77	-1.88	18.25	16.76	-8.16
Sehar	13.64	13.12	-3.88	17.75	15.69	-11.59
Kiran–95	17.40	16.84	-3.25	21.35	19.47	-8.81
LU-26s	13.97	12.50	-10.51	17.45	15.23	-12.72
AS-2002	17.20	16.68	-3.00	20.70	19.33	-6.63
Mean	14.61	13.78	-5.80	18.17	16.21	-11.07
LSD (5%) (T)	0.0636			0.1667		
LSD (5%) (G)	0.2109			0.5530		
LSD (5%) (T x G)	0.2983			0.7820		

conditions, while 28.66 g was noted under heat stress conditions. Biomass/plant substantially declined in heat stress however more biomass was noted in genotype TD-1 (9133.33 g), followed by Kiran-95 (8608.33 g) and NIA-Sarang (8358.33 g) and Benazir (8175.00 g). Moreover, maximum decrease was manifested by SRN-87 (-20.72%) and minimum by Benazir (-5.76%) and TD-1 (-6.24 g) caused by stress. The average reduction of -15.99% was noticed in total biomass/plant owing to late sowing and consequently due to heat stress. The results are in agreement with Arain *et al*. (2022) also reported the likewise findings.

Leaf area (cm^2). Leaf area is one of the main determinants of crop yield as it regulates plant water through its influence on transpiration (Levitt, 1980). Results concerning leaf area of wheat genotypes showed significant variations under the stimulus of heat stress; however, some varieties demonstrated higher reductions in leaf area than the others due to heat stress. The results of wheat genotypes for leaf area (cm^2) under normal field and glasshouse imposed heat stress plantings are depicted (Table 5). The reduction in leaf area under heat stress conditions ranged between -6.25 and -15.86 cm^2. The minimum drop (-6.25 cm^2) due to heat stress was seen in NIA-Sarang. Under normal field conditions, leaf area ranged from 14.75 to 25.75 cm^2 with the mean value of 18.17 cm^2 and the genotypes such as TD-1, NIA-Sarang, TJ-83 and NIA-2B (25.75, 24.88, 21.55 and 14.75 cm^2) revealed the maximum leaf area, while the minimum leaf area was detected in the genotype NIA-2B (14.75 cm^2). Under glasshouse imposed heat stress planting, the leaf area varied between 12.41 to 23.33 cm^2 with the mean leaf area of 16.21 cm^2. The maximum leaf area was measured by the genotype TD-1 (23.33 cm^2), followed by NIA-Sarang and TJ-83 (23.32 and 19.56 cm^2 respectively), however the minimum leaf area was reported by the genotype NIA-2B (12.41 cm^2). The glasshouse heat stress declined leaf area from an average of 18.17 cm^2 in field to 16.21 cm^2 under glasshouse stress conditions.

Table 6. Mean performance and reduction% of Total biomass/plant and leaf area (cm^2)^4 of wheat grown, in normal and late sowing conditions

Genotypes	Total biomass/plant		Reduction %	Leaf area (cm^2)		Reduction %
	Normal sowing	Late sowing		Normal sowing	Late sowing	
NIA-Sundar	7783.33	6791.67	-12.74	22.28	16.53	-25.81
NIA-Sarang	9008.33	8358.33	-7.22	22.90	21.33	-6.88
NIA-AS-14	8050.00	7008.33	-12.94	21.45	15.68	-26.92
NIA-AS-9	7541.67	6366.67	-15.58	24.00	17.55	-26.89
NIA-AS-10	8598.33	7716.67	-10.25	22.53	17.40	-22.77
NIA-2B	8041.67	7075.00	-12.02	23.75	15.68	-34.00
Hamal	8316.67	7225.00	-13.13	20.80	14.93	-28.25
NIA- 5B	8216.67	7033.33	-14.40	22.95	16.63	-27.56
NIA-6	8983.33	7766.67	-13.54	23.03	16.45	-28.56
SRN-87	8083.33	6408.33	-20.72	24.38	17.08	-29.95
SRN-11	7708.33	6525.00	-15.35	23.33	16.58	-28.94
CT-49	7416.67	6108.33	-17.64	24.30	14.88	-38.79
NRC-1236	8333.33	6775.00	-18.70	24.98	18.70	-25.13
Bathoor-08	9083.33	7725.00	-14.95	26.18	16.63	-36.49
Tatara	8583.33	7291.67	-15.05	26.45	17.68	-33.18
TJ-83	8483.33	7750.00	-8.64	24.63	22.48	-8.73
TD-1	9741.67	9133.33	-6.24	27.03	24.80	-8.23
Benazir	8675.00	8175.00	-5.76	20.15	18.30	-9.18
Sehar	8600.00	7150.00	-16.86	24.23	18.08	-25.39
Kiran–95	9458.33	8608.33	-8.99	27.88	25.78	-7.53
LU-26s	8708.33	7808.33	-10.33	24.10	17.53	-27.28
AS-2002	8633.33	7741.67	-10.33	22.58	20.78	-7.97
Mean	33.93	28.66	-15.99	23.81	18.25	-23.38
LSD (5%) (T)	0.1984			0.0544		
LSD (5%) (G)	0.6581			0.1804		
LSD (5%) (T x G)	0.9307			0.2551		

In natural field conditions heat stress generally reduced the leaf area of all the twenty 22 wheat genotypes examined in the range of -6.88 to -38.79 cm^2. Under heat stress, the maximum reductions in leaf area were nonetheless noted in CT-49 closely followed by Bathoor-08, NIA-2B and Tatara displaying their weakness to heat stress. Other cultivars such as TJ-83, TD-1, AS-2002, Kiran-95 and NIA-Sarang articulated tolerance to heat stress due to the motive that these genotypes were less affected by stress (Table 6). Our findings are in agreement with Elbasyoni (2018), who also observed that increased temperature during the late sown conditions decreased total chlorophyll content, leaf area and grain yield.

SPAD chlorophyll. Performance of wheat genotypes for SPAD chlorophyll under normal and glasshouse sowing conditions is presented in Table 7. Under late sowing glasshouse heat conditions, the values of chlorophyll (relative greenness rg) varied between 37.50 and 52.25 rg with an average rg of 42.49. The maximum SPAD chlorophyll was articulated by the genotype Kiran-95 (52.25 rg), followed by TD-1 and AS-2002 (51.50 and 50.75 rg respectively), however the minimum SPAD chlorophyll was testified by the genotype NIA-5B (37.50 rg). The reduction in rg under heat stress conditions ranged between -5.50 to -12.92 rg. The minimum reduction due to heat stress however was seen in TD-1 (-5.50 rg).

Under normal field conditions, SPAD chlorophyll ranged from 41.35 to 56.50 rg with the mean rg of 46.71 and the genotypes such as Kiran-95, TD-1, AS-2002 and NIA-5B (56.50, 54.50, 54.00 and 41.35 rg) recorded maximum SPAD chlorophyll, whereas the minimum SPAD chlorophyll was noted in the genotype NIA-5B (41.35 rg). Similarly, in natural filed conditions results concerning chlorophyll content of wheat genotypes showed significant distinctions under the inducement of heat stress; however, some varieties revealed higher reductions in SPAD chlorophyll in comparison with the others. Heat stress declined the SPAD chlorophyll of

Table 7. Mean performance and reduction% of SPAD chlorophyll and grain filling duration of wheat grown, in field and glasshouses conditions

Genotypes	SPAD chlorophyll		Reduction %	Grain filling duration		Reduction %
	Field	Glasshouse		Field	Glasshouse	
NIA-Sundar	90.00	84.25	-6.39	28.50	25.00	-12.28
NIA-Sarang	97.75	90.75	-7.16	29.50	27.75	-5.93
NIA-AS-14	94.75	87.50	-7.65	29.50	27.50	-6.78
NIA-AS-9	93.50	87.75	-6.15	28.50	27.00	-5.26
NIA-AS-10	91.50	86.50	-5.46	26.50	23.75	-10.38
NIA-2B	94.25	85.50	-9.28	27.25	25.25	-7.34
Hamal	92.50	85.00	-8.11	27.00	24.50	-9.26
NIA- 5B	93.50	87.25	-6.68	26.50	24.25	-8.49
NIA-6	94.00	85.75	-8.78	28.75	25.75	-10.43
SRN-87	94.75	86.50	-8.71	27.25	25.50	-6.42
SRN-11	93.00	85.25	-8.33	27.50	25.50	-7.27
CT-49	91.00	85.00	-6.59	28.00	25.00	-10.71
NRC-1236	91.25	85.75	-6.03	26.50	23.75	-10.38
Bathoor-08	94.50	85.25	-9.79	26.25	23.50	-10.48
Tatara	93.25	83.50	-10.46	27.00	24.00	-11.11
TJ-83	96.00	91.00	-5.21	28.00	26.50	-5.36
TD-1	96.25	92.25	-4.16	28.75	26.75	-6.96
Benazir	97.25	92.50	-4.88	29.50	27.25	-7.63
Sehar	89.00	82.00	-7.87	27.00	23.50	-12.96
Kiran–95	95.50	92.50	-3.14	30.00	28.00	-6.67
LU-26s	90.50	83.50	-7.73	27.75	25.50	-8.11
AS-2002	95.50	91.50	-4.19	29.00	27.00	-6.90
Mean	93.61	87.13	-6.94	27.93	25.57	-8.50
LSD (5%) (T)	0.2126			0.2148		
LSD (5%) (G)	0.7052			0.7125		
LSD (5%) (T x G)	0.9972			1.0076		

all wheat genotypes assessed in the range of -6.98 to -18.70%. The maximum reductions in leaf area in stress conditions on the other hand were noted in Sehar closely followed by NIA-6, NIA-2B and SRN-87 presenting their feebleness to heat stress. Other cultivars like AS-2002, Benazir, Kiran-95, NIA-Sarang and TD-1 articulated tolerance to heat stress due to the motive that these genotypes were less affected by the heat stress (Table 8). Current results are in close confirmation with the observation of Bokshi *et al.* (2022) and Cao *et al.* (2015) for chlorophyll content.

Grain filling duration. The response of hexaploid wheat genotypes for grain filling duration under normal field and glasshouse heat stress conditions period is shown in Table 7. Under heat stress conditions, the values for grain filling duration varied between 25.50 and 28.00 with the mean value of 25.57 days. The maximum grain filling duration was taken by the genotype NRC-1236 (28.00 days), followed by CT-49 and NIA-Sundar (27.75 and 27.50 days respectively), however the minimum grain filling duration was reported in the genotype NIA-Sundar with an average days of 25.50. The reduction under glasshouse temperature conditions for grain filling fluctuated between -5.26 to -12.96. The minimum reduction (-5.26 days) due to heat stress was seen in NIA-Sarang.

Under normal field conditions, grain filling duration ranged from 26.25 to 30.00 days with the mean days of 27.93 yet the genotypes such as NRC-1236, NIA-Sundar, TD-1 and Sehar took 30.00, 29.50, 29.00 and 26.25 days for grain filling duration, whereas the minimum grain filling duration was observed in the genotype Sehar (26.25 days) for this trait.

It is vibrant to know the physiological, biochemical and genetic mechanisms which govern the various seed filling events under stress environments; this will help to devise strategies to improve stress tolerance. The impact of high temperatures on grain filling duration in wheat has been reported by Asseng *et al.* (2015).

Table 8. Mean performance and reduction% of SPAD chlorophyll and Grain filling duration of wheat grown, in normal and late sowing conditions (Field)

Genotypes	SPAD chlorophyll		Reduction %	Grain filling duration		Reduction %
	Normal sowing	Late sowing		Normal sowing	Late sowing	
NIA-Sundar	50.97	42.73	-16.17	38.25	25.50	-33.33
NIA-Sarang	59.79	54.45	-8.92	35.75	31.75	-11.19
NIA-AS-14	46.89	41.73	-11.01	36.25	28.50	-21.38
NIA-AS-9	46.75	41.40	-11.44	38.00	30.50	-19.74
NIA-AS-10	48.50	41.83	-13.76	8.50	24.75	-35.71
NIA-2B	51.93	43.28	-16.66	34.50	28.25	-18.12
Hamal	50.81	43.65	-14.08	35.25	26.50	-24.82
NIA- 5B	47.70	40.43	-15.25	35.25	25.50	-27.66
NIA-6	51.62	42.35	-17.95	39.25	29.50	-24.84
SRN-87	49.64	41.63	-16.14	37.25	26.50	-28.86
SRN-11	48.13	40.58	-15.69	35.75	28.75	-19.58
CT-49	45.64	40.60	-11.05	38.50	27.75	-27.92
NRC-1236	50.85	43.99	-13.50	32.25	24.25	-24.81
Bathoor-08	47.78	41.40	-13.35	35.50	27.50	-22.54
Tatara	51.36	45.19	-12.01	32.50	26.00	-20.00
TJ-83	58.97	52.85	-10.38	37.25	32.50	-12.75
TD-1	61.02	55.23	-9.49	37.50	32.50	-13.33
Benazir	56.94	52.50	-7.80	38.25	33.75	-11.76
Sehar	50.74	41.25	-18.70	36.50	25.50	-30.14
Kiran–95	62.19	56.90	-8.51	36.25	32.50	-10.34
LU-26s	50.46	43.80	-13.19	37.50	28.00	-25.33
AS-2002	58.38	54.30	-6.98	38.25	33.50	-12.42
Mean	52.14	45.55	-12.82	36.56	28.63	-21.66
LSD (5%) (T)	0.1157			0.1703		
LSD (5%) (G)	0.3839			0.5649		
LSD (5%) (T x G)	0.5429			0.7989		

They found massive influence on grain filling duration under the conditions of heat stress. The wheat genotypes showed a differential reaction with heat stress environment. In the conditions of extremely high temperature, the genotypes lessened grain filling duration fluctuating from -10.34 to -35.71%. In heat stress, the maximum decline was noticed in NIA-AS-10 virtually followed by NIA-Sundar and Sehar, therefore representing their vulnerability to heat stress. On the other hand, the genotypes Kiran-95, NIA-Sarang, Benazir, AS-2002 and TJ- 83 did not shorten the grain filling duration under heat stress circumstances presenting their higher tolerance to heat stress (Table 8). Seed filling is influenced by various metabolic processes occurring in the leaves, especially production and translocation of photo assimilates, importing precursors for biosynthesis of seed reserves, minerals and other functional constituents. These findings are the agreement with Thapa *et al.* (2020).

From the overall results of the screening experiment, the cultivars NIA-Sarang, TJ-83, TD-1, Benazir and A×S-2002 performed better than other genotypes. These cultivars gave relatively less declines due to heat stress with respect to days to 50% heading, days to 75% maturity, total biomass/plant, leaf area, SPAD chlorophyll and grain filling duration.

Conflict of Interest. The authors declare that they have no conflict of interest.

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