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WHEAT GENOTYPES RESPONSE TO HEAT STRESS TOLERANCE NORMAL AND DELAY SOWING DATES

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خلا صہ

بڑھتی ہوئی گلوبل وارمنگ کے منظر نامے میں، گرمی کے تناؤ کو زیادہ اہمیت حاصل ہو گئی ہے۔ بد قسمتی سے، پاکستان بھی سب سے زیادہ گرمی سے متاثرہ ملک کی قطار میں ہے۔ اس سلسلے میں، گندم پاکستان کی سب سے اہم فصل ہے جو گرمی کے تناؤ سے انتہائی متاثر ہوتی ہے۔ اس تناظر میں، گندم کی ورائیٹیز کو 2 مختلف تاریخوں پر کاشت کر کے پرکھا گیا۔ اس ضمن میں 25 نومبر اور 25 دسمبر 2015 کو گندم لگائی 25 نومبر والی کاشت کو نارمل جب کے 25 دسمبر والی کاشتکاری کو گرمی کی مطابق تصور کیا گیا۔ عام اور زیادہ درجہ حرارت میں ورائیٹیز کی الگ الگ پیداوار گندم کی پیداوار بڑہانے کے لیے تجربے کی مناسبت بتاتے ہیں۔ کاشت کاری میں تاخیر کی وجہ سے گندم کی مختلف خصلتوں میں کمی دیکھی گئی جس سے زیادہ حرارت کی وجہ سے گندم کی پیداوار میں کمی کی نشاندہی ہوئی۔ گرمی کے تناؤ سے اوسطاً فزیکل میچورٹی، فلگ لیف ایریا، اسپیسفک فلگ لیف ویٹ، گرینس پر اسپائیک، گرین ویٹ پر اسپائیک، تھاؤزنڈ گرین ویٹ، گرین ییلڈ پر پلانٹ، آرگینک ییلڈ پر پلانٹ، کراپ انڈیکس، ریلیٹو واٹر کنٹینٹ اور سیل میمبرین اسٹیبلٹی یں بالترتیب 7.01، 31.38، 20.63، 20.50، 37.93، 30.63، 37.87، 31.62، 9.38، 16.95 اور 10.96 فیصد کمی واقع ہوئی۔ گرمی کے تناؤ میں سب سے زیادہ پیداوار بالترتیب امداد زیرو فائیو، نیاسارنگ، ٹی ڈی ون میں دیکھنے میں آئی جس سے ان ورائیٹیز کی گرمی میں کاشت کو زیادہ موزون قرار دیا گیا۔ گرمی کے دباؤ میں سب سے کم پیداوار بالترتیب خرمن اور اے ایس دو ہزار دو میں دیکھنے میں آئی جس سے ان ورائیٹیز کی گرمی میں کاشت کو غیر موزون قرار دیا گیا۔ باقی ورائیٹیز معمولی طور پر گرم تناؤ برداشت کرنے والے تھے۔

Abstract

In the scenario of increasing global warming, heat stress attained greater importance. Unfortunately, Pakistan is also in the queue of the most heat-affected country. In this regard, wheat is the most important staple crop in Pakistan which is highly affected by heat stress. In this context, the genotype of wheat was evaluated at 2 sowing dates. Normal planting on 25 November and delay planting on 25 December 2015 were considered as normal and summer stress conditions, respectively. Significant differences between genotypes in normal and high temperatures indicating the suitability of the experiment to improve bread wheat genotype for heat tolerance. A decrease in various traits was noted due to delay planting indicating a visible effect of high temperature on physico-yield traits. At average physical maturity, flag leaf area, specific flag leaf weight, grain spike-^{1}, grain weight spike-^{1}, 1000-grain weight, grain yield plant^{-1}, organic yield plant-^{1}, crop index, relative water content and cell membrane stability showed a decrease of 7.01, 31.38, 20.63, 20.50, 37.93, 30.63, 37.87, 31.62, 9.38, 16.95 and 10.96%, respectively, under heat stress conditions.While the wheat genotypes like Imdad-05, NIA-Sarang and TD-1 showed minimum reductions under heat stress conditions for various traits suggesting their heat tolerance, nonetheless cultivars Khirman and AS-2002 expressed maximum declines under heat stress expressing their susceptibility to heat stress conditions. The remaining genotypes were moderately heated stress-tolerant.

Key words: Delay sowing, Genotypes response, Heat stress, Normal sowing, Wheat

Introduction

Heat stress, especially high heat in delay growth stage, seriously affects wheat yield and quality (Uthayakumaran and Wrigley, 2017). Wheat often encounters high temperatures above 32 °C after flowering, which is a critical period for wheat yield and quality formation. High temperature stress reduced the photosynthetic capacity of wheat, accelerated plant aging, shortened grouting time, and significantly reduced grain size. High temperature conditions are also one of the main factors inducing dry hot air. In the main wheat-producing areas like Sindh and Panjab in pakistan, dry and hot winds often occur in the early, middle and delay stages of wheat filling, which seriously affects the yield and quality of wheat. It has been reported that the average temperature in the world by 2100 will increase by 1.8 to 4.0 °C compared with the average temperature between 1980 and 2000. Under the background of increasing global environmental temperature, the frequency of high temperature stress in wheat filling period will also increase, and the direct damage of high temperature stress to wheat will become increasingly obvious and prominent(kumar *et al*., 2015; Nizamani *et al*., 2019)

Previous studies have taken many research methods to study the response of wheat to high temperature stress, and to screen and evaluate heat resistance. Chlorophyll fluorescence changes, changes in cell membrane permeability, changes in canopy temperature, etc. after high temperature stress are used as physiological indicators for heat resistance screening and evaluation, especially cell membranes. The change in permeability is applied more in heat resistance screening. The thermal sensation index or heat damage index calcudelayd on the basis of 1000-grain weight and bulk density is also used by many people for heat resistance evaluation. You *et al*., (2009) calcudelayd the dry-hot wind stress resistance index and stress resistance coefficient according to the wheat flag leaf functional period and 1000-grain weight, and evaluated the wheat dry heat resistance. Although there are many studies on the effects of high temperature stress on wheat yield, many researchers pay attention to heat resistance and ignore production when screening and evaluating wheat heat tolerance, or because the test method is limited to laboratory measurements, etc. There is no uniform and simple method for evaluating the heat tolerance of wheat (khan *et al*., 2015; Rind *et al*., 2019).

Wheat is a winter cereal crop requiring relatively low temperatures ranging from 12 to 22 ° C, which is considered best for its reproductive development (Farooq *et al*., 2011). Exposure to high temperatures can cause considerable morphological and physical damage, accelerating leaf intensification (Wang *et al*., 2011) reducing photosynthesis (Ristic ET AL., 2007) and reducing starch biosynthesis (Zhao *at al*., 2008). Physical and morphological characteristics such as chlorophyll content, canopy temperature reduction, biomass, 1000-grain weight, grain yield and yield-redelayd traits were all affected by heat stress (Singh *et al*., 2016). Bala *et al*., (2014) showed that heat stress reduced grain yield, reduced grain yield, plant height, grain filling stage, pedunal length, inflorescence weight and 1000-grain weight. Delay heat stress is the reason for the shortening of the grain filling period. Therefore, improper grain filling will affect the total yield of wheat crops (Khokhar *et al*., 2019a). Under delay sowing conditions, the yield per plant, biomass per plant and grain per plant reached (Rane *et al*., 2007). The total biomass and yield per square meter decreased significantly with planting delay during maturity. Higher temperatures were associated with water limitations and resulted in a rapid decrease in grain volume (Mitra & Bhatia, 2008)

The optimum sowing date for different varieties varies by planting system, depending on the growing conditions of the particular area, and can be assessed by sowing at different seeding dates. Another important factor in coping with the heat stress challenge is through genotypic selection, which produces higher yields and is resistant to adverse conditions and precocious (Kumar *et al*., 2013). Wheat plants can exhibit a wider range of calorie compensation, escape and tolerance mechanisms through different molecular, biochemical, physiological, developmental and growth adaptation mechanisms (Barnabás *et al*., 2008)

Therefore, heat resistance should be an essential feature of recently developed wheat farming. Leaf rolling, leaf detachment, leaf size reduction, leaf thickening, reduced growth period, evaporation cooling, and other morphological and individual growth adjustments reduce heat-induced damage. Bavei *et al.,* (2011) reported that when assimilation is limited, maintaining green or delayed senescence is thought to play an important role in the development of wheat grains, and that green farming is associated with drought and heat stress Adapt well to the situation. High temperatures can cause loss of membrane integrity, major photosynthetic processes, changes in lipid composition and protein denaturation (Wahid et al., 2007) . Thermal stability of membranes due to thermal stress (usually measured as cellular ion leakage) has been used to demonstrate heat tolerance of wheat germplasm ((Khokhar *et al*., 2019b; Somro *et al*., 2019; Rind *et al*., 2019; Nizamani *et al*., 2020). Blum *et al*., (2001) revealed that the yield of spring wheat lines was high, and it had a high membrane thermal stability in the flowering stage flag. The purpose of this study is to identify the morphological and physiological basis of heat-tolerant stress at the end of wheat, and to propose a reliable heat resistance screening strategy for wheat breeding programs in Pakistan and elsewhere.

Objectives of the study

i. To identify the potential source of terminal heat tolerance in wheat genotypes for a future breeding program
ii. To study the effect of terminal heat on different agro-physiological traits in bread wheat
iii. To assess the genetic variability among the heat-tolerant genotypes of wheat

Materials and methods

In this context, the experimental materials were evaluated in two sowing dates viz., normal planting (25th November 2015) and delay planting (25th December 2015), considered as normal and heat stress conditions, respectively.

Treatments = Two factors (A and B)
Factor - A: Sowing dates (D) = 2
D1 = Normal sowing (25th November)
D2 = Delay sowing (25th December)
Factor – B: Genotypes = 15

1. NIA-Amber	6. AS-2002	11. Benazir
2. Mehran	7. SKD-1	12. Anmol
3. Khirman	8. TD-1	13. Kiran-95
4. Imdad-05	9. TJ-83	14. NIA-Sunahri
5. Sehar-2006	10. NIA-Sarang	15. Moomal

Data were collected from 10 randomly labeled indexed plants of each genotype replicated for the following traits.

Statistical analysis: Data for different parameters of each genotype were averaged and statistically analyzed. Significant differences between means were determined using standard analysis of variance techniques.

Estimation of relative decrease (%): Relative decrease (%) was measured by the subtraction of the mean value of stress from the mean value of non-stress, divided by the mean value of stress, and multiplied by 100 as under.
Relative decrease (RD %) = [(non-stress - heat stress) / non-stress] x 100

Results and discussions

Temperature: Temperature: Meteorological data on daily basis for the minimum and maximum temperatures measured during the entire crop season (2015–2016) at the experimental site are given in fig. 1. Higher temperatures were observed during the sowing of an experiment in November, although temperatures declined in the months of December and January. From February to May, the temperature rises by about 5 ^{0}C on average for each month. During the grain-filling period during the months of February and March, the temperature reached 35 ^{0}C, which exceeded 40 ^{0}C in 1 week of April 2016 in sfig. 2. This temperature condition exceeds the limit value (25 ^{0}C) wheat crop. Therefore, the delay sown wheat crop faced terminal heat stress.

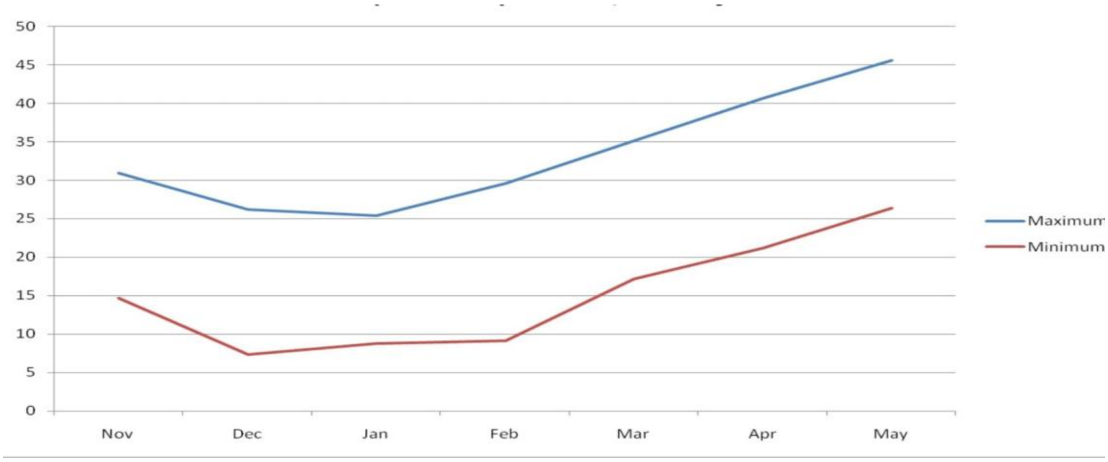

Fig.1. Miximum and minimum temperature of wheat season 2015-2016.

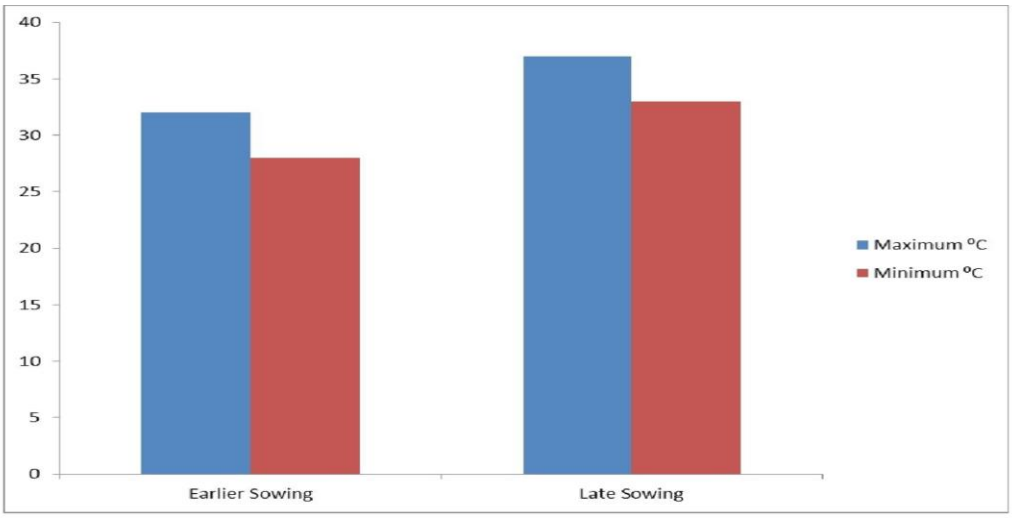

Fig.2. Maximum and minimum temperatures of wheat crop at 20th February to 20th march, at SAU, Tandojam

Analysis of variance: Mean squares (Table 1) by analysis of variance indicated that heat stress had a significant effect on all symptoms studied. There are also significant differences between genotypes of all yields studied and physiological traits, which allows wheat breeders to select heat-resistant genotypes for one or more morphological and physiological characteristics. The mean class due to genotype is also important for all traits under non-stress and heat stress conditions. For all traits studied, the mean squared value of the analysis of variance from genotype x treatment interactions (Table 1) was also significant. The importance of genotype X treatment interactions indicates that the genotype behaves differently under stress conditions. These interactions can help wheat breeders select the best-performing variety based on one or more reliable heat tolerance indicators.

Table 1. Analysis of variance

Traits	Mean squares				
	Replication (D.F.=2)	Genotype (G) (D.F.=14)	Treatment (T) (D.F.=1)	G x T (D.F=14)	Error (D.F.=28)
Physiological maturity	0.88	17.23**	1322.50**	6.57**	0.79
Flag leaf area	1.64	27.92**	872.67**	7.81**	1.20
Specific flag leaf weight	3.02	6.62**	438.02**	4.63**	1.34
Grains spike^{-1}	4.26	95.76**	3046.19**	56.85**	1.46
Grain weight spike^{-1}	0.01	0.16**	14.57**	0.07**	0.01
1000-grain weigh	1.17	80.74**	1518.07**	14.79**	0.80
Grain yield plant^{-1}	5.38	3.71**	292.86**	0.56*	0.26
Biological yield plant^{-1}	8.85	4.80**	1581.31**	1.89**	0.50
Harvest index	6.13	108.29**	688.18**	10.08**	0.74
Relative water content	16.48	86.89**	4888.96**	58.66**	4.70
Cell membrane stability	2.77	104.37**	1470.64**	60.01**	1.48

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

Mean Performance and Relative Decrease

Physiological maturity (75%): In our experiment, the decline was recorded averagely by 7.01% due to heat stress (Table 2). The maximum reduction, however, was observed in Khirman (10.33%) followed by AS-2002 (8.62%) under heat stress condition. The best performance was shown by Imdad-05 with a minimum relative decrease of 4.30%, and the 2nd and 3rd better performing were NIA-Sarang and TD-1 (4.63 and 5.48%), respectively, with less decline in heat stress condition. In non-stress, physiological maturity ranged from 113.67 to 119.33, while in heat stress condition, it was ranged from 104 to 111.33 days. The present findings are in agreement with Ishaq *et al*., (2015) who reported that terminal heat stress significantly affected the physiological maturity and shortened from 10.46 to 12.67% maturity grown under heat stress conditions. The reduction in maturity days was also found in the research of Hossain *et al*., (2015) with the decrement of 13.04% under the delay sowing dates. Nahar *et al*., (2010) also observed the reduction up to 15% in the maturity period of wheat genotypes due to the effect of heat stress.

Table 2. Mean performance for physiological maturity and flag leaf area of wheat

Genotypes	Physiological maturity (75%)		R.D.*	Flag leaf area cm^2		R.D*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
NIA-Amber	119.00	109.33	8.13	18.48	12.59	31.87
Mehran	118.33	108.67	8.17	21.00	16.34	22.19
Khirman	119.33	107.00	10.33	22.70	12.11	46.65
Imdad-05	116.33	111.33	4.30	14.64	12.34	15.71
Sehar-2006	113.67	106.00	6.74	14.50	9.49	34.55
AS-2002	116.00	106.00	8.62	20.06	10.79	46.21
SKD-1	115.00	106.00	7.83	14.87	8.87	40.35
TD-1	115.67	109.33	5.48	17.35	14.20	18.16
TJ-83	115.00	108.00	6.09	17.50	14.16	19.09
NIA-Sarang	115.00	109.67	4.63	18.18	15.23	16.23
Benazir	111.67	104.00	6.87	11.28	7.25	35.73
Anmol	116.33	107.00	8.02	17.52	12.14	30.71
Kiran-95	114.67	107.00	6.69	17.15	9.36	45.42
NIA-Sunahri	117.67	110.33	6.24	16.65	13.00	21.91
Moomal	118.33	110.00	7.04	18.67	10.10	45.89
Mean	116.13	107.98	7.01	17.37	11.86	31.38
LSD (5%) (G)	1.02			1.26		
LSD (5%) (T)	0.37			0.46		
LSD (5%) (G x T)	1.44			1.78		

*= **Relative decrease due to heat stress treatment.**

Flag leaf area (cm^2): Terminal heat stress is a major constraint in the development of flag leaf area. Singh and Dwivedi (2015) found that heat stress caused by delay sowing significantly decreased the flag leaf area. The flag leaf area ranged from 11.28 to 22.70 under non-stress conditions and 7.25 to 16.34 in heat stress conditions (Table 2). Nonetheless, the average of all the genotypes was 17.37 cm2 in non-stress condition and 11.86 cm2 under heat stress conditions. On average, heat stress caused 31.38% decline. The highest loss in leaf area was observed in Khirman (46.65%) closely followed by AS-2002 (46.21%) under heat stress conditions. The lowest decline was noted in Imdad-05 (15.71%) in heat stress condition and it was followed by NIA-Sarang and TD-1 (16.23 and 18.16%), respectively. The maximum flag leaf area was found in Khirman (22.70 cm2) and minimum in Benazir (11.28 cm2) under non-stress conditions. The greatest flag leaf area was noted in Mehran (16.34 cm2) and the lowest also in Benazir (7.25 cm2) due to heat stress conditions. The effect of heat stress become more clear when we observe the findings of different researchers like, Hamam *et al.*, (2015) reported 12.89% decrement in flag leaf area due to heat stress and Hamam and Khaled, (2009) demonstrated that heat stress reduced the flag leaf area up to 13.29% under delay sowing dates with increased heat stress.

Specific flag leaf weight (mg/cm2): The specific flag leaf weight varied for 20.62 to 25.18 mg/cm2 in non-stress condition, while in heat stress condition it ranged for 14.60 to 21.42 mg/cm2. The mean of all the genotypes was 22.90 mg/cm2 in non-stress condition and 18.19 mg/cm2 in heat stress conditions. The reduction of 20.63% on average was observed due to heat stress. The minimum relative decrease nevertheless was found in Imdad-05 (12.69%) closely followed by NIA-Sarang and TD-1 (13.96 and 16.27%), respectively, due to heat stress. The maximum loss due to heat stress was observed in Khirman (30.50%) nearly followed by AS-2002 (30.33%). The highest specific flag leaf weight was recorded in Khirman (25.18 mg/cm2) and the lowest in NIA-Amber (20.62 mg/cm2) at the non-stress condition. The maximum specific flag leaf weight was recorded in Imdad-05 (21.42 mg/cm2) and the minimum in AS-2002 (14.60 mg/cm2) under the heat stress condition (Table 3).

Table 3. Mean performance for specific flag leaf weight and grains spike^{-1} of wheat

Genotypes	Specific flag leaf weight mg/cm²		R.D.*	Grains spike^{-1}		R.D*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
NIA-Amber	20.62	16.00	22.41	63.40	43.00	32.18
Mehran	21.38	16.50	22.83	58.17	38.00	34.67
Khirman	25.18	17.50	30.50	62.00	38.00	38.71
Imdad-05	24.53	21.42	12.69	67.13	63.00	6.15
Sehar-2006	22.41	18.00	19.69	51.90	43.50	16.18
AS-2002	20.96	14.60	30.33	56.87	36.40	35.99
SKD-1	20.79	16.50	20.63	55.33	44.10	20.30
TD-1	22.99	19.25	16.27	48.20	43.50	9.75
TJ-83	25.14	21.00	16.47	57.53	50.15	12.83
NIA-Sarang	23.13	19.90	13.96	65.93	61.50	6.72
Benazir	22.87	18.00	21.28	48.23	39.00	19.14
Anmol	23.64	17.38	26.49	60.77	51.10	15.91
Kiran-95	24.00	19.53	18.63	49.43	38.90	21.31
NIA-Sunahri	22.53	18.34	18.59	54.70	46.36	15.25
Moomal	23.34	18.97	18.72	65.73	51.00	22.41
Mean	22.90	18.19	20.63	57.69	45.83	20.50
LSD (5%) (G)	1.33			1.39		
LSD (5%) (T)	0.48			0.50		
LSD (5%) (G x T)	1.88			1.97		

*= **Relative decrease due to heat stress treatment.**

Grains spike-^{1}: In non-stress, the range of grains spike-^{1} was counted as 48.20 to 67.13 kernels, while in heat stress varieties recorded 36.40 to 63.00 grains spike-^{1} (Table 3). On average, the genotypes produced 57.69 grains spike and heat stress caused the decline of 20.50% averagely, in all the varieties grown under delay sowing condition (Table 2). The highest reduction was observed in Khirman (38.71%) followed by AS-2002 (35.99%) under the heat stress condition. The lowest reduction was noticed in Imdad-05 (6.15%) closely followed by NIA-Sarang and TD-1 (6.72 and 9.75%, respectively) under heat stress condition. In normal condition, grains spike^{-1} ranged from 48.20 to 67.13, while in heat stress condition, it ranged from 36.40 to 63.00 grains per spike. These findings are supported by Hamam *et al.*, (2015) who found a decline of 18.13% in grain numbers per spike due to heat stress. El-Ameen, (2012), Abd El-Majeed *et al.* (2005) and Sial *et al.*, (2005) also reported that heat stress caused a significant reduction in the number of grains per spike under heat stress conditions.

Grain weight spike^{-1} (g): In non-stress, grain weight spike^{-1} ranged from 1.58 to 2.17 while in heat stress condition, it ranged from 0.79 to 1.68 grain weight spike^{-1}. The average grain weight spike-1 of all the genotypes was 1.72g in non-stress and 1.07g in heat stress conditions. The average decline due to heat stress was 37.93%. The maximum reduction was however observed in Khirman (55.31%) closely followed by AS-2002 (54.07%), while the minimum was found in Imdad-05 (22.58%) followed by NIA-Sarang and TD-1 (26.98 and 32.32%), respectively in heat stress conditions. The higher grain weight spike^{-1} was recorded by Imdad-05 (2.17g) and the lowest by Mehran (1.58g) under non-stress condition while in heat stress condition, the higher grain weight per spike was observed in Imdad-05 (1.68g) and the lowest (0.79g) in AS-2002 (Table 4). Our results are in agreement Laghari *et al.*, (2012) who reported a 45.83% reduction in grain weight due to terminal heat stress. Khokhar *et al.*, (2010) and Menshawy, (2007) also found that early sowing wheat gave higher grain weight per spike as compared to delay sowing wheat which may be due to longer grain filling duration in early planting wheat and exemption from terminal heat stress.

Table 4. Mean performance for grain weight spike^{-1} and 1000-grain weight of wheat

Genotypes	Grain weight spike^{-1} (g)		R.D.*	1000-grain weight (g)		R.D*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
NIA-Amber	1.60	1.02	36.25	21.91	13.95	36.33
Mehran	1.58	0.90	43.04	26.67	16.42	38.43
Khirman	1.79	0.80	55.31	27.82	15.01	46.05
Imdad-05	2.17	1.68	22.58	36.27	29.50	18.67
Sehar-2006	1.61	1.00	37.89	27.22	18.94	30.42
AS-2002	1.72	0.79	54.07	31.00	18.65	39.84
SKD-1	1.67	0.96	42.51	26.09	17.00	34.84
TD-1	1.64	1.11	32.32	33.24	25.65	22.83
TJ-83	1.60	1.05	34.38	28.76	22.00	23.50
NIA-Sarang	1.89	1.38	26.98	34.03	27.50	19.19
Benazir	1.63	1.02	37.42	32.77	22.00	32.87
Anmol	1.77	1.14	35.59	28.89	20.00	30.77
Kiran-95	1.66	1.00	39.76	31.62	23.49	25.71
NIA-Sunahri	1.80	1.14	36.67	32.99	24.60	25.43
Moomal	1.70	1.12	34.12	28.83	19.43	32.60
Mean	1.72	1.07	37.93	29.87	20.90	30.63
LSD (5%) (G)	0.01			1.03		
LSD (5%) (T)	6.96			0.37		
LSD (5%) (G x T)	0.02			1.46		

*= **Relative decrease due to heat stress treatment.**

1000-grain weight (g): The trait 1000-grain weight (g) is one of the most important yields contributing traits, while terminal heat stress is the major environmental factor which reduces the size and boldness of grain. The highest 1000-grain weight was weighed in genotype Imdad-05 (36.27g) and the lowest in NIA-Amber (21.91g) under non-stress conditions, whereas, in heat stress condition, the maximum 1000-grain weight was observed in genotype Imdad-05 (29.50g) and minimum (13.95g) in NIA-Amber (Table 4). The average 1000-grain weight of all the genotypes grown under non-stress was 29.87g and the genotypes grown in heat stress condition showed the mean value of 20.90g for 1000-grain weight. However, heat stress caused a decline of 30.63% on an average for 1000-grain weight. The minimum relative decrease of 18.67% was shown by genotype Imdad-05, followed by NIA-Sarang and TD-1 (19.19 and 22.83%), respectively, under heat stress condition, yet the highest decrease percentage was exhibited by Khirman (46.05%) followed by AS-2002 (39.84%) under heat stress conditions. Terminal heat stress reduced the seed index similar to our results (Hamam et al., 2009; Hossain *et al*., 2015; Singh *et al*., 2016; Mondal *et al*., 2013).

Grain yield plant^{-1} (g): The increment of all other characters provides a better background to enhance the grain yield plant^{-1}. In our experiment, grain yield plant-1 ranged from 5.75 to 13.34g in non-stress condition, while in heat stress condition it varied from 2.50 to 9.81g (Table 5). The mean performance of all the genotypes in non-stress condition was 8.38g however in terminal heat stress condition it was 5.33g. On an average, 37.87% loss in grain yield plant-1 occurred due to terminal heat stress. The greatest performance was observed in Imdad-05, with a minimum reduction of 26.46% followed by NIA-Sarang and TD-1 (28.80 and 32.32%), respectively under heat stress condition. The highest relative decrease percentage was shown by Khirman (56.52%) followed by AS-2002 (50.82%) in terminal heat stress condition. The maximum grain yield plant^{-1} was obtained by Imdad-05 (13.34g) and the minimum by Khirman (5.75g) in non-stress condition, while in heat stress condition the highest grain yield plant-1 was also shown by Imdad-05 (9.81g) and the lowest by Khirman (2.50g). Our results are near an agreement with those of Hossain *et al*., (2015), Abd-Elrahman *et al*., (2014) and Alam *et al*., (2014) who observed that heat stress reduced the grain yield up to 49.5, 40 and 45%, respectively. El-Ameen, (2012) reported that delaying the sowing date resulted in a substantial reduction in grain yield by 63.34%.

Table 5. Mean performance for grain yield plant^{-1} and biological yield plant^{-1} of wheat genotypes grown under non-stress and heat stress conditions

Genotypes	Grain yield plant^{-1} (g)		R.D.*	Biological yield plant^{-1} (g)		R.D*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
NIA-Amber	7.80	4.50	42.31	18.21	12.00	34.10
Mehran	6.75	3.86	42.81	17.62	11.00	37.57
Khirman	5.75	2.50	56.52	16.60	8.57	48.37
Imdad-05	13.34	9.81	26.46	26.32	20.50	22.11
Sehar-2006	8.12	5.00	38.45	20.22	13.60	32.74
AS-2002	6.10	3.00	50.82	17.38	10.00	42.46
SKD-1	6.71	4.14	38.30	18.26	12.50	31.54
TD-1	11.23	7.60	32.32	23.80	17.21	27.69
TJ-83	8.00	5.25	34.38	19.59	14.00	28.53
NIA-Sarang	12.50	8.90	28.80	25.43	19.34	23.95
Benazir	8.17	5.23	36.01	19.43	13.65	29.75
Anmol	7.97	5.00	37.29	19.56	14.00	28.43
Kiran-95	6.85	4.43	35.33	17.74	12.50	29.54
NIA-Sunahri	8.74	5.76	34.07	19.00	13.68	28.00
Moomal	7.60	5.00	34.21	20.20	14.25	29.46
Mean	8.38	5.33	37.87	19.96	13.79	31.62
LSD (5%) (G)	0.58			0.81		
LSD (5%) (T)	0.21			0.29		
LSD (5%) (G x T)	0.83			1.15		

*= **Relative decrease due to heat stress treatment.**

Biological yield plant^{-1} (g): When wheat experiences high temperatures at anthesis stage, phonological development becomes rapid leading to poor biomass production and sterility, consequently poor yield and reduced overall biological yield per plant are obtained. In non-stress, biological yield plant^{-1} ranged from 16.60 to 26.32g, while under heat stress condition, it ranged from 8.57 to 20.50g. The average grain yield of all the genotypes in non-stress condition was 19.96g, and under the heat, stress condition was 13.79g, thus, averagely 31.62% reduction was caused by terminal heat stress. The lowest decrease percentage, however, was recorded by Imdad-05 (22.11%), closely followed by NIA-Sarang and TD-1 (23.95 and 27.69%), respectively, under the heat stress condition. The maximum loss was seen in Khirman with decrease percentage of 48.37, followed by AS-2002 (42.46%). The higher biological weight exhibited by genotype Imdad-05 was 26.32g and lowest by Khirman 16.60g in non-stress conditions, while in heat stress condition, the greater biological weight was obtained from Imdad-05 20.50g and the less (8.57g) by Khirman (Table 5). Alam *et al*. (2014), Hossain *et al*. (2013), Laghari *et al*., (2012) and Irfaq *et al*., (2005) reported reductions in the biological yield of all the wheat genotypes grown under heat stress conditions in their experiments. Their results also support our findings.

Harvest index (%): In our experiment, there was the difference of one month in both sowing dates. Heat stress occurred at the anthesis stage of wheat genotypes under the 2nd planting date because of this, the major effect was recorded on grain yield. Thus, the harvest index was also decreased by heat stress. The overall average of all the genotypes in non-stress condition was 41.37%, and in terminal heat, stress condition was 37.59% (Table 6). Terminal heat stress caused a decline of 9.38% averagely under the 2nd sowing date. The maximum reduction was observed in Khirman (15.77%), closely followed by AS-2002 (14.51%), and minimum in Imdad-05 (5.58%) closely followed by NIA-Sarang and TD-1 (6.01 and 6.40%, respectively) under the heat stress condition. In non-stress condition, harvest index ranged from 34.63 to 50.68%, while in heat stress condition, it ranged from 29.17 to 47.85%. Singh and Dwivedi, (2015), Nawaz *et al*. (2013) and Moshatati *et al*., (2012) also reported the decline in harvest index under the heat stress conditions, and their results are consistent with our findings.

Relative water content (%): The range of relative water content was 70.87 to 81.92% under the early sown crop whereas, in delay sowing dates, it ranged from 52.32 to 76.41% (Table 6). The mean performance of all the genotypes grown under non-stress condition was 76.98%, while in heat stress condition, it was 64.11%. Heat stress caused a decline of 16.95% on an average, over the genotypes. The best performance for relative water content under the heat stress condition was given by genotype Imdad-05 with the lowest decrement percentage of 6.73. After the Imdad-05, the higher performance was observed in genotypes NIA-Sarang and TD-1 with the lower relative decline of 7.76 and 9.87%, respectively. The maximum reduction (26.17%) however was recorded in Khirman, which was closely followed by AS-2002 (25.69%) in terminal heat stress condition. In non-stress condition, the greatest value was noted in genotype Imdad-05 (81.92%) and the lowest value was expressed by Khirman (70.87%), while in heat stress condition, the highest percentage of decline was recorded in Imdad-05 (76.41%) and the lowest in Khirman (52.32%). Our results are in conformity with the findings of Savicka and Skute, (2012) who reported the reduced relative water content under the heat stress conditions.

Cell membrane stability (%): When the tissue is subjected to high temperatures, the conductivity increases due to damage of the cell membrane and subsequent solute leakage. In the present study, a decrease in cell membrane stability was also observed as the temperature increased. Maximum cell membrane stability was recorded in genotype Imdad-05 (70.80%) and the smallest Khirman (53.34%) was recorded at the optimal temperature. At high temperatures, the highest cell membrane stability was observed in the Imdad-05 genotype (67.40%), the lowest in Khirman (44.24%). The average performance of all genotypes grown under normal sowing was 59.19%, while in the delay sowing, the average performance was 52.83%. Therefore, the average loss due to thermal stress was 10.96% (Table 6). Khirman (17.06%) and AS-2002 (16.22%) showed the greatest reduction under heat stress conditions. However, under heat stress conditions, a small decrease was measured by genotype Imdad-05 (4.80%) and NIA-Sarang and TD-1 (6.61 and 7.50%), respectively. It was found that in all tested wheat genotypes, heat stress during flowering significantly reduced cell membrane stability. Our findings are consistent with the results of Khan et al., (2013) and Kumar et al., (2012) they also stated a decrease in cell membrane stability under terminal heat stress conditions.

Conclusions

Significant differences between all genotypes at normal and high temperatures, indicating that the experiment is suitable for improving the heat tolerance of bread wheat genotypes. The minimal reduction in various traits under heat stress conditions is shown by the genotypes Imdad-05, NIA-Sarang and TD-1, thus showing their tolerance to heat stress. The greatest decline in all traits under terminal heat stress conditions was demonstrated by genotypes Khirman and AS-2002 for their sensitivity to heat stress. The highest values were recorded by genotypes Imdad-05, NIA-Sarang and TD-1 under non-stress and heat stress conditions.

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