Research Article

Effect of heat stress on physiological and yield contributing traits in wheat (*Triticum aestivum* L.)

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Abstract

Heat stress is increasing drastically and has become a major threat to wheat production in various wheat growing regions. Exposure of wheat genotypes to temperatures above the critical threshold level during flowering and grain-filling stages can cause reproductive failure and grain yield reduction. To withhold this situation, a research was carried out on twenty bread wheat genotypes viz. AS-11, AS-12, AS-13, AS-14, AS-15, AS-16, AS-17, AS-18, AS-19, AS-20, AS-21, AS-22, AS-23, AS-24, AS-25, AS-26, AS-27, AS-28, AS-29 and Chakwal-86 (check), at the Experimental Field, Nuclear Institute of Agriculture (NIA), Tandojam. The experiment was conducted in Randomized Complete Block Design having three replications during Rabi season, for evaluating the response of terminal heat stress in wheat genotypes. The analysis of variance revealed significant differences among the genotypes at both normal and high temperatures. Reduction in various traits was observed due to late planting, which indicated visible effects of high temperature on physio-yield traits. On the basis of average performance, tillers plant⁻¹, spikelets spike⁻¹, grain yield plant⁻¹, grains spike⁻¹, grain weight of main spike⁻¹ and biological weight plant⁻¹ showed reduction of 24.83, 7.1, 39.78, 14.87, 25.49 and 37.41, respectively under heat stress conditions. However, minimum reduction under heat stress was manifested in the wheat genotypes as AS-15, AS-26 and AS-13 for various traits, suggesting their presence of heat tolerance. Nonetheless, the advance lines AS-14 and AS-19 expressed maximum decline under heat stress displaying their susceptibility to heat stress conditions. The remaining genotypes exhibited moderate heat stress tolerance. Thus, the selected advance lines have great potential for heat tolerance and can be utilized for future breeding program.

Keywords: Bread wheat; Heat stress; Morpho-yield traits; Temperature

Introduction

Wheat is widely grown crop adapted under cool growing environment. Although it is also grown under moderately high temperature (25-32°C) for longer duration and very high temperature (33-40 °C) for a shorter period are very common in subtropical environments of South East Asia [1]. Its production in hot areas is feasible but yield has been always declined due to heat stress, especially at the stage of anthesis and grain filling. Therefore heat stress is one the main abiotic stress causing significant yield losses of wheat crop in arid, semiarid, subtropical, and tropical regions of the world [2].

According to Halford *et al.* [3] the average global temperature is rising at the rate of 0.18°C every decade. It is estimated that the climate will also be affected by continuous increase in temperature and frequency of hot days will also increase. To withhold such critical situation, it is drastically needed to adopt heat tolerant varieties and to understand the mechanism of plant response to tolerate the extreme temperature and how tolerance can be improved.

High temperature stress during reproductive development termed as terminal heat stress. Studies suggest that optimal temperature for grain set and grain filling is between 19°C and 22°C in wheat [4]. The threshold temperature considered as the value of daily mean temperature, at which a detectable reduction in growth begins, is 26°C for wheat at post anthesis stage [5]. In wheat, terminal heat stress with ambient temperature > 30°C, during reproductive development stage has been found to decrease productivity [6]. Accompanied with rising mean temperature as a result of global warming, high temperature at the time of grain filling affects grain production in many environments [7]. It is one of the major causes of yield reduction which affects more than 36 million hectares in temperate environments [8]. Both

physiological and morphological traits like chlorophyll content, canopy temperature depression, photosynthetic rate, biomass, thousand grain weights, grain yield and yield associated traits are influenced by heat stress [8]. Grain yield and its quality are the principal characters of a cereal crop. They are complex quantitative characters, which are influenced by a number of yield contributing characters. Hence, the selection for desirable genotypes should not only be based on yield alone, but other yield components should also be considered. Heat stress, being a major environmental yield constraint, its severity relies upon its intensity, duration and stage of the crop [9]. The occurrence of heat stress at reproductive stage is more harmful than vegetative stage as it causes direct effects on grain number, size of grain, dry weight and finally yield of the crops [10]. It has been reported that, the sowing dates in terms of change in temperature are critical for determining appropriate crop yields. Therefore, the present study was conducted to evaluate the performance of new wheat advance lines along with check variety, to estimate the effects of early and terminal heat stresses on yield and its associated traits.

Material and methods

The experiment comprising of twenty wheat genotypes was carried out at the experimental farm of Nuclear Institute of Agriculture, Tandojam. The experimental material were sown in Randomized Complete Block Design (RCBD) with three replications in two sowing dates *viz.* normal planting (15th November, 2016) and late planting (15th December, 2016) as to determine the effect of heat stress on reduction of yield and its components in late sowing wheat. The experiment was conducted during Rabi season 2016-2017. Daily minimum and maximum temperature were recorded throughout the season. From each replication, five plants were tagged randomly for collecting necessary data under field

conditions and some observations were recorded under the laboratory condition.

Treatments: 02

T1 Normal sowing (15th November)

T2 Late sowing (15th December)

Genotypes: 20

1. AS 11
2. AS 12
3. AS 13
4. AS 14
5. AS 15
6. AS 16
7. AS 17
8. AS 18
9. AS 19
10. AS 20
11. AS 21
12. AS 22
13. AS 23
14. AS 24
15. AS 25
16. AS 26
17. AS 27
18. AS 28
19. AS 29
20. Chakwal 86 (check)

Traits recorded:

1. Tillers plant⁻¹

2. Spikelets spike⁻¹
3. Grain yield plant⁻¹ (g)
4. Grains spike⁻¹
5. Grain weight of main spike⁻¹ (g)
6. Biological weight plant⁻¹ (g)
7. Flag leaf area (%)
8. Relative water content (%)

Results

Analysis of variance

The analysis of variance for mean squares (Table 1) indicated that heat stress has significant effect on tillers plant⁻¹, spikelets spike⁻¹, grain yield plant⁻¹, grains spike⁻¹, grains weight of main spike⁻¹, and biological weight plant⁻¹. Thus, indicating that morphological characters can be best indicator for wheat breeder for selecting heat tolerant varieties. The mean performance from analysis of variance for genotype x treatment interaction was also significant for all the studied traits. The significance of genotype x treatment interaction expressed that genotypes performed variably over the stress conditions. The present interaction can assist wheat breeder for identifying the best high yielding varieties on one or more reliable heat tolerant indicators.

Table 1. Mean squares from analysis of variance for various morphological traits of wheat genotypes grown under non- stress and heat stress conditions

Traits	Replication (D.F=2)	Genotype (G) (D.F=19)	Treatment (T) (D.F=1)	G x T (D.F=19)	Error (D.F=38)
Tillers plant ⁻¹	1.612	12.7498**	98.645**	1.0566**	0.1470
Spikelets spike ⁻¹	0.137	4.901**	49.152*	0.621*	0.163
Grain yield plant ⁻¹	0.862	85.623**	2671.171**	3.543**	1.061
Grains spike ⁻¹	1.413	304.373**	3248.961**	16.801**	0.852
Grains weight spike ⁻¹	0.013	1.187**	12.390**	0.129**	0.0226
Biological weight plant ⁻¹	0.033	205.722**	5981.232**	16.433**	0.633
Flag leaf area	14.783	83.051**	3473.733**	32.822**	4.641
Relative water content	1.641	544.713**	4523.712**	24.511**	3.143

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

Mean performance of different traits grown under stress and non-stress conditions

Tillers plant⁻¹

In non-stress conditions, tillers plant⁻¹ ranged from 4.53 to 10.4, while under heat stress condition, it ranged from 3.5 to 9.6. The average of tillers plant⁻¹ of all the genotypes in non-stress condition was 7.71 and under the heat stress condition was 5.87, thus averagely 24.68% reduction was caused by terminal heat stress. The lowest decrease percentage however was recorded by AS 15 (7.69%), closely followed by AS 26 and AS 13 (9.93 and 10.36%), respectively, under the heat stress condition. The maximum loss was observed in AS 14 with decrease percentage of (47.44%), followed by AS 29 (47.07%). The higher tillers plant⁻¹ exhibited by genotype AS 15 was 10.4 and the lowest by AS 23 4.53 in normal condition, however in heat stress conditions, the maximum tillers plant⁻¹ was obtained from AS 15 (9.06) and the less by AS 23 (3) (Table 2, Fig. 1).

Spikelets spike⁻¹

In normal condition, the range of spikelets spike⁻¹ was counted as 20.26 to 23.06, while in heat stress varieties recorded 17.93 to 22.46 spikelets spike⁻¹ (Table 2, Fig. 2). On an average, the genotypes produced 21.63 spikelets spike⁻¹ in non-stress condition and 20.1 under heat stress conditions. The reduction of 7.1 averagely noticed among the genotypes due to heat stress. The lowest decline in spikelets spike⁻¹ was observed in AS 15 (2.60%), followed by AS 26 and AS 13 (3.43% and 3.95%) respectively, in heat stress condition. The highest reduction was recorded in AS 14 (13.45%), closely followed by AS 23 (13.04%) in heat stress condition. The highest number of spikelets was counted AS 15 (23.06%) and the lowest grain was counted in AS 14 (20.26) under non-stress condition. The maximum grains spike⁻¹ was recorded in AS 15 (22.46) and minimum number of grains in AS 18 (17.93) in heat stress condition.

Table 2. Mean performance of tillers plant⁻¹ and spikelets spike⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Genotypes	Tiller plant ¹		R.D.*	Spikelets spike ⁻¹		R.D.*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
AS 11	9.73	7.86	19.21	21.73	20.23	7.04
AS 12	7.21	5.73	20.41	20.26	18.46	8.88
AS 13	9.26	8.34	10.36	22.02	21.13	3.95
AS 14	6.66	3.53	47.44	21.33	18.46	13.45
AS 15	10.42	9.62	7.69	23.06	22.46	2.60
AS 16	8.61	5.93	31.04	23.04	21.22	7.82
AS 17	7.53	6.61	12.35	21.93	20.21	7.88
AS 18	7.26	5.33	26.58	20.61	17.93	12.96
AS 19	5.81	4.26	26.55	22.04	19.66	10.63
AS 20	8.86	6.41	27.76	21.46	20.33	5.26
AS 21	5.53	3.73	32.54	20.63	19.53	5.19
AS 22	8.06	5.33	33.87	22.53	21.02	6.79
AS 23	4.53	3.01	33.77	21.02	18.26	13.04
AS 24	7.81	6.73	13.71	21.26	20.33	4.37
AS 25	7.42	5.24	29.72	21.53	20.11	7.10
AS 26	9.66	8.73	9.93	22.43	21.66	3.43
AS 27	5.73	4.41	23.21	22.21	20.86	6.03
AS 28	7.53	6.06	19.52	21.26	20.26	4.70
AS 29	8.53	4.62	46.07	21.33	20.13	5.62
Chakwal-86 (check)	8.26	6.21	24.93	21.22	20.06	5.37
Mean	7.71	5.87	24.83	21.63	20.12	7.1
LSD (5%) (G)	0.44			0.50		
LSD (5%) (T)	0.13			0.15		
LSD (5%) (G x T)	0.62			0.71		

*=Relative decrease due to heat stress treatments

Figure 1. Mean performance of tillers plant⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Figure 2. Mean performance of spikelets spike⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Grain yield plant⁻¹

In our experiment, grain yield plant⁻¹ ranged from 17.25 to 31.89g, in non-stress condition, while in heat stress condition it varied from 8.91 to 24.09g (Table 3, Fig. 3). The mean performance of all the genotypes in non-stress condition was 23.25g, however in terminal heat stress condition, it was 14.17g. On an average, 39.78% loss in grain yield plant⁻¹ occurred due to terminal heat stress. The greatest performance was observed in AS 15 with minimum reduction of (24.55%), followed by AS 26 and AS 13 (30.08% and 32.84%) respectively under heat stress condition. The highest relative decrease percentage was displayed by AS 14 (48.48%), followed by AS 19 (46.30%) in terminal heat stress condition. The maximum grain yield plant⁻¹ was opted by AS 15 (31.89g) and the minimum by AS 14 (17.25g) in non-stress condition, whereas in heat stress condition the highest grain yield plant⁻¹ was also manifested by AS 15 (24.09g) and the lowest by AS 14 (8.91g).

Grains spike⁻¹

In non-stress condition, the range of grains spike⁻¹ was counted as 60.46 to 81.13, whereas in heat stress conditions, the varieties recorded 47.86 to 76.72 grains spike⁻¹ (Table 3, Fig. 4). On the basis of an average, the genotypes produced 70.88 grains spike⁻¹ in non-stress condition and 60.35 under heat stress conditions. The reduction of 14.87 averagely noticed among the genotypes due to heat stress. The lowest decline in grains spike⁻¹ was observed in AS 15 (5.43%), followed by AS 13 and AS 16 (9.29% and 9.34%) respectively, under heat stress condition. The highest reduction was recorded in AS 14 (25.37%), followed by AS 28 (22.79%) in heat stress condition. The highest grain number was counted by AS 15 (81.13) and the lowest grain was counted in AS 23 (60.46) under non-stress condition. The maximum grains spike⁻¹ was recorded in AS 15 (76.72) and minimum number of grains in AS 14 (47.86) in heat stress conditions.

Table 3. Mean performance of grain yield plant⁻¹ and grains spike⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Genotypes	Grain yield plant ⁻¹		R.D. *	Grains spike ⁻¹		R.D. *
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
AS 11	22.73	13.19	41.97	67.41	53.43	20.72
AS 12	25.93	15.13	41.65	64.26	55.42	13.78
AS 13	27.07	18.18	32.84	79.01	71.66	9.29
AS 14	17.25	8.91	48.48	64.13	47.86	25.37
AS 15	31.89	24.09	24.45	81.13	76.72	5.43
AS 16	25.35	15.71	38.06	78.14	70.84	9.34
AS 17	22.01	13.42	39.02	75.18	65.83	12.43
AS 18	23.63	14.78	37.45	74.21	63.52	14.39
AS 19	18.42	9.89	46.30	66.66	53.82	19.29
AS 20	26.95	17.36	35.58	76.83	64.54	15.99
AS 21	19.46	10.98	43.57	74.61	66.46	10.91
AS 22	24.11	14.97	37.90	65.44	53.06	14.33
AS 23	18.79	10.28	45.29	60.46	53.35	11.75
AS 24	22.94	13.17	42.58	69.62	55.29	20.56
AS 25	23.63	13.18	44.22	66.66	54.82	17.79
AS 26	28.29	19.78	30.08	80.66	72.23	10.48
AS 27	18.25	11.46	37.20	73.13	63.23	13.53
AS 28	21.97	11.98	45.47	70.82	54.66	22.79
AS 29	23.16	13.03	43.73	61.83	51.73	16.29
Chakwal-86 (check)	23.31	14.01	39.87	67.56	58.83	13.01
Mean	23.25	14.17	39.78	70.88	60.35	14.87
LSD (5%) (G)	1.14			1.07		
LSD (5%) (T)	0.36			0.34		
LSD (5%) (GxT)	1.62			1.52		

* =Relative decrease due to heat stress treatments

Figure 3. Mean performance of grain yield plant⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Figure 4. Mean performance of grains spike⁻¹ for wheat genotypes grown under non-stress and heat stress conditions

Grains weight of main spike⁻¹(g)

According to the results of grain weight of main spike⁻¹, the highest value for main spike yield was recorded in AS 15 (3.66 g) spike⁻¹, while lowest value was observed in AS 14 (2.02 g) at normal temperature (Table 4, Fig. 5). Maximum main spike yield was observed in AS 15 (3.04 g) spike⁻¹ and minimum main spike yield was observed in AS 14 (1.06 g) in high temperature condition. However, decrease percent for main spike yield among genotypes ranged from 7.10 to 47.52 %. Genotype AS 15 showed less reduction (7.10%) in main spike yield.

Biological weight plant⁻¹

In non-stress conditions, the biological weight plant⁻¹ ranged from 46.73 to 64.01 g, while under heat stress condition, it ranged from 25.04 to 53.33 g. The average biological

yield of all the genotypes in non-stress condition was 55.24 g and under the heat stress condition was 40.35 g, in this way, averagely 37.41% reduction was brought about by terminal heat stress. The lowest decrease percentage however was recorded by AS 15 (16.71 %), closely followed by AS 26 and AS 13 (17.97 and 18.62%), respectively, under the heat stress condition. The maximum loss was observed in AS 14 with decrease percentage of (46.50 %), followed by AS 19 (42.91 %). The higher biological weight plant⁻¹ exhibited by genotype AS 15 was 64.01 g and lowest by AS 14 46.73 g in non- stress condition, while in heat stress conditions, the greater biological weight plant⁻¹ was obtained from AS 15 (53.33 g) and the less by AS 14 (25.04 g) (Table 4, Fig. 6).

Table 4. Mean performance of grain weight spike⁻¹ and biological weight plant⁻¹ for different

Genotypes	Grain weight spike ⁻¹		R.D.*	Biological weight plant ⁻¹		R.D.*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
AS 11	2.81	1.79	36.29	51.03	37.63	26.27
AS 12	2.71	2.31	14.76	58.04	41.66	28.27
AS 13	2.88	2.51	12.84	55.33	45.01	18.62
AS 14	2.02	1.06	47.52	46.73	25.04	46.50
AS 15	3.66	3.43	7.10	64.01	53.33	16.71
AS 16	2.78	2.39	14.02	60.33	46.72	22.55
AS 17	2.23	1.92	14.79	54.04	42.31	21.66
AS 18	2.57	2.19	14.78	56.66	45.01	20.49
AS 19	2.06	1.15	44.17	47.33	27.02	42.91
AS 20	2.81	2.41	13.92	61.33	48.83	20.34
AS 21	2.84	1.71	40.14	47.33	31.11	34.52
AS 22	2.66	2.03	23.68	54.33	39.62	27.11
AS 23	2.64	1.83	30.68	49.51	35.63	28.08
AS 24	2.69	1.73	35.68	60.66	44.61	26.47
AS 25	2.52	2.02	19.84	58.31	43.02	26.24
AS 26	3.11	2.81	9.67	57.33	47.04	17.97
AS 27	2.54	1.57	38.18	48.03	37.11	22.91
AS 28	2.89	2.02	30.10	60.05	38.03	36.66
AS 29	2.41	1.49	37.91	51.33	31.02	39.60
Chakwal-86 (check)	2.77	2.11	23.82	63.53	48.01	24.40
Mean	2.67	2.02	25.49	55.24	40.35	37.41
LSD (5%) (G)	0.17			0.93		
LSD (5%) (T)	0.05			0.29		
LSD (5%) (G x T)	0.24			1.32		

wheat genotypes grown under non-stress and heat stress conditions

*=Relative decrease due to heat stress treatment

Figure 5. Mean performance of grain weight spike⁻¹ for different wheat genotypes grown under non-stress and heat stress conditions

Figure 6. Mean performance of biological weight plant⁻¹ for wheat genotypes grown under non-stress and heat stress conditions

Flag leaf area (cm²)

The flag leaf area ranged from 28.91 to 47.33 cm² under non-stress conditions and 19.93 to 33.43 cm² in heat stress conditions. Nonetheless, the average of all the genotypes was 36.03 cm² in non-stress conditions and 25.78 cm² under heat stress conditions. On an average, heat stress caused 28.05% decline (Table 5, Fig. 7). The highest loss in leaf area was observed in AS 14 (50.52%), followed by AS 19 (39.95%) under heat stress conditions. The lowest decline was noted in AS 15 (13.61%), followed by AS 13 and AS 16 (17.16 and 17.63 %) in heat stress conditions. The maximum flag leaf was found in AS 14 (47.33 cm²) under non-stress condition. The greatest flag leaf was noticed in AS 16 (33.43) and the lowest in AS 21 (19.93) due to heat stress.

Relative water content (%)

The range of relative water content was from 70.25 to 90.46% under sown crop, whereas in late sowing dates, it ranged from 54.67 to

84.91% (Table 5). The mean performance of all the genotypes grown under non-stress conditions was 76.37%, while in heat stress conditions, it was 63.88%. Heat stress caused a decline of 16.67 on an average, over the genotypes (Table 5, Fig. 8). The best performance of relative water content under the heat stress condition was given by genotype AS 15 with the lowest decrement percentage of 6.13%. After AS 15, the highest performance was expressed by genotypes AS 26 and AS 13 with lower relative decline of 8.16% and 10.03%, respectively. The maximum reduction 22.22%, however was recorded in AS 14, which was followed by AS 28 26.41% in terminal heat stress condition. In non-stress conditions, the greatest value was noted in genotype AS 15 (90.46%) and the lowest value was expressed by AS 28 (70.25%), whereas in heat stress conditions, the highest percentage of decline was recorded in AS 15 (84.91%) and the lowest in AS 28 (51.69%).

Table 5. Mean performance for relative water content (%) and flag leaf area (cm) of wheat genotypes grown under non-stress and heat stress conditions

Genotypes	Relative water content %		R.D.*	Flag leaf area		R.D.*
	Non-stress	Heat stress	%	Non-stress	Heat stress	%
AS 11	72.47	64.7	10.72	34.76	26.83	22.81
AS 12	78.12	67.64	13.41	29.32	21.37	27.11
AS 13	83.72	75.32	10.03	36.87	30.54	17.16
AS 14	70.29	54.67	22.22	43.07	21.31	50.52
AS 15	90.46	84.91	6.13	34.61	29.84	13.78
AS 16	75.38	61.31	18.66	40.59	33.43	17.63
AS 17	71.54	64.29	10.13	38.37	28.48	26.39
AS 18	74.94	59.21	20.99	34.97	25.73	26.42
AS 19	73.14	57.8	20.97	47.33	28.42	39.95
AS 20	80.83	67.86	16.04	34.88	27.66	20.69
AS 21	73.92	59.1	20.04	30.86	19.93	35.41
AS 22	76.52	66.22	13.46	36.75	22.67	38.31
AS 23	71.69	57.62	19.62	32.64	21.01	35.63
AS 24	71.92	57.73	19.73	28.91	20.79	28.08
AS 25	73.31	61.14	16.60	40.49	28.15	30.47
AS 26	88.78	81.53	8.16	32.23	26.14	18.89
AS 27	80.66	69.59	13.72	37.8	25.01	33.83
AS 28	70.25	51.69	26.41	32.13	25.02	22.12
AS 29	79.33	66.58	16.07	37.73	26.83	28.88
Chakwal-86 (check)	72.33	58.55	19.12	36.45	26.6	27.02
Mean	76.37	63.88	16.67	36.03	25.78	28.05
LSD (5%) (G)	2.01			2.26		
LSD (5%) (T)	0.63			0.71		
LSD (5%) (G x T)	2.84			3.19		

* =Relative decrease due to heat stress treatments

Figure 7. Mean performance of flag leaf area (cm²) for different wheat genotypes grown under non-stress and heat stress conditions

Figure 8. Mean performance of relative water content% for wheat genotypes grown under non-stress and heat stress conditions

Discussion

Heat stress is increasing at an alarming rate and reducing wheat production at a large scale. To determine that, at what extent wheat production is influencing, a detailed study was conducted to determine the effects of heat on newly developed advance wheat lines. In tillers plant⁻¹, an average, 24.68 % reduction was caused by terminal heat stress. The lowest decrease percentage however was recorded by AS 18 (3.58 %), closely followed by AS 11 and AS 15 (8.94 and 12.88 %), respectively, under the heat stress conditions. The maximum loss was observed in AS 14 with decrease percentage of (47.44 %), followed by AS 29 (47.07 %). In non-stress conditions, tillers plant⁻¹ ranged from 4.53 to 10.4, while under heat stress conditions, it ranged from 3 to 9.6. The higher tillers plant⁻¹ exhibited by genotype AS 15 (10.4) and lowest by AS 23 (4.53) in non- stress conditions, whereas in heat stress conditions, the greater tillers plant⁻¹ was obtained from AS 15 (9.06) and the less by AS 23 (3) (Table 2). Spikelets spike⁻¹ is also a main character contributing towards increase in yields. As spikelets spike⁻¹ increase ultimately number of the grain spike⁻¹ will increase, resulting in higher grain yield plant⁻¹. Maximum number of spikelets spike⁻¹ was recorded in AS 15 (23.06) and minimum spikelets spike⁻¹ was observed in AS 12 (20.26) at normal temperature. At high temperature stress, maximum number of spikelets spike⁻¹ was recorded in AS 15 (22.46) and less spikelets spike⁻¹ exhibited in AS 23 (18.26). The decrease percent for number of spikelets spike⁻¹ among genotypes ranged from 2.60 to 13.45 %. The genotype AS 14 and AS 18 showed the highest reduction (13.46 and 12.96 %). However, the genotypes AS 15, AS 26 and AS 13 exhibited less reduction in number of spikelets spike⁻¹ (2.60, 3.43 and 3.95%), respectively. Considering the reduction percentage for spikelets spike⁻¹, the present results showed valuable results under

stress condition. Hence, those genotypes showing low reduction in number of spikelets spikes⁻¹ can be used as genetic stock for future breeding program. These results are in accordance with Irshad *et al.* [11]. Heat stress caused a decline of 40.04 % averagely under the heat stress condition. The best performance was showed by AS 15 with minimum decrease of 24.45 %, followed by AS 26 and AS 13 (30.08 and 32.84 %), respectively. Whereas, the lowest performance was recorded by AS 14, followed by AS 19 with increased reduction of (48.48 and 46.30%) in grain yield plant⁻¹ under heat stress conditions. In normal conditions, harvest index ranged 31.89 to 17.25 g, whereas under the heat stress conditions, it ranged from 8.91 to 24.09 g. Grains spike⁻¹ is also a key character in wheat breeding; it directly involves enhancing the grain yield plant⁻¹. Heat stress caused a decline of 14.87 % averagely, in all the varieties grown under late sowing condition (Table 3). The highest reduction was observed in AS 14 (25.37 %), followed by AS 28 (22.79 %) under heat stress conditions. The lowest reduction was noticed in AS 15 (5.43 %), closely followed by AS 13 and AS 26 (9.29 and 10.39 %, respectively) under heat stress conditions. In normal conditions, grains spike⁻¹ ranged from 60.46 to 81.13, while in heat stress conditions, it ranged from 47.86 to 71.66. The present results are in agreement of Hanson [12] who found significant difference in number of grain spike⁻¹ with different sowing dates. The results of Hanson [12] further revealed that greater number of grains spike⁻¹ can be due to favorable temperature at the stage of seed development and maximum number of branches plant⁻¹ with more productive spikes. Abd El-Majeed [13] and El-Ameen [14] noticed huge reduction in grain numbers because of late sowing and temperature stress. These findings were also supported by Hamam [15] who found 18.13% decline in

grains number per spike due to terminal heat stress. Grain weight spike⁻¹ is a key trait in wheat breeding, because it directly influence with grain yield plant⁻¹. Heat stress during the grain filling period resulted in reduced grain development, ultimately decreased the grains weight in wheat crop [16]. For grain weight spike⁻¹, the highest value was recorded in AS 15 (3.66 g) spike⁻¹, while lowest value was recorded for AS 14 (2.02 g) at normal temperature. Considering the high temperature, maximum value for main spike yield was observed in AS 15 (3.04 g) spike⁻¹ and minimum was observed in AS 14 (1.06 g). The decrease percent for main spike yield among genotypes ranged from 7.10 to 47.52 %. The genotype AS 15 showed less reduction (7.10%) in main spike yield, indicating that these genotypes have great potential towards high temperature tolerance. High temperature reduces the grain filling period, which cause reduction in grain weight. Mumtaz *et al.* [17] Menshawy [18] and Khokhar *et al.* [19] found that early sowing wheat give higher grain weight spike⁻¹ as compared to late sowing wheat which may be due to longer grain filling duration in early planting and exemption from terminal heat stress. Our results are in agreement with Laghari *et al.* [20] who also reported 45.83% reduction in grain weight due to terminal heat stress. With respect to biological weight plant⁻¹, wheat genotypes showed different response for this trait at various planting dates. Maximum biological weight plant⁻¹ was observed in AS 15 (64 g) and minimum biological weight plant⁻¹ was observed in AS 14 (46.73 g) at normal temperature. At high temperature, the maximum biological weight plant⁻¹ was observed in AS 15 (53.3 g) and minimum biological weight plant⁻¹ was observed in AS 14 (25 g). The decrease percent for biological weight plant⁻¹ among genotypes ranged from 16.71 to 46.50 %. The genotypes AS 14 and AS 19 showed the highest reduction (46.50 and 42.91 %,) in

biological weight plant⁻¹, respectively. However, minimum reduction was noticed in AS 15 16.71 %, followed by AS 26 (17.97 %) and AS 13 (18.62%), under heat stress. Irfaq [21] Laghari *et al.* [20] Hossain *et al.* [22] and Alam *et al.* [23] reported reduction in the biological weight plant⁻¹ in all the wheat genotypes grown under heat stress condition in their experiments. Their results also support our findings that terminal heat stress is a major constraint in the development of flag leaf area. Dabi *et al.* [24] found that heat stress caused by late sowing significantly decreased the flag leaf area. On an average, heat stress caused decline of 28.05% in flag leaf area. The minimum relative decrease was however recorded in AS 15 (13.61%), followed by AS 13 and AS 16 (17.16 and 17.63%), respectively under high temperature. The maximum reduction nevertheless was measured in AS 14 and AS 19 (50.52 and 39.95%), respectively in heat stress condition. In the optimum temperature, flag leaf area ranged from 28.91 to 47.33 cm², while in heat stress conditions, it ranged from 19.93 to 33.43 cm² (Table 6). Terminal heat stress caused a reduction of 16.67% averagely under late sowing date (Table 6). Nonetheless, maximum reduction was noticed in AS 14 (23.64%), followed by AS 19(22.34%) in heat stress condition. Whereas, minimum reduction was recorded in AS 15 (6.13%) followed by AS 26 and AS 13 (8.16% and 10.03%, respectively) under heat stress condition. The highest relative water content was measured in genotype AS 15 (90.46%) under the both non-stress as well as in the heat stress (84.91%) conditions. The lowest relative water content was observed in genotype AS 14 in non-stress (70.29%) as well as in heat stresses (53.67%) conditions.

Authors' contributions

Conceived and designed the experiments: TF Abro & WD Sipio, Performed the experiments: ZA Soomro & WD Sipio, Analyzed the data: AW Baloch, WA Jatoi &

GM Bhanbhan, Contributed materials/ analysis/ tools: AH Mastoi, KA Laghari & M Arsal, Wrote the paper: TF Abro & MA Mastoi.

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