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Use of Heat Susceptibility Index as a Measure of Heat Tolerance in Wheat

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ABSTRACT

Keywords

Wheat, Heat Susceptibility Index, Heat tolerance, Temperature Stress, Canopy Temperature

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High temperature is a major environmental stress factor limiting wheat (*Triticum aestivum L.*) productivity. Improvement of heat tolerance in wheat is an important breeding objective. The present investigation was carried out to evaluate and identify terminal heat tolerant bread wheat genotypes on the basis heat susceptibility index. This experiment was conducted using 20 genotypes in split plot design with three replications under three dates of sowing i.e. 24th December, 4th January and 14th January. Various traits like days to 50 percent flowering, days to maturity, plant height (cm), earhead length (cm), spikelets spike^{-1}(No), grains spike^{-1}(No), grain yield per plant(g), grain yield per plot(g), leaf rolling(%), canopy temperature depression (CTD) (^{0}C) and 1000 grain weight(g) were studied and used for the calculation of heat susceptibility index (HSI). Among all genotypes, NIAW 3583, NIAW 3578, NIAW 3895, NIAW 3991 and Netravati had minimum values of HSI for different traits, representing high temperature tolerance of these genotypes. On the other hand wheat genotypes which are heat susceptible on basis of HSI viz., NIAW 3170, NIAW 4013, NIAW 3927 and NIAW 4033 had high HSI value with optimum mean yield.

Introduction

Wheat (*Triticum aestivum L.*) is a self-pollinating annual plant belonging to the family Poaceae (grasses) and genus Triticum. It is one of the most important cereal crops for the majority of world's population as it is used as a staple food of about two billion people (i.e. approximately 40% of world population).

The growing pace of population is declining the cultivated land which is a great concern for world's food security. With the passage of time this problem will be intensified further demanding increased cereal production to 1.7-fold to meet future challenges of food security (Mba *et al.*, 2012). Due to advantage of wheat crop for its adaptability to variable climate and low-cost productivity, the International Food Policy Research Institute (IFRI) has taken up wheat improvement programme as more effective measure to meet the food security of the world (Pinstrup-Andreson, 2001). The National Commission on Agriculture also has estimated that India needs approximately 110 million tons of wheat by 2020 (Joshi, 2007). However, to meet the demand for food for growing population, a significant increase in the grain production is required, particularly in crops like wheat which is among one of the largest food crops in terms of area of cultivation and production. This demand can be met by developing high yielding varieties and varieties resistant to biotic and abiotic stresses. A number of abiotic stresses like drought, floods, high temperature, salinity, chilling etc. are responsible for yield losses over world including India.

It has been reported that seed germination and seedling emergence in wheat are adversely affected by exposure to heat stress or high temperature (Tewolde *et al.*, 2006). Lower grain weight and altered grain quality are the two reported manifestations of heat stress during the post anthesis grain filling stage by affecting availability and translocation of photosynthates to the developing kernel, and start synthesis and deposition within kernel (Bhullar and Jenner, 1985). Wheat productivity is adversely affected by heat stress in arid, semi-arid, tropical and sub-tropical regions of the world (Fischer, 1986). Heat stress has negative impact on growth and development of wheat according to various reports. Heat stress changed the morphology and reduced the grain size, plant height, grain growth duration, kernel number and kernel weight.

Terminal heat stress (high temperature > 32ºC), as a result of global warming, at the time of grain filling is a major limitation to wheat production in many environments and is major cause of yield reduction (Hays *et al*.,2007).A significant portion of wheat grown in South Asia is considered to be affected by heat stress, of which the majority is present in India (Joshi *et al.*, 2007).The losses upto 50% in yield potential have been estimated when crop is expressed to 32-38ºC temperature at crucial grain formation stage (Wardlaw *et al*.,1989).

Present trend in India and neighbouring countries indicate that the “Cool period” for wheat crop is shrinking which indicate the threat of increasing terminal heat stress (Joshi *et al.*, 2007). Hence, wheat crop improvement programme is aimed at development of varieties tolerant to late heat stress. Thus, the present investigation was undertaken with to study the effect of staggered sowing on thermo tolerance in wheat genotypes by calculating their heat susceptibility index.

Materials and Methods

The present investigation was carried out at Botany Farm, College of Agriculture, Pune during Rabi season, 2018-19 for evaluation and identification of wheat genotypes for thermotolerance. The experiment was conducted in a split plot design with three staggered sowing as D1: 24^{th} December 2018, D2:4^{th} January 2019, D3:14^{th} January 2019 and three replications. The experimental material for the study consisted of 20 genotypes of wheat obtained from Wheat Research Station, Niphad, MPKV Rahuri, Maharashtra. The list of genotypes along with their source is presented in Table 1.

Various morphological, physiological and biochemical observations are recorded like days to 50 percent flowering, days to maturity, plant height (cm), earhead length (cm), spikelets spike^{-1} (No), grains spike^{-1} (No), grain yield per plant(g), grain yield per plot(g), leaf rolling(%), canopy temperature depression (CTD) (^{0}C) and 1000 grain weight(g). Heat susceptibility index (HSI) was calculated for grain yield and other quantitative traits twice, first over normal sown (D1-24^{th} Dec.2018) and late sown condition (D2-4^{th} Jan.2019) and second over normal sown (D1-24^{th} Dec.2018) and very late sown condition (D3-14^{th} Jan 2019) by using the formula as suggested by Fisher and Maurer (1978).

HSI = [l-YD/YP]/D

Where,

YD = mean of the genotypes in stress environment.
YP = mean of the genotypes under non-stress environment.
D = 1-[mean YD of all genotypes/mean YP of all genotypes].

Results and Discussion

Days to 50% flowering

In this experiment, for days to 50 % flowering over D1 and D2 condition, the highest heat susceptibility index value was recorded by the genotype NIAW3170 (1.60) followed by NIAW 4013(1.37), NIAW 3927 (1.36) and NIAW 4033 (1.35). The lower values were recorded by the genotypes NIAW 3578 (0.60), NIAW 3583 (0.64), NIAW 3895 (0.72) and NIAW 3771 (0.78) indicated their tolerance to late sown condition. HSI values over D1 and D3 condition was higher for genotypes NIAW 3170 (1.31), NIAW 3927 (1.17) and lowest for genotypes NIAW 3583 (0.63), NIAW 3578 (0.64) and NIAW 3895 (0.79) (Table 2).

Days to maturity

HSI for days to maturity varied among the genotypes. Over D1-D2 condition, higher HSI was observed in genotypes viz; NIAW 4033 (4.77), NIAW 3898 (4.67), NIAW3170 (4.65), NIAW 4013 (4.63) and NIAW 3927 (4.43) Lower HSI was observed in genotypes NIAW 3583 (0.82).

For D1-D3 condition, genotypes NIAW 4013 (1.97), NIAW 3927 (1.24), NIAW 4033 (1.13), NIAW 3170 (1.09) and NIAW 3975 (1.16) showed greater HIS. While genotypes NIAW 3583 (0.69), NIAW 3991 (0.72), NIAW 3578 (0.73), Netravati (0.75) and NIAW 3983 (0.76) had less HSI.

Plant height

Highest HSI for plant height over D1-D2 condition was obtained for genotype NIAW 3170 (2.28) followed by NIAW 4013 (2.15), NIAW 3908 (1.26), NIAW 3898 (1.24), NIAW 3927 (1.22) and NIAW 4033 (1.21). Highest HSI for D1-D3 condition was observed in genotype NIAW 4013 (2.64) followed by NIAW 3170 (2.11), NIAW 3927 (1.11) and NIAW 3898 (1.08). While lower HSI was observed in genotypes NIAW 3991 (0.70), NIAW 3578 (0.86), NIAW 3583 (0.88), NIAW 3895 (0.88), Netravati (0.89) and checks NIAW 34 (0.98) and Phule Samadhan (0.92).

Genotypes like NIAW 3170, NIAW4013, NIAW3908, NIAW 3927 are susceptible to high temperature as they possessed more HSI value. While genotypes like NIAW 3895, NIAW 3583, NIAW 3991, Netravati and NIAW 3578 are highly heat tolerant as they had less HSI values.

1000 grain weight (g)

Among 20 genotypes, over D1-D2 condition, highest HSI for 1000 grain weight was observed in the genotype NIAW 3927 (2.16) followed by NIAW 3170 (2.08), NIAW 3942 (2.02), NIAW 3947 (1.15) and NIAW 4013 (1.10). Genotype NIAW 3583 (0.13) exhibited lowest HSI followed by NIAW 3895 (0.65), NIAW 3771 (0.77), NIAW 3991 (0.83) and NIAW 3908 (0.90). Whereas, under D1-D3 condition, highest HSI was calculated for genotype NIAW 3170 (2.38) showing its susceptibility to high temperature.

Genotypes which are having high HSI value for various yield contributing traits like 1000 grain weight, number of spiklets per spike, number of grains per spike are susceptible to high temperature. On the contrary, genotypes which had less HSI values are tolerant to high temperature condition.

Number of grains per spike

Over D1-D2 condition, highest HSI for number of grains per spike was recorded for genotype NIAW 3170 (1.49). While lowest HSI was obtained for NIAW 3583 (-0.39) showing its high tolerance to temperature stress condition. Over D1-D3 condition, genotypes NIAW 3977 (1.98), NIAW 4013 (1.95), NIAW 3170 (1.85) and NIAW 4033 (1.89) had high HSI for number of grains per spike.

Number of spikelets per spike

Genotype NIAW 3170 (2.58) had highest HSI for number of spikelets per spike over D1-D2 condition. Next to this, genotypes NIAW 4033 (2.17), NIAW 3975 (1.62) and NIAW 4013 (1.54) had high HSI than that of checks NIAW 34 (0.90) and Phule Samadhan (1.10) showing their susceptible nature to high temperature condition. On the contrary genotypes, NIAW 3583 (0.27), NIAW 3895 (0.46), Netravati (0.52) and NIAW 3578 (0.71) had less HSI.

HSI for number of spikelets per spike over D1-D3 condition was highest for NIAW 4013 (1.87) followed by NIAW 3170 (1.57), NIAW 3927 (1.54), NIAW 4013 (1.53) and NIAW 3975 (1.49) and showed more HSI than the checks NIAW 34 (1.01) and Phule Samadhan (1.23). While lowest HSI was obtained for genotype NIAW 3895 (0.07) which was followed by NIAW 3578 (0.36), NIAW 3583 (0.38), Netravati (0.44) and NIAW 3991 (0.50).

Earhead length

In this experiment, for earhead length over D1 and D2 condition, the highest HSI value was recorded for genotype NIAW 3975 (1.71) which was followed by NIAW 3927 (1.56), NIAW 4013 (1.48), NIAW 3170 (1.45) and the checks NIAW34 (1.17) and Phule Samadhan (1.00) showed their high susceptibility for late sown condition and lower values were recorded by the genotypes NIAW 3578 (-0.06), NIAW 3895 (-0.59), NIAW 3583 (-1.15) and NIAW 3927 (0.21) indicated their tolerance to late sown condition.

Table.1 List of 20 genotypes of Wheat

S. No.	Genotypes	S. No.	Genotypes
1.	NIAW-3977	11.	NIAW-3578
2.	NIAW-3583	12.	NIAW-3170
3.	NIAW-3771	13.	NIAW-3898
4.	NIAW-3895	14.	NIAW-3908
5.	NIAW-3927	15.	Netravati
6.	NIAW-3991	16.	NIAW-34
7.	NIAW-3983	17.	Phule Samadhan
8.	NIAW-3980	18.	NIAW-4013
9.	NIAW-4093	19.	NIAW-3947
10.	NIAW-3942	20.	NIAW-3975

Table.2 Heat susceptibility index

Heat Susceptibility Index									
Sr. No.	**Genotype**	**Days for 50 % flowering**		**Days for Maturity**		**Plant height**		**1000 grain weight**	
		D1-D2	D1-D3	D1-D2	D1-D3	D1-D2	D1-D3	D1-D2	D1-D3
1	NIAW 3977	0.94	1.09	3.16	0.86	0.71	0.92	1.06	1.25
2	NIAW 3583	0.64	0.63	0.82	0.69	0.58	0.88	0.13	0.32
3	NIAW 3771	0.78	0.82	2.88	0.77	1.11	0.98	0.77	0.64
4	NIAW 3895	0.72	0.79	1.21	0.75	0.19	0.88	0.65	0.77
5	NIAW 3927	1.36	1.17	4.43	1.24	1.22	1.11	1.02	2.34
6	NIAW 3991	0.79	0.84	3.06	0.72	0.47	0.70	0.83	0.76
7	NIAW 3983	0.98	1.03	1.37	0.76	1.25	1.04	1.08	1.20
8	NIAW 3980	0.93	1.01	1.62	0.87	1.17	1.02	1.06	1.20
9	NIAW 4033	1.35	1.16	4.77	1.13	1.21	1.06	0.82	1.03
10	NIAW 3942	0.81	0.98	1.72	0.91	1.25	1.01	2.02	1.22
11	NIAW 3578	0.60	0.64	1.65	0.73	0.70	0.86	0.99	0.92
12	NIAW 3170	1.60	1.31	4.66	1.09	2.28	2.11	2.08	2.38
13	NIAW 3898	1.00	1.12	4.67	0.77	1.24	1.08	0.96	1.15
14	NIAW3908	0.95	0.92	3.20	0.92	1.26	1.06	0.90	1.06
15	NETRAVATI	0.90	0.96	3.29	0.75	0.58	0.89	0.98	0.70
16	NIAW 34	0.96	0.99	2.47	0.93	0.75	0.98	1.04	1.17
17	Phule Samadhan	0.81	0.95	2.25	0.93	0.93	0.92	1.05	1.10
18	NIAW 4013	1.37	1.18	4.63	1.97	2.15	2.64	1.10	1.27
19	NIAW 3947	0.98	1.07	2.35	0.82	1.05	1.05	1.15	1.34
20	NIAW 3975	0.99	1.08	3.87	1.06	0.89	0.98	1.04	1.28

Table.3 Heat susceptibility index

Heat Susceptibility Index									
Sr. No.	**Genotype**	**No. of grains per spike**		**No. of spikelets per spike**		**Earhead length**		**Leaf Rolling**	
		D1-D2	D1-D3	D1-D2	D1-D3	D1-D2	D1-D3	D1-D2	D1-D3
1	NIAW 3977	0.96	1.98	1.43	1.32	0.50	0.60	1.51	0.60
2	NIAW 3583	-0.39	0.60	0.27	0.38	-1.15	0.34	0.47	1.18
3	NIAW 3771	0.47	0.93	1.14	1.38	1.56	1.43	0.61	0.33
4	NIAW 3895	0.40	0.45	0.46	0.07	1.23	0.21	1.24	0.89
5	NIAW 3927	0.79	1.67	1.13	1.54	1.56	1.24	2.73	1.61
6	NIAW 3991	0.42	0.94	0.89	0.50	1.22	0.27	0.55	0.56
7	NIAW 3983	0.68	1.23	1.12	1.38	1.18	1.05	1.35	1.42
8	NIAW 3980	0.52	0.97	1.37	1.29	1.33	0.99	0.89	1.33
9	NIAW 4033	0.80	1.89	2.17	1.45	1.43	1.42	3.21	3.17
10	NIAW 3942	0.84	1.20	1.23	1.14	0.84	1.10	0.73	1.08
11	NIAW 3578	0.02	1.84	-0.71	0.36	-0.06	-0.16	0.47	0.46
12	NIAW 3170	1.49	1.85	2.58	1.57	1.45	1.58	5.49	2.38
13	NIAW 3898	0.85	1.89	1.20	1.31	0.26	0.28	2.06	5.40
14	NIAW3908	1.01	0.72	1.15	0.36	1.48	1.67	0.35	0.60
15	NETRAVATI	-0.28	0.10	0.52	0.44	1.19	0.92	0.61	0.57
16	NIAW 34	0.44	0.68	0.90	1.01	1.17	1.38	0.32	0.65
17	Phule Samadhan	0.39	0.86	1.10	1.23	1.00	1.20	1.04	1.35
18	NIAW 4013	0.78	1.95	1.54	1.87	1.48	0.37	1.49	1.65
19	NIAW 3947	0.58	1.69	1.40	1.41	0.91	0.89	1.19	0.88
20	NIAW 3975	1.31	1.91	1.08	1.49	1.71	0.50	1.12	0.35

Table.4 Heat susceptibility index

		Heat susceptibility Index					
Sr. No.	**Genotype**	**CTD**		**Yield per plant**		**Yield Per plot**	
		D1-D2	D1-D3	D1-D2	D1-D3	D1-D2	D1-D3
1	NIAW 3977	0.79	1.01	1.11	1.05	1.41	1.25
2	NIAW 3583	0.31	0.89	0.50	0.80	-0.25	0.11
3	NIAW 3771	0.86	0.93	0.72	1.04	0.55	0.63
4	NIAW 3895	1.13	0.56	0.73	0.80	-0.28	0.09
5	NIAW 3927	1.45	1.04	0.85	0.99	1.48	1.23
6	NIAW 3991	1.09	1.03	0.26	0.87	1.02	0.89
7	NIAW 3983	0.46	1.03	0.98	1.10	0.46	1.14
8	NIAW 3980	0.80	0.69	0.98	1.03	1.16	1.12
9	NIAW 4033	1.14	1.21	1.12	1.17	1.59	1.62
10	NIAW 3942	0.50	1.14	1.06	1.01	1.32	1.15
11	NIAW 3578	0.34	0.97	0.68	0.89	0.54	1.21
12	NIAW 3170	1.14	1.34	2.26	1.89	1.55	1.34
13	NIAW 3898	1.43	1.01	0.96	1.03	1.56	1.29
14	NIAW3908	1.06	0.64	1.10	1.04	0.82	0.96
15	NETRAVATI	1.12	1.03	0.93	1.02	0.75	1.04
16	NIAW 34	1.09	1.02	0.85	0.87	1.07	0.86
17	Phule Samadhan	1.00	1.02	0.90	1.00	1.10	0.91
18	NIAW 4013	1.22	1.06	2.31	2.18	1.54	1.35
19	NIAW 3947	0.84	1.24	1.15	1.04	0.78	1.22
20	NIAW 3975	1.36	0.55	1.14	1.03	1.29	1.23

HSI over D1 and D3 condition was more for genotypes NIAW 3908 (1.67), NIAW 3170 (1.58), NIAW 3991 (1.58), NIAW 3771 (1.43) and NIAW 3578 (1.49). While less HSI was observed for genotypes NIAW 3578 (-0.16), NIAW 3895 (0.21), NIAW 3898 (0.28), NIAW 3583 (0.34) and NIAW 3895 (0.79) indicated their tolerance for very late sown condition.

Leaf rolling (%)

For leaf rolling, higher HSI values over D1-D2 condition were obtained for genotypes NIAW 3170 (5.49), NIAW 4033 (3.21), NIAW 3927 (2.73) and NIAW 3898 (2.06). While lower HSI was obtained for NIAW 34 (0.32), NIAW 3908 (0.35), NIAW 3578 (0.47), NIAW 3583 (0.47) and NIAW 3977 (0.54).

HSI for leaf rolling over D1-D3 condition was highest for NIAW 3898 (5.40) followed by NIAW 4033 (3.17), NIAW 3170 (2.38), NIAW 4013 (1.65) and NIAW 3927 (1.67) as compared to checks NIAW 34 (0.65) and Phule Samadhan (1.35). While lowest HSI was obtained for genotype NIAW 3975 (0.35) which was followed by NIAW 3771 (0.33), NIAW 3578 (0.46), NIAW 3991 (0.56) and Netravati (0.57) (Table 3).

Canopy Temperature Depression (CTD)

Genotype NIAW 3927 (1.45) had highest HSI for canopy temperature depression (CTD) over D1-D2 condition. Next to this, genotypes NIAW 3898 (1.43), NIAW 3170 (1.42) and NIAW 4013 (1.22) had high HSI than that of checks NIAW 34 (1.09) and Phule Samadhan (1.00) showing their susceptible nature to high temperature condition. On the contrary genotypes NIAW 3583 (0.31), NIAW 3578 (0.34), NIAW 3983 (0.46) and NIAW 3942 (0.50) had less HSI.

HSI value for canopy temperature depression (CTD) over D1-D3 condition was highest for NIAW 3170 (1.34) followed by, NIAW 3947 (1.24), NIAW 4033 (1.21), NIAW 3942 (1.14) and NIAW 4013 (1.06) as compared to checks NIAW 34 and Phule Samadhan (1.02). While lowest HSI was obtained for genotype NIAW 3975 (0.55) which was followed by NIAW 3895 (0.56), NIAW 3908 (0.64), NIAW 3583 (0.89) and NIAW 3583 (0.89).

Yield per plant (g)

Among 20 genotypes, over D1-D2 conditions, highest HSI for yield per plant was possessed by genotype NIAW 4013 (2.31) followed by NIAW 3170 (2.20), NIAW 3983 (1.19), NIAW 3947 (1.15), NIAW 3975 (1.14). Genotype NIAW 3991 (0.26) exhibited lowest HSI followed by NIAW 3583 (0.50), NIAW 3578 (0.68), NIAW 3771 (0.72) and NIAW 3895 (0.73) (Table 4).

Whereas, under D1-D3 condition, highest HSI was calculated for genotype NIAW 4013 (2.18) showing its susceptibility to high temperature. It was followed by genotypes NIAW 4033 (1.17), NIAW 3983 (1.10), NIAW 3170 (1.07), NIAW 3977 (1.05) and the checks NIAW 34 (0.87) and Phule Samadhan (1.00). On the contrary, genotype NIAW 3583 (0.80) had lowest HSI showing its tolerance to high temperature and it was followed by NIAW 3895 (0.80), NIAW 3991 (0.87) and NIAW 3578 (0.89).

Yield per plot (g)

In this experiment, for yield per plot over D1 and D2 condition, the highest HSI value was recorded for the genotype NIAW 3898 (1.56) followed by NIAW 4033 (1.59), NIAW 3170 (1.55), NIAW 4013 (1.54) and the checks NIAW34 (1.07) and Phule Samadhan (1.10) which showed their high susceptibility for late sown condition. While the lower values were recorded for genotypes NIAW 3895 (-0.28), NIAW 3583 (-0.25), NIAW 3578 (0.54) and NIAW 3771 (0.55) indicating their tolerance to late sown condition. Highest value indicates susceptibility whereas lowest value shows resistance of genotypes to high temperature.

HSI for yield per plot over D1 and D3 condition was higher for genotypes NIAW 4033 (1.62), NIAW 4013 (1.35), NIAW 3170 (1.34) and NIAW 3977 (1.25). While lower HSI were observed for genotypes NIAW 3895 (0.09), NIAW 3583 (0.11) and NIAW 3771 (0.63) and NIAW 3991(0.89) indicating their tolerance for very late sown condition.

Similar study was also conducted by Bhardwaj et al (2017) who classified wheat genotypes in four groups i.e. highly heat tolerant, tolerant, moderately tolerant and susceptible based on HSI values for various yield contributing characters. Munjal and Dhanda (2016) used HSI and HRI to screen wheat genotypes tolerant to temperature condition. Their results revealed that significant variability exist in wheat genotypes for various yield attributing traits according to their susceptible or tolerating nature to temperature stress and Heat Response Index which is very useful criteria for selection of genotypes tolerant to abiotic stress condition.

In conclusions the global warming is a major challenge of crop production. Every year temperature is rising. Also within year fluctuations in temperature is more in recent years. Under such circumstances, only resistant genotypes is a solution for crop production. With this objective the present investigation is carried out for wheat, resulted into following broad conclusions;

Genotypes NIAW 3583, NIAW 3578 and NIAW 3895 had lower HSI for yield and yield contributing characters like days to 50 % flowering, days to maturity, earhead length, number of spikelets per spike, number of grains per spike, 1000 grain weight and hence can able to sustain in high temperature.

By screening twenty promising wheat genotypes under field condition for high temperature stress induced by late sowing and very late sowing conditions, genotypes viz; NIAW 3583, NIAW 3578 NIAW 3895, NIAW 3991 and Netravati are identified as highly thermotolerant on the basis of HSI and grain yield. Genotype NIAW 3583 is suitable for normal, late and very late sown conditions.

This identified genotypes can be use for development of thermotolerant varieties in future breeding programme.

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