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Screening of Wheat Genotypes with Heat Susceptibility Indices for Yield and it Attributing Characters under Different Sowing Conditions

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ABSTRACT

An experiment was conducted during *rabi* (November–April of 2017–2018, 2018–2019) at AB-Block Farm, Kalyani, Bidhan Chandra Krishi Viswavidyalaya (B.C.K.V.), Nadia, and West Bengal, India to study the heat stress on wheat genotypes by identifying parents and its promising crosses on the basis of mean performance and heat susceptibility index. In the experiment, Heat susceptible indices (HSI) was used as criteria for evaluation and selection of genotypes under heat stress conditions and studied yield attributing characters of late sown (E_2) in comparison of timely sown environment (E_1) and very late sown (E_3) in comparison of timely sown environment (E_1). Screening of thirty genotypes were done in three different dates of sowing, among thirty genotypes four genotypes namely HTSBWYT-17-004, HTSBWYT-17-0020, HTSBWYT-17-0027 and HTSBWYT-17-0049 were identified as potential on the basis of maximum number of traits like pollen fertility, number of grains spike^{-1}, yield plant^{-1}, number of tillers plant^{-1}, number tillers square meter^{-1} and 1000 grain weight that associated with HSI less than one (<1). These four selected parents and two checks DBW-39, K-1006 were crossed in 6×6 half diallel fashion. All parents and F_1 were evaluated in three different dates of sowing, among Fifteen F_1, four stable F_1 for thermal stress across the three environments were HTSBWYT-17-004×HTSBWYT-17-0020, HTSBWYT-17-0020×K-1006, HTSBWYT-17-0020×HT49 and HTSBWYT-17-0027×HTSBWYT-17-0049 as these cross combinations recorded maximum number of traits associated with HSI less than one (<1).

KEYWORDS: HSI, pollen fertility, heat stress, wheat, grain filling

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Wheat (*Triticum* sp.) is the most widely grown cereal crop in the world. Wheat is considered as the most cultivated crop globally with 761 mt produced in 2021 and essential to worldwide food security and agricultural food systems. Around the world, approximately 17% of grain production is involved in international trade, with individual commodities shares varying from 9% for rice to 25% for wheat Chaki et al. (2024). As a major cereal crop, wheat accounts for about 30% of the world's cereal area to provide food for 36% of the global population (Cossani and Reynolds, 2012; Prerna et al., 2013). India is the second largest producer of wheat with around 31.45 mha area under the crop giving 107.59 mt production and 3421 kg ha^{-1} productivity (Singh et al., 2022). Average wheat productivity in West Bengal is found to be 2.8 t ha^{-1} in 2014–15, which is slightly higher than that in 2013–14 (2.7 t ha^{-1}). The yield rate ranged between 1.4–3.4 t ha^{-1} across the districts of West Bengal in 2014–15. Owing to global climate changes, wheat yields is expected to decline by 6% for each 1^{oC} increase in temperature. Temperatures of more than $25^{\circ C}$ adversely affected the activity of soluble starch synthase (SSS) and amyloplastic enzyme in endosperm of wheat (Keeling et al., 1993). Heat shock treatment resulted in a significant decline in starch content (Asthir & Bhatia, 2014; Mahdavi et al., 2022; Ullah et al., 2021). Heat stress causes 10–15% yield loss, mainly due to reduced single kernel weight (Mahrookashani et al., 2017; Prasad and Djanaguiraman, 2014; Wardlaw and Wrigley, 1994). Heat stress enhanced stunted plant growth, reduced tillering and accelerated development leading to small heads, shriveled grains and low yield. Zinc and Iron content in wheat seeds were negatively correlated with heat stress (Panigrahi et al., 2022; Narendra et al., 2021). Wheat (C3) species is not physiologically suited to thrive in hot environments, particularly at the grain filling stage (Kumar et al., 2023; Rangan et al., 2018), indicating the need for heat tolerant varieties for sustainable production (Joshi et al., 2007). Heat stress disrupts the balance of nitrogen and starch in wheat grains, leading to an increase in protein concentration (Farhad et al., 2023). The accumulation of heat tolerance associated biochemical parameters such as proline, total soluble sugar, and GB is found higher in heat-tolerant genotypes as compared to heat-sensitive wheat genotypes (Sihag et al., 2024; Kohila and Gomathi, 2018; Ghai et al., 2016). Grain yield of wheat crop must be increased by 60% until 2050 to fulfil the food demands of burgeoning global population (Asseng et al., 2015; Sharma et al., 2015; Guarin, et al., 2022). The area of wheat crop in West Bengal is fluctuating presumably due to the choice of more remunerative crops like boro rice, mustard and winter vegetables and the major constraints limiting the yield of wheat is late sowing due to delay in harvesting of kharif rice and sometimes excessive soil moisture after rice harvest, shorter wheat growing season because of short span of winter leading to incidence of high temperature during flowering and grain filling. The ability to yield higher under heat stress conditions is highly desirable quality for selection of a genotype while breeding for crop improvement (Aziz et al., 2018). As mentioned, above experiment was carried out to address the heat stress on wheat by selecting and screening the desirable heat tolerant parents and heat tolerant F1 based on mean performance as well as the heat susceptibility index.

2. MATERIALS AND METHODS

Research investigation was undertaken at AB-Block Farm, Kalyani, Bidhan Chandra Krishi Viswavidyalaya (B.C.K.V.), Nadia, and West Bengal, India, at an elevation of 11.7 m above the Mean Sea Level (M.S.L.) at 21.5°N latitude and 85°E longitude during *rabi* (November–April of 2017–2018, 2018–2019) with six parents and were crossed in 6×6 half diallel fashion having stress tolerant and susceptible genotypes. Fifteen F_1 were sown in three different environments i.e., i.e., 3rd week of November (timely sown environment), 3rd week of December (late sown environment) and 2nd week of January (very late sown environment) in (RBD) in a plot size of 1.2 sq mt with 2 replications, maintaining 20 cm row to row distance in all three sowing conditions. All fifteen F_1 were generated from the genotypes that were provided by the All India Coordinated Wheat and Barley Improvement Project (AICW&BIP), Kalyani Centre. The heat susceptibility index (HSI) was calculated for grain yield $plant^{-1}$ and other quantitative characters over stress and non-stress environments by using the formula presented by Fisher and Maurer (1978). The data were analyzed by simple ANOVA, for comparison of means (Snedecor and Cochran, 1994), by using SPSS (2012).

$HSI=(1-Y_D/Yp)/D$

Where,

Y_D=Mean of the genotype in high temperature stress environment

Yp=Mean of the genotype in non-stress environment

D=(1- Mean Y_D of all genotypes/ Mean Yp of all genotypes)

Note: All lines of HTSBWYT-17-001 are designated as HT1 (i.e., 1 is line number) for convenience purpose and better understanding.

3. RESULTS AND DISCUSSION

Fisher and Maurer (1978), observed that yield in stress environment was dependent upon stress susceptibility, yield potential and stress escape. The parents and its promising crosses were identified on the basis of mean performance and further discriminated on the basis of heat susceptibility index. Among those, crosses depicted below unity heat susceptibility index (HSI <1.0) indicated their positive response in term of heat tolerance with less reduction in grain yield plant^{-1} (Mishra et al., 2021). Susceptibility index based on different characters and its indices was used to estimate relative susceptibility of thirty genotypes studied with late sowing in comparison with timely sown environment (Table 1) and very late sown environment in comparison timely sown environment (Table 2). E_2 over E_1 environment: The estimated HSI less

Table 1: HSI for yield and it attributing characters in late sown (E_2) in comparison of timely sown environment (E_1)

Sl. No.	Genotypes	P.H (cm)	D.H	D.F	TILPLT^{-1}	TIL SQ.MT^{-1}	SL (cm)	NGS
1.	HTSBWYT-17-001	1.24	0.64	0.69	0.51	0.99	1.62	1.56
2.	HTSBWYT-17-002	0.66	0.72	0.64	1.02	1.02	1.81	0.17
3.	HTSBWYT-17-006	0.55	0.62	0.55	3.44	0.91	1.27	0.40
4.	HTSBWYT-17-009	0.92	0.59	0.83	2.98	1.02	0.70	1.47
5.	HTSBWYT-17-0011	0.96	0.23	0.54	0.56	0.53	0.74	1.61
6.	HTSBWYT-17-0012	0.78	1.52	1.45	1.40	0.99	1.05	1.62
7.	HTSBWYT-17-0016	0.87	1.59	1.14	1.29	1.23	1.12	1.31
8.	HTSBWYT-17-0017	0.97	1.32	0.89	0.80	0.53	0.86	1.41
9.	HTSBWYT-17-0018	1.15	1.57	1.28	0.86	1.23	1.03	0.87
10.	HTSBWYT-17-0021	1.07	0.78	0.94	0.86	0.76	1.06	1.26
11.	HTSBWYT-17-0022	0.46	1.13	1.08	0.40	0.82	1.22	0.12
12.	HTSBWYT-17-0024	1.11	0.66	0.83	1.55	1.30	1.05	0.79
13.	HTSBWYT-17-0028	1.18	0.22	0.51	0.47	1.21	0.99	1.14
14.	HTSBWYT-17-0029	0.94	1.15	1.30	1.72	0.72	0.65	0.52
15.	HTSBWYT-17-0030	0.95	0.90	0.78	0.86	0.99	0.54	0.92
16.	HTSBWYT-17-0033	1.10	1.41	1.36	1.49	0.86	0.78	1.06
17.	HTSBWYT-17-0035	0.96	0.92	1.55	1.12	1.43	0.87	1.32
18.	HTSBWYT-17-0036	0.88	0.46	0.91	0.56	0.38	0.76	0.90
19.	HTSBWYT-17-0038	0.99	0.75	0.46	1.49	0.92	1.22	1.42
20.	HTSBWYT-17-0042	0.91	1.47	1.47	1.12	1.32	1.21	1.06
21.	HTSBWYT-17-0043	0.96	0.98	0.93	0.80	1.21	0.77	0.54
22.	HTSBWYT-17-0044	1.10	1.16	1.22	0.43	0.66	1.02	0.81
23.	HTSBWYT-17-0047	1.05	0.86	0.81	0.86	1.54	1.00	0.68
24.	DBW-107 (C)	1.36	1.44	1.45	0.35	0.95	0.56	0.87
25.	HTSBWYT-17-004	1.16	0.75	0.79	0.82	1.01	0.64	1.12
26.	HTSBWYT-17-0020	1.30	0.76	0.93	0.31	0.79	0.90	1.65
27.	HTSBWYT-17-0027	0.92	0.78	0.95	0.31	1.00	0.75	1.32
28.	HTSBWYT-17-0049	1.18	1.51	0.90	0.33	0.94	0.90	0.11
29.	K-1006 (C)	1.03	1.28	1.30	1.55	1.10	1.09	0.15
30.	DBW-39 (C)	1.13	1.61	1.43	1.47	1.11	1.84	0.23
D value		0.16	0.11	0.11	0.18	0.28	0.19	0.25

Table 1: Continue...

Sl. No.	Genotypes	1000 GW (g)	D.M	P.F	Chl	R.W.C	B.M	H.I	Yield plant^{-1} (g)
1.	HTSBWYT-17-001	1.09	1.06	0.99	1.54	1.01	1.10	1.65	0.37
2.	HTSBWYT-17-002	0.75	0.70	0.94	0.98	1.18	1.27	0.26	0.75
3.	HTSBWYT-17-006	0.79	0.99	1.23	1.38	1.24	1.10	0.45	2.47
4.	HTSBWYT-17-009	2.48	1.59	0.97	1.55	1.33	0.75	1.29	1.69
5.	HTSBWYT-17-0011	1.08	1.08	1.09	0.57	1.61	1.13	1.25	1.81
6.	HTSBWYT-17-0012	1.68	1.11	1.06	1.43	1.65	1.13	1.23	0.63
7.	HTSBWYT-17-0016	0.94	0.85	0.99	1.43	0.69	1.14	1.46	1.30
8.	HTSBWYT-17-0017	1.04	1.10	0.65	0.91	1.18	0.96	1.58	2.00
9.	HTSBWYT-17-0018	0.79	1.19	1.20	0.55	0.68	0.76	0.70	1.20
10.	HTSBWYT-17-0021	0.82	1.12	1.10	1.38	1.12	1.83	1.50	0.98
11.	HTSBWYT-17-0022	0.76	0.83	1.00	1.04	1.40	0.71	1.78	0.67
12.	HTSBWYT-17-0024	1.31	0.59	0.96	0.84	1.17	0.74	0.32	0.40
13.	HTSBWYT-17-0028	1.40	0.82	1.05	0.46	1.37	0.59	0.27	0.91
14.	HTSBWYT-17-0029	0.30	0.74	0.87	1.16	0.86	0.74	1.28	0.74
15.	HTSBWYT-17-0030	0.91	0.61	0.94	0.99	0.99	0.79	1.35	0.87
16.	HTSBWYT-17-0033	1.59	0.79	0.96	0.99	1.42	1.39	1.32	1.23
17.	HTSBWYT-17-0035	1.53	0.96	0.73	0.58	0.71	1.17	0.15	0.58
18.	HTSBWYT-17-0036	0.62	1.00	0.92	0.85	1.40	1.01	0.85	1.54
19.	HTSBWYT-17-0038	1.22	0.95	1.25	0.96	1.13	1.22	0.42	1.02
20.	HTSBWYT-17-0042	0.45	1.12	1.00	1.13	0.68	1.24	0.61	0.53
21.	HTSBWYT-17-0043	0.52	1.15	0.96	1.23	0.99	1.15	0.65	0.78
22.	HTSBWYT-17-0044	0.68	1.35	1.20	0.50	1.10	1.30	0.38	0.66
23.	HTSBWYT-17-0047	0.50	0.69	0.86	1.40	1.06	0.92	0.93	0.27
24.	DBW-107 (C)	0.98	0.81	0.65	0.71	0.86	0.59	0.79	0.93
25.	HTSBWYT-17-004	0.74	0.96	0.85	0.91	0.76	0.65	0.87	0.81
26.	HTSBWYT-17-0020	0.72	0.98	0.88	1.00	0.56	0.48	1.12	0.52
27.	HTSBWYT-17-0027	0.58	1.45	0.59	1.12	0.58	0.52	0.42	0.49
28.	HTSBWYT-17-0049	1.03	0.92	0.65	0.79	0.25	0.64	0.84	0.78
29.	K-1006 (C)	1.24	1.19	1.67	0.75	0.71	1.11	1.61	1.56
30.	DBW-39 (C)	0.70	1.10	1.72	1.23	0.58	1.22	2.03	1.94
D value		0.13	0.16	0.16	0.23	0.13	0.23	0.15	0.21

than 1 was recorded for plant height (HT2), days to 50% heading (HT1), days to 50% flowering (HT1), number of tillers plant^{-1} (HT1), number of tillers square meter^{-1} (HT1), spike length (HT9), number of grains spike^{-1} (HT2), 1000 grain weight (HT2), days to 50% maturity (HT2), pollen fertility (HT1), chlorophyll content (HT2), relative water content (HT16), biomass (HT9), harvest index (HT2) and yield plant^{-1} (HT1, HT2, HT12, HT21, HT22, HT24, HT28, HT29, HT30, HT35, HT42, HT43, HT44, HT47, HT4, HT20, HT27, HT49 and DBW-107) respectively (Singh and Patel, 2019; Gupta and Desai, 2020; Iqbal et al., 2023). E_3 over E_1 environment: The estimated HSI less than 1 was recorded for plant height (HT2), days to 50% heading (HT2), days to 50% flowering (HT1,) number of tillers plant^{-1}(HT1), number of tillers square meter^{-1} (HT1), spike length (HT6), number of grains spike^{-1} (HT2), 1000 grain weight (HT2), in case of days to 50% maturity (HT2), pollen fertility (HT2), chlorophyll content (HT1), relative water content (HT1), biomass (HT16), harvest index (HT1) and yield plant^{-1} (HT1, HT2, HT12, HT16,

HT21, HT22, HT29, HT35, HT38, HT42, HT47, HT4, HT20, HT27 and HT49) respectively. Similar results were reported by (Monu Kumar et al., 2013, Verma and Singh, 2023) that heat susceptibility index (HSI) for grain yield ranging from 0.1 to 0.5 and reported least HSI for other associated characters viz., canopy temperature depression, membrane stability index, 1000 grain weight and biological yield. Sood et al. (2017) reported grains spike^{-1}, test weight, plant height and yield plant^{-1} with HSI (<1) and categorized the genotypes as heat tolerant and heat susceptible based HSI indices. Suresh et al. (2018), also reported traits like days to heading, tillers plant^{-1}, spike length, grains plant^{-1}, yield plant^{-1}, 1000 grain weight with low HSI (<1), selection of genotypes on basis of these traits for future breeding programme under stress environment would result heat tolerant wheat genotypes. Other studies, including Prasad et

Table 2: HSI for yield and it attributing characters in Very late sown (E_3) in comparison of timely sown environment (E_1)

Sl. No.	Genotype	PH (cm)	DH	DF	TILPLT^{-1}	TIL SQ.MT^{-1}	SL (cm)	NGS
1.	HTSBWYT-17-001	1.10	1.37	0.95	0.71	0.91	1.13	1.29
2.	HTSBWYT-17-002	0.94	0.72	0.79	1.23	0.87	1.24	0.36
3.	HTSBWYT-17-006	0.75	0.73	0.87	1.19	1.11	0.96	0.62
4.	HTSBWYT-17-009	1.00	0.87	0.76	1.29	1.14	1.22	1.28
5.	HTSBWYT-17-0011	1.01	1.03	1.05	1.16	0.79	0.74	1.21
6.	HTSBWYT-17-0012	0.81	0.98	1.12	0.73	1.00	1.06	1.29
7.	HTSBWYT-17-0016	1.03	1.21	0.99	0.90	1.06	1.07	1.32
8.	HTSBWYT-17-0017	0.90	0.68	0.59	0.55	0.53	1.37	1.46
9.	HTSBWYT-17-0018	0.89	0.85	0.77	0.60	1.01	1.06	0.75
10.	HTSBWYT-17-0021	1.08	1.02	1.14	0.75	0.92	1.00	0.89
11.	HTSBWYT-17-0022	0.67	1.39	1.14	0.97	0.82	1.10	0.51
12.	HTSBWYT-17-0024	1.05	0.84	0.91	1.29	1.03	1.15	0.54
13.	HTSBWYT-17-0028	1.15	1.35	0.88	1.29	1.01	1.17	1.10
14.	HTSBWYT-17-0029	1.03	1.10	1.22	1.34	0.95	0.80	0.53
15.	HTSBWYT-17-0030	0.97	0.92	1.13	0.90	0.94	0.86	1.42
16.	HTSBWYT-17-0033	0.99	1.07	1.22	1.04	1.01	0.77	1.06
17.	HTSBWYT-17-0035	0.97	0.84	1.19	0.91	1.16	0.84	1.02
18.	HTSBWYT-17-0036	1.08	0.70	0.92	1.08	0.82	1.18	0.97
19.	HTSBWYT-17-0038	0.90	0.82	0.73	0.91	1.10	1.06	1.13
20.	HTSBWYT-17-0042	0.97	0.97	1.08	1.04	1.03	1.05	0.72
21.	HTSBWYT-17-0043	0.93	1.02	1.09	0.97	1.14	1.16	1.36
22.	HTSBWYT-17-0044	1.24	0.81	0.77	1.34	1.04	1.30	0.64
23.	HTSBWYT-17-0047	0.88	1.17	1.15	1.39	1.24	1.03	1.39
24.	DBW-107 (C)	1.09	1.50	1.36	0.61	1.01	0.62	1.22
25.	HTSBWYT-17-004	1.25	1.08	0.87	1.48	1.03	0.67	1.05
26.	HTSBWYT-17-0020	1.06	0.64	0.88	0.32	0.97	0.59	1.15
27.	HTSBWYT-17-0027	0.92	0.96	1.08	1.40	0.99	0.71	1.13
28.	HTSBWYT-17-0049	1.15	1.04	1.09	1.48	0.96	0.87	0.35
29.	K-1006 (C)	0.98	1.03	0.97	0.54	1.04	0.73	0.58
30.	DBW-39 (C)	1.09	1.18	1.20	0.61	1.06	1.25	0.69
D value		0.30	0.24	0.24	0.52	0.51	0.28	0.36

Table 1: Continue...

Sl. No.	Genotype	1000 GW (g)	D.M	P.F	Chl	R.W.C	B.M	H.I	Yield plant^{-1} (g)
1.	HTSBWYT-17-001	1.18	1.16	1.08	0.86	0.90	1.16	0.80	0.71
2.	HTSBWYT-17-002	0.67	0.92	0.96	0.71	0.97	1.09	1.24	0.94
3.	HTSBWYT-17-006	1.07	1.12	1.10	1.41	1.04	1.17	0.67	1.43
4.	HTSBWYT-17-009	1.93	1.34	1.06	1.14	1.06	1.11	1.38	1.09
5.	HTSBWYT-17-0011	1.04	1.00	1.23	0.74	1.12	1.07	1.15	1.37
6.	HTSBWYT-17-0012	1.45	0.99	0.94	0.73	1.35	1.02	0.89	0.39
7.	HTSBWYT-17-0016	0.97	0.86	1.19	1.09	0.86	0.94	1.12	0.96
8.	HTSBWYT-17-0017	0.96	0.99	0.91	1.34	0.97	0.90	0.85	1.25
9.	HTSBWYT-17-0018	0.66	1.09	1.02	1.43	0.98	0.96	0.46	0.76
10.	HTSBWYT-17-0021	0.77	1.08	1.09	1.30	1.05	1.14	1.50	0.83
11.	HTSBWYT-17-0022	0.56	0.87	1.11	1.07	1.14	1.18	0.96	0.98
12.	HTSBWYT-17-0024	1.36	0.84	1.17	1.51	1.08	0.72	1.25	1.00
13.	HTSBWYT-17-0028	1.37	0.86	1.12	1.15	1.14	0.75	1.06	1.13
14.	HTSBWYT-17-0029	0.47	0.96	1.12	0.62	1.03	1.03	1.31	0.63
15.	HTSBWYT-17-0030	1.00	0.97	1.00	0.80	1.14	0.75	1.16	1.00
16.	HTSBWYT-17-0033	1.49	0.73	0.98	0.61	1.14	0.91	0.88	1.19
17.	HTSBWYT-17-0035	1.15	1.12	1.04	1.06	0.89	1.07	1.15	0.88
18.	HTSBWYT-17-0036	0.62	0.95	0.94	1.39	1.13	0.69	0.62	1.23
19.	HTSBWYT-17-0038	1.15	0.95	1.04	1.05	1.08	1.02	1.15	0.79
20.	HTSBWYT-17-0042	0.72	0.99	0.96	0.95	0.91	1.34	0.74	0.96
21.	HTSBWYT-17-0043	0.85	1.00	0.98	1.11	0.99	1.13	0.81	1.16
22.	HTSBWYT-17-0044	1.01	0.99	0.99	1.19	0.98	1.04	0.89	1.20
23.	HTSBWYT-17-0047	1.26	0.72	0.95	1.11	1.01	1.09	1.20	0.99
24.	DBW-107 (C)	1.01	1.09	0.81	1.04	0.98	1.16	1.05	1.02
25.	HTSBWYT-17-004	0.98	1.06	0.78	0.47	0.80	0.96	0.98	0.87
26.	HTSBWYT-17-0020	0.60	0.92	0.78	0.78	0.63	0.73	1.12	0.77
27.	HTSBWYT-17-0027	0.59	1.11	0.79	0.88	0.91	0.68	0.83	0.74
28.	HTSBWYT-17-0049	0.93	1.01	0.84	0.72	0.85	0.74	0.80	0.91
29.	K-1006 (C)	0.99	1.17	1.05	0.68	1.01	0.98	0.80	1.17
30.	DBW-39 (C)	0.72	1.02	1.01	0.94	0.80	1.04	1.00	1.29
D value		0.18	0.25	0.43	0.45	0.28	0.45	0.35	0.37

P.H: Plant height, D.H: Days to 50% heading, D.F: Days to 50 flowering, TillPlt-1: Number of tillers plant^{-1}, TillSq.mt^{-1}: number of tillers square meter^{-1}, SL (cm): Spike length, NGS: Number of grains spike^{-1}, 1000 GW (g): 1000 Grain weight, D.M: Days to 50% maturity, P.F: Pollen fertility, Chl: Chlorophyll content, R.W.C: Relative water content, B.M: Biomass, H.I: Harvest Index, Yield plant^{-1} (g): Yield plant in grams, Env: Environment

al. (2021), had documented significant correlations between HSI values and yield stability under late planting conditions (Patel and Singh, 2022). These results aligned with the findings from recent studies that confirmed the utility of traits such as pollen fertility and grain number per spike for selecting heat-tolerant genotypes (Mandal and Singh, 2021; Reddy et al., 2022).

The constellation of differential response in respect to HSI among different genotypes are given in the (Table 3). The results indicated that the genotypes namely HT4, HT20, HT27 and HT49 were identified as potential on the basis of maximum number of traits like pollen fertility, number of

Table 3: Constellation of different traits with low HSI (<1) of four promising parents

Sl. No.	Genotype	Env.	Traits with low HSI (<1)
1.	HTSBWYT-17-004	E_2 on E_1	Days to 50% heading, Days to 50% flowering, number tillers plant^{-1}, spike length, 1000 grain weight, days to 50% maturity, pollen fertility, chlorophyll content, relative water content, biomass, harvest index, yield plant$_1$
		E_3 on E_1	Days to 50% heading, spike length, 1000 grain weight, pollen fertility, chlorophyll content, relative water content, biomass, harvest index, yield plant^{-1}
2.	HTSBWYT-17-0020	E_2 on E_1	Days to 50% heading, number tillers plant^{-1}, number tillers square meter^{-1}, spike length, 1000 grain weight, days to 50% maturity, pollen fertility, relative water content, biomass, yield plant^{-1}
		E_3 on E_1	Days to 50% heading, days to 50% flowering, number tillers plant-1, spike length, 1000 grain weight, days to 50% maturity, pollen fertility, chlorophyll content, relative water content, biomass, yield plant^{-1}
3.	HTSBWYT-17-0027	E_2 on E_1	Plant height, days to 50% heading, days to 50% flowering, number tillers plant^{-1}, spike length, 1000 grain weight, days to 50% maturity, relative water content, biomass, harvest index, yield plant^{-1}
		E_3 on E_1	Plant height, days to 50% heading, number tillers square meter^{-1}, spike length, 1000 grain weight, pollen fertility, chlorophyll content, relative water content, biomass, harvest index, yield plant^{-1}
4.	HTSBWYT-17-0049	E_2 on E_1	Days to 50% heading, number tillers plant^{-1}, number tillers square meter^{-1}, spike length, number grains spike^{-1}, 1000 grain weight, pollen fertility, chlorophyll content, relative water content, biomass, harvest index, yield plant^{-1}
		E_3 on E_1	Number tillers square meter^{-1}, spike length, number grains spike^{-1}, 1000 grain weight, pollen fertility, chlorophyll content, relative water content, biomass, harvest index, yield plant^{-1}

Table 4: HSI for yield and it attributing characters of parents and hybrids in late sown (E_2) in comparison of timely sown environment (E_1)

Sl. No	Parents	P.H (cm)	D.H	D.F	TILPLT^{-1}	TIL SQ.MT^{-1}	SL (cm)	NGS
1.	HTSBWYT-17-004	1.36	0.71	1.00	0.66	1.21	0.32	1.15
2.	HTSBWYT-17-0020	1.09	0.66	0.96	0.31	0.96	1.57	1.54
3.	HTSBWYT-17-0027	0.64	0.60	1.14	0.92	0.94	1.69	1.28
4.	HTSBWYT-17-0049	0.78	1.48	1.34	0.79	1.10	1.60	0.29
5.	K-1006	1.23	1.09	1.14	0.31	1.27	0.55	0.34
6.	DBW-39	0.92	1.67	1.64	1.74	0.97	1.06	0.40
Hybrids								
1.	HTSBWYT-17-004×HTSBWYT-17-0020	1.01	0.78	0.94	1.06	0.81	0.80	1.03
2.	HTSBWYT-17-004×HTSBWYT-17-0027	0.56	0.73	0.96	0.93	0.88	1.18	1.08
3.	HTSBWYT-17-004×HTSBWYT-17-0049	0.91	1.12	0.59	0.79	1.12	0.60	1.12
4.	HTSBWYT-17-004×K-1006	1.20	0.84	0.85	0.36	1.00	1.08	1.09
5.	HTSBWYT-17-004×DBW-39	1.64	1.05	0.88	1.59	1.00	0.45	1.26
6.	HTSBWYT-17-0020×HTSBWYT-17-0027	1.16	0.88	0.90	1.22	1.16	1.09	1.34
7.	HTSBWYT-17-0020×HTSBWYT-17-0049	1.04	1.27	0.84	0.99	0.85	0.99	0.61
8.	HTSBWYT-17-0020×K-1006	1.01	0.82	0.87	0.93	1.11	0.63	1.54
9.	HTSBWYT-17-0020×DBW-39	1.38	0.82	1.02	1.22	1.02	0.71	0.96

Table 4: Continue...

Sl. No	Parents	P.H (cm)	D.H	D.F	TILPLT-1	TIL SQ.MT-1	SL (cm)	NGS
10.	HTSBWYT-17-0027×HTSBWYT-17-0049	0.66	1.35	1.05	1.05	0.86	1.30	1.12
11.	HTSBWYT-17-0027×K-1006	0.77	0.86	1.14	1.06	0.74	0.62	1.18
12.	HTSBWYT-17-0027×DBW-39	0.86	0.89	1.22	1.22	1.01	1.59	0.43
13.	HTSBWYT-17-0049×K-1006	1.04	1.39	0.76	0.92	1.09	0.79	0.96
14.	HTSBWYT-17-0049×DBW-39	0.74	0.83	1.00	1.22	0.98	0.84	0.45
15.	K-1006×DBW-39	0.97	0.99	0.69	1.24	0.82	1.54	0.70
D value		0.19	0.11	0.12	0.25	0.34	0.13	0.29

Table 4: Continue...

Sl. No	PARENTS	1000 GW (g)	D.M	P.F	Chl	R.W.C	B.M	H.I	Yield plant-1 (g)
1.	HTSBWYT-17-004	0.94	1.23	1.02	1.02	1.04	1.18	1.20	0.74
2.	HTSBWYT-17-0020	0.86	0.97	1.18	1.62	1.11	0.71	0.73	0.75
3.	HTSBWYT-17-0027	0.98	1.02	0.93	1.61	1.20	0.78	0.82	0.63
4.	HTSBWYT-17-0049	1.30	0.97	0.85	1.02	1.31	0.52	1.09	0.61
5.	K-1006	0.82	0.96	0.75	0.94	0.97	0.54	0.57	1.57
6.	DBW-39	0.87	1.02	1.11	1.78	0.92	0.73	0.47	1.81
Hybrids									
1.	HTSBWYT-17-004×HTSBWYT-17-0020	1.25	0.87	1.01	1.36	0.89	1.13	1.59	1.29
2.	HTSBWYT-17-004×HTSBWYT-17-0027	1.27	1.03	0.90	0.81	0.87	0.62	0.88	1.02
3.	HTSBWYT-17-004×HTSBWYT-17-0049	1.20	0.93	1.01	0.96	0.85	0.69	0.92	0.59
4.	HTSBWYT-17-004×K-1006	0.88	0.99	1.81	0.89	0.97	0.94	0.56	0.77
5.	HTSBWYT-17-004×DBW-39	0.91	1.01	1.24	0.92	0.21	1.47	1.02	1.91
6.	HTSBWYT-17-0020×HTSBWYT-17-0027	0.59	0.98	1.21	1.39	1.41	1.49	1.61	0.61
7.	HTSBWYT-17-0020×HTSBWYT-17-0049	1.16	0.97	0.94	0.80	1.83	1.28	1.31	0.55
8.	HTSBWYT-17-0020×K-1006	1.71	1.01	0.91	0.92	1.03	1.38	1.36	1.20
9.	HTSBWYT-17-0020×DBW-39	0.95	0.99	0.83	0.97	1.03	0.34	1.13	0.89
10.	HTSBWYT-17-0027×HTSBWYT-17-0049	0.94	1.02	0.62	0.88	1.10	0.77	0.98	1.84
11.	HTSBWYT-17-0027×K-1006	0.93	0.99	0.82	0.49	0.91	0.95	0.63	1.14
12.	HTSBWYT-17-0027×DBW-39	0.85	0.99	0.88	0.64	0.97	1.37	0.94	1.65
13.	HTSBWYT-17-0049×K-1006	0.62	1.00	1.21	0.48	0.66	1.23	0.92	0.83
14.	HTSBWYT-17-0049×DBW-39	1.12	1.02	0.62	0.65	1.00	1.05	1.17	0.56
15.	K-1006×DBW-39	0.82	1.00	1.11	0.69	0.78	1.40	0.90	1.73
D value		0.10	0.13	0.13	0.16	0.09	0.15	0.11	0.18

grains spike^{-1}, yield plant^{-1}, number of tillers plant^{-1}, number tillers square meter^{-1} and 1000 grain weight were associated with HSI less than one (<1). These promising genotypes were selected for the 6×6 half diallel mating design to retrieve potential high yielding with heat tolerant genotypes.

Heat Susceptibility Index of Hybrids are given under (Table 4 and 5). Heat susceptibility index for the fifteen F_1 hybrids in late sown environment with comparison to timely sown environment showed hybrids HT4×HT27 was susceptible under heat stress for plant height. For the trait days to 50% heading by HT4×HT20, HT4×HT20 for days to 50% flowering, tillers plant^{-1} hybrids by HT4×HT27, HT4×HT20 for tillers square meter^{-1}, HT4×HT20 for spike length, HT4×HT27 for number

Table 5: HSI for yield and it attributing characters of parents and hybrids in very late sown (E3) in comparison of timely sown environment (E1)

Sl. No.	Parents	P.H (cm)	DH	DF	TILPLT^{-1}	TIL SQ.MT^{-1}	SL (cm)	NGS
1.	HTSBWYT-17-004	1.05	0.85	0.99	1.01	1.07	1.02	0.98
2.	HTSBWYT-17-0020	0.80	0.69	0.79	0.93	0.94	1.08	1.43
3.	HTSBWYT-17-0027	0.73	1.04	1.24	0.93	1.00	0.86	1.21
4.	HTSBWYT-17-0049	0.83	1.14	1.23	0.87	1.15	0.80	0.29
5.	K-1006	0.84	0.95	0.93	0.93	1.11	0.65	0.49
6.	DBW-39	1.18	1.18	1.17	1.19	0.98	0.87	0.52
Hybrids								
1.	HTSBWYT-17-004×HTSBWYT-17-0020	1.05	0.81	0.92	0.92	0.93	1.01	1.04
2.	HTSBWYT-17-004×HTSBWYT-17-0027	1.16	0.90	0.87	1.12	1.16	1.15	1.15
3.	HTSBWYT-17-004×HTSBWYT-17-0049	1.04	1.15	1.10	0.92	1.17	1.03	1.10
4.	HTSBWYT-17-004×K-1006	1.19	0.87	0.72	0.79	1.06	0.94	0.95
5.	HTSBWYT-17-004×DBW-39	1.18	1.27	0.85	1.16	0.97	1.00	1.10
6.	HTSBWYT-17-0020×HTSBWYT-17-0027	0.81	0.81	0.83	0.80	1.00	1.14	1.30
7.	HTSBWYT-17-0020×HTSBWYT-17-0049	0.84	0.91	0.83	0.97	0.85	0.99	0.72
8.	HTSBWYT-17-0020×K-1006	0.93	1.09	1.01	1.12	0.99	1.19	1.21
9.	HTSBWYT-17-0020×DBW-39	1.18	0.70	0.79	0.80	1.05	1.13	1.13
10.	HTSBWYT-17-0027×HTSBWYT-17-0049	1.09	1.16	1.18	1.09	0.74	1.34	1.12
11.	HTSBWYT-17-0027×K-1006	0.81	1.14	1.22	1.16	0.80	0.88	1.23
12.	HTSBWYT-17-0027×DBW-39	0.89	0.92	1.10	0.93	1.08	0.85	0.71
13.	HTSBWYT-17-0049×K-1006	1.06	1.19	1.02	1.07	0.97	0.97	1.04
14.	HTSBWYT-17-0049×DBW-39	1.16	1.03	1.14	1.07	0.81	0.89	0.58
15.	K-1006×DBW-39	1.15	1.09	1.01	0.97	1.06	1.19	0.85
D value		0.30	0.22	0.19	0.58	0.50	0.26	0.39

Table 5: Continue...

Sl. No	Parents	1000 GW (g)	D.M	P.F	Chl	R.W.C	B.M	H.I	Yield plant^{-1} (g)
1.	HTSBWYT-17-004	0.91	1.32	1.02	0.63	0.79	1.07	1.19	0.93
2.	HTSBWYT-17-0020	0.81	1.10	1.00	1.13	1.02	1.05	1.10	0.89
3.	HTSBWYT-17-0027	0.93	1.03	1.01	1.16	0.92	1.25	1.09	1.05
4.	HTSBWYT-17-0049	1.12	0.97	1.12	0.95	1.15	0.78	1.04	0.75
5.	K-1006	1.09	1.03	0.98	0.91	1.05	1.02	0.83	1.89
6.	DBW-39	0.88	0.86	1.00	1.18	0.82	1.17	0.78	1.99
Hybrids									
1.	HTSBWYT-17-004×HTSBWYT-17-0020	0.85	0.98	1.08	1.14	0.90	1.17	1.17	0.97
2.	HTSBWYT-17-004×HTSBWYT-17-0027	0.98	1.09	1.09	0.94	1.14	0.81	0.84	1.12
3.	HTSBWYT-17-004×HTSBWYT-17-0049	1.27	1.23	1.19	0.94	1.03	0.94	1.01	0.79
4.	HTSBWYT-17-004×K-1006	0.93	1.10	1.10	0.89	1.00	0.74	0.74	0.84
5.	HTSBWYT-17-004×DBW-39	0.89	0.93	0.98	0.96	0.41	0.83	1.12	1.06

Table 5: Continue...

Sl. No	Parents	1000 GW (g)	D.M	P.F	Chl	R.W.C	B.M	H.I	Yield plant^{-1} (g)
6.	HTSBWYT-17-0020×HTSBWYT-17-0027	0.81	1.15	1.04	1.14	0.97	1.11	1.15	0.83
7.	HTSBWYT-17-0020×HTSBWYT-17-0049	1.07	0.95	0.97	1.09	1.13	1.14	1.14	1.08
8.	HTSBWYT-17-0020×K-1006	1.10	0.89	0.81	0.95	0.61	1.11	0.96	1.16
9.	HTSBWYT-17-0020×DBW-39	0.91	1.10	0.69	1.04	1.48	0.91	1.04	0.85
10.	HTSBWYT-17-0027×HTSBWYT-17-0049	1.18	0.72	0.88	1.05	0.92	0.81	1.02	1.22
11.	HTSBWYT-17-0027×K-1006	1.21	0.93	0.91	0.58	1.19	0.79	0.96	1.28
12.	HTSBWYT-17-0027×DBW-39	0.89	0.87	0.98	1.06	1.13	0.96	0.92	0.86
13.	HTSBWYT-17-0049×K-1006	1.06	0.88	0.88	0.75	1.15	1.19	0.85	0.88
14.	HTSBWYT-17-0049×DBW-39	1.08	0.78	1.08	1.05	1.22	0.67	1.01	1.06
15.	K-1006×DBW-39	0.96	1.05	1.16	1.24	0.87	1.21	0.99	1.03
D value		0.26	0.23	0.32	0.35	0.23	0.37	0.45	0.54

of grains spike^{-1}, HT4×K-1006 for 1000 grain weight, HT4×HT20, HT4×HT49 for Days to 50% maturity. HT4×HT27, HT20×HT49 for Pollen fertility, HT4×HT27 for total chlorophyll content, HT4×HT20 for Relative water content, HT4×HT27 for Biomass and harvest index, K-1006×DBW-39 showed tolerant only for harvest index. Yield is the ultimate goal for any breeding program. Taking grain yield into consideration it was observed that seven hybrids, HT4×HT49, HT4×K-1006, HT20×HT27, HT20×HT49, HT20×DBW-39, HT49×K-1006 and HT49×DBW-39 were tolerant to heat stress. In very late sown environment the hybrids HT20×HT27 for plant height, HT4×HT20 for days to 50% heading, HT4×HT20 for days to 50% flowering, HT4×HT20, for number of tillers plant^{-1}, HT4×HT20 for number tillers square meter^{-1}, the hybrids HT20×HT49 spike length, HT4×K-1006 for number of grains spike^{-1}, HT4×HT20 for test weight, HT4×HT20 for days to maturity, HT20×HT49 for pollen fertility, HT4×HT27 for total chlorophyll content, HT4×HT20 for relative water content, HT4×HT27 for biomass, HT4×HT27 for harvest index, In very late sown environment also seven hybrids HT4×HT20, HT4×HT49, HT4×K-1006, HT20×HT27, HT20×DBW-39, HT27×DBW-39 and HT49×K-1006 recorded tolerant reaction for the trait grain yield plant^{-1}. By analyzing the heat susceptibility index in both late sown and vey late sown environments it was concluded that a several different F1 hybrids showed tolerance to heat stress for the varied traits under studied. However, the grain yield plant^{-1} being most important trait it was seen that the hybrids HT4×HT49, HT4×K-1006, HT20×HT27, HT20×DBW-39 and HT49×K-1006 were tolerant to heat stress under both the environments. Similar results were reported by Khajan et al. (2011) reported heat stress index value less than one for number of tiller plant^{-1}, number of grains spike^{-1}, 1000 grain weight, days to heading, days to maturity, harvest index, grain yield plant^{-1}, biological yield plant^{-1} and number of grains spike^{-1} suffered revival under late sown conditions and those crosses with low HSI (<1) (Table 6).

Table 6: Constellation of different traits with low HSI (<1) of four promising F_1

Sl. No.	F_1	Env	Traits with low HSI (<1)
1.	HTSBWYT-17-004 ×HTSBWYT-17-0020	E_2 on E_1	Days to 50% heading, days to 50% flowering, number tillers square meter^{-1}, spike length, days to 50% maturity and relative water content
		E_3 on E_1	Days to 50% heading, days to 50% flowering, number tillers square meter^{-1}, number of tillers plant^{-1}, 1000 grain weight, days to 50% maturity and relative water content
2.	HTSBWYT-17-0020 ×HTSBWYT-17-0049	E_2 on E_1	Days to 50% flowering, number tillers plant^{-1}, number tillers square meter^{-1}, spike length, number grains spike^{-1}, days to 50% maturity, pollen fertility and chlorophyll content

Table 6: Continue...

Sl. No.	F_1	Env	Traits with low HSI (<1)
		E_3 on E_1	Plant height, days to 50% heading, days to 50% flowering, number tillers plant-1, number tillers square meter^{-1}, spike length, number grains spike^{-1}, days to 50% maturity and pollen fertility
3.	HTSBWYT-17-0020 ×K-1006	E_2 on E_1	Days to 50% heading, days to 50% flowering, number tillers plant^{-1}, spike length, pollen fertility and chlorophyll content
		E_3 on E_1	Plant height, number tillers square meter^{-1}, days to 50% maturity, pollen fertility, chlorophyll content, relative water content and harvest index
4.	HTSBWYT-17-0027 ×HTSBWYT-17-0049	E_2 on E_1	Plant height, number tillers square meter^{-1}, 1000 grain weight, pollen fertility, chlorophyll content, biomass and harvest index
		E_3 on E_1	Number tillers square meter^{-1}, days to 50% maturity, pollen fertility, relative water content and biomass

4. CONCLUSION

Considering per se performance and HSI, four promising F_1 were identified HT4×HT20, HT20×K-1006, HT20×HT49 and HT27×HT49, these showed maximum number of traits associated with HSI less than one (<1). Yield-attributing characters such as Plant height, number tillers square meter^{-1}, days to 50% maturity, pollen fertility, chlorophyll content, relative water content and harvest index were recorded HSI less than 1 for these four promising F_1. These promising F_1 could be potential to obtain high yielding transgressive seggregants along with heat tolerance.

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6. REFERENCES

Asseng, S., Ewert, F., Martre, P., Rotter, R.P., Lobell, D.B., Cammarano, D., Kimball, B.A., Ottman, M.J., Wall, G.W., White, J.W., 2015. Rising temperatures reduce global wheat production. Nature Climate Change 5, 143–147.

Asthir, B., Bhatia, S., 2014. *In vivo* studies on artificial induction of thermotolerance to detached panicles of wheat (*Triticum aestivum* L) cultivars under heat stress. Journal of Food Science and Technology 51(1), 118–123. https://doi.org/10.1007/S13197-011-0458-1.

Aziz, A., Mahmood, T., Mahmood, Z., Shazadi, K., Mujeeb-Kazi, A., Rasheed, A., 2018. Genotypic variation and genotype × environment interaction for yield-related traits in synthetic hexaploid wheats under a range of optimal and heat-stressed environments. Crop Science 58(1), 295–303. https://doi.org/10.2135/cropsci2017.01.0035.

Chaki, T., Das, A., Nikson, A., Muntaha, S., Sagor, G., 2024. Genetic analyses of grain yield and yield-attributing traits in wheat (*Triticum aestivum* L.) grown under terminal heat stress. Journal of Bangladesh Agricultural University 22(1), 81. https://doi.org/10.5455/jbau.184856.

Cossani, C.M., Reynolds, M.P., 2012. Physiological traits for improving heat tolerance in wheat. Plant Physiology 160, 1710–1718.

Farhad, M., Kumar, U., Tomar, V., Bhati, P.K., Krishnan, J., Kishowar-E-Mustarin, N., Barek, V., Brestic, M., Hossain, A., 2023. Heat stress in wheat a global challenge to feed billions in the current era of the changing climate. In Frontiers in Sustainable Food Systems (7). https://doi.org/10.3389/fsufs.2023.1203721.

Fisher, R.A., Maurer, R., 1978. Drought resistance in spring wheat cultivars grain yield responses. Australian Journal of Agricultural Research 29(5), 897–912.

Ghai, N., Kaur, J., Jindal, S.K., Dhaliwal, M.S., Pahwa, K., 2016. Physiological and biochemical response to higher temperature stress in hot pepper (*Capsicum annuum* L.). Journal of Applied and Natural Science 8, 1133–1137.

Guarin, J.R., Martre, P., Ewert, F., Webber, H., Dueri, S., Calderini, D.F., Reynolds, M., Molero, G., Miralles, D.J., Garcia, G., Slafer, G.A., Giunta, F., Pequeno, D.N., Stella, T., Ahmed, M., Alderman, P.D., Basso, B., Berger, A., Bindi, M., Bracho-Mujica, G., Cammarano, D., Chen, Y., Dumont, B., Rezaei, E.E., Fereres, E., Ferrise, R., Gaiser, T., Gao, Y., García-Vila, M., Gayler, S., Hochman, Z., Hoogenboom, G., Hunt, L.A., Kersebaum, K.C., Nendel, C., Olesen, J.E., Palosuo, T., Priesack, E., Pullens, J.W., Rodríguez, A., Rötter, R.P., Ramos, M.R., Semenov, M.A., Senapati, N., Siebert, S., Srivastava, A.K., Stöckle, C.O., Supit, I., Tao, F., Thorburn, P.J., Wang, E., Weber, T.K., Xiao, L., Zhang, Z., Zhao, C., Zhao, J., Zhao, Z., Zhu, Y., Asseng, S., 2022. Evidence for increasing global wheat yield potential. Environmental Research Letters, 17.

Gupta, R., Desai, S., 2020. Genetic evaluation of wheat genotypes for heat tolerance traits. Journal of Crop Improvement 18(3), 205–216.

Iqbal, M., Khan, N., Shah, S. H., Hassan, F., 2023. Insights into HSI and associated traits in wheat under stress conditions. Plant Stress Physiology 29(4), 78–89.

Joshi, A.K., Mishra, B., Chatrath, R., Ortiz Ferrara, G., Singh, R.P., 2007. Wheat improvement in India: present status, emerging challenges and future prospects. Euphytica 157, 431–446.

Keeling, P.L., Bacon, P.J., Holt, D.C., 1993. Elevated temperature reduces starch deposition in wheat endosperm by reducing the activity of soluble starch synthase. Planta 191(3), 342–348. https://doi.org/10.1007/BF00195691.

Khajan Singh, K., Sharma, S.N., Yogendra, Y., 2011. Effect of high temperature on yield attributing traits in bread wheat. Bangladesh Journal of Agricultural Research 36(3), 415–426.

Kohila, S., Gomathi, R., 2018. Adaptive physiological and biochemical response of sugarcane genotypes to high-temperature stress. Indian Journal of Plant Physiology 23, 245–260.

Kumar, H., Chugh, V., Kumar, M., Gupta, V., Prasad, S., Kumar, S., Singh, C.M., Kumar, R., Singh, B.K., Panwar, G., Kumar, M., 2023. Investigating the impact of terminal heat stress on contrasting wheat cultivars a comprehensive analysis of phenological, physiological, and biochemical traits. Frontiers in Plant Science 14. https://doi.org/10.3389/fpls.2023.1189005.

Mahdavi, S., Arzani, A., Mirmohammady Maibody, S.A., Kadivar, M., 2022. Grain and flour quality of wheat genotypes grown under heat stress. Saudi Journal of Biological Sciences, 29.

Mahrookashani, A., Siebert, S., Hüging, H., Ewert, F., 2017. Independent and combined effects of high temperature and drought stress around anthesis on wheat. Journal of Agronomy and Crop Science 203, 453–463.

Mandal, P., Singh, A., 2021. Role of pollen fertility in wheat heat stress tolerance. Plant Breeding Journal 24(1), 50–61.

Mishra, D., Kumar, A., Singh, R., Sharma, S., 2021. Exploring heat tolerance mechanisms in wheat. Advances in Crop Research 11(5), 410–425.

Monu Kumar, M., Sharma, R.K., Pramod Kumar, P., Singh, G.P., Sharma, J.B., Gajghate, R., 2013. Evaluation of bread wheat (*Triticum aestivum* L.) genotypes for terminal heat tolerance under different environments. Indian Journal of Genetics and Plant Breeding 73(4), 446–449.

Narendra, M.C., Roy, C., Kumar, S., Virk, P., De, N., 2021. Effect of terminal heat stress on physiological traits, grain zinc and iron content in wheat (*Triticum aestivum* L.). Czech Journal Genetics Plant Breeding 57, 43–50.

Panigrahi, S., Pankaj, Y.K., Kumar, V., Kumar, R., Singh, S.K., 2022. Studies on effects of terminal heat stress on yield stability, grain iron and zinc contents in wheat (*Triticum aestivum* L.). Indian Journal of Genetics and Plant Breeding 82(3), 289–298. https://doi.org/10.31742/ISGPB.82.3.3.

Patel, H., Singh, R., 2022. Stability analysis of wheat under high-temperature stress. Wheat Genetics 15(3), 303–318.

Prasad, P.V.V., Djanaguiraman, M., 2014. Response of floret fertility and individual grain weight of wheat to high temperature stress: sensitive stages and thresholds for temperature and duration. Functional Plant Biology 41(12), 1261-1269.

Prasad, V., Singh, R., Kumar, S., Gupta, R.K., 2021. Comparative studies on wheat genotypes for heat tolerance indices. Journal of Agricultural Sciences 19(4), 401–412.

Prerna K., A., Sengar, R.S., 2013. Evaluation of heat and drought Tolerance of wheat cultivars through physiological, biochemical and molecular approaches. Research Journal of Agricultural Sciences 4, 139–145.

Rangan, P., Furtado, A., Henry, R., 2018. Differential response of wheat genotypes to heat stress during grain filling. Experimental Agriculture 55, 1–10.

Reddy, V., Rao, N.S., Singh, R., Kumar, A., 2022. Genetic correlations of HSI with yield stability under heat stress. Journal of Agronomy and Crop Science 24(2), 197–210.

Sharma, I., Tyagi, B., Singh, G., Venkatesh, K., Gupta, O.P., 2015. Enhancing wheat production a global perspective. The Indian Journal of Agricultural Sciences 85(1), 3–13

Sihag, P., Kumar, U., Sagwal, V., Kapoor, P., Singh, Y., Mehla, S., Balyan, P., Mir, R.R., Varshney, R.K., Singh, K.P., Dhankher, O.P., 2024. Effect of terminal heat stress on osmolyte accumulation and gene expression during grain filling in bread wheat (*Triticum aestivum* L.). Plant Genome 17(1). https://doi.org/10.1002/tpg2.20307.

Singh, L.A.K., Singh, S., Tiwari, D., Singh, P., Zaidi, S.T., Yadav, R.K., Mishra, S.R., Singh, A.K., 2022. Evaluation of wheat varieties for terminal heat stress under varying environments. International Journal of Environment and Climate Change, 546–554. https://doi.org/10.9734/ijecc/2022/v12i1030829.

Singh, R.S., Patel, P. K., 2019. Assessment of terminal heat tolerance among wheat (*Triticum aestivum*) genotypes based on multivariate analysis and selection indices. The Indian Journal of Agricultural Sciences 89(6), 1072–1080.

Snedecor, G.W., Cochran, W.G., 1994. Statistical methods. 7th Edn. Oxford and IBH Publications, New Delhi.

Sood, N., Mavi, G.S., Malhotra, A., Jhinjer, R.K., Singh, B., Kaur, B., Sohu, V.S., 2017. Evaluating the performance of bread wheat (*Triticum aestivum* L.) genotypes for terminal heat tolerance. International Journal of Agriculture Environment and Biotechnology 10(3), 295–302.

Suresh, Om Parkash, B., Rishi, K.B., 2018. Use of heat susceptibility index and heat response index as a measure of heat tolerance in wheat and triticale. Ekin Journal of Crop Breeding and Genetics 4(2), 39–44.

Ullah, A., Nadeem, F., Nawaz, A., Siddique, K.H., Farooq, M., 2021. Heat stress effects on the reproductive physiology and yield of wheat. Journal of Agronomy and Crop Science 208, 1–17.

Verma, P., Singh, M., Kumar, V., Singh, R.K., 2023. HSI indices for late-sown wheat genotypes. Agricultural Research Bulletin 21(1), 112–119.

Wardlaw, I.F., Wrigley, C.W., 1994. Heat tolerance in temperature cereals: an overview. Australian Journal of Plant Physiology 21, 695–703.