

Estimation of Thermal Stress Tolerance for Yield and its Contributing Attributes in Bread Wheat

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Abstract In bread wheat (*Triticum aestivum* L. em. Thell.), development of thermal stress tolerant cultivars and realization of potential at yield in hot irrigated climate is enshrined goal of our breeding program. By keeping the above fact in view, the present study was conducted in two environments i.e. normal and late sown conditions with 10 diverse genotypes, their 45 F's and F's to magnify the yield level of wheat in high temperature areas by selecting stress tolerant parents and cross combinations. In the present study, as per the HSI value of parents and crosses genotypes were classified in to four different categories i.e. highly heat tolerant (HSI < 0.50), heat tolerant (HSI: 0.51–0.75), moderately heat tolerant (HSI:

0.76–1.00) and heat susceptible (HSI > 1.00). The overall ranking indicated that parent Raj 3777, Raj 4037 and Raj 4083 were most desirable parents in late sown condition as they were included in top three parents for most of the characters while among the crosses, Raj 4120 × Raj 4083 followed by Raj 4120 × Raj 4238 and Raj 4083 × Raj 4238 displayed maximum tolerance as they attained top three rank for more than two characters.

Keywords Wheat, Heat susceptibility index, Thermal stress tolerant.

Introduction

Wheat (*Triticum aestivum* L. em. Thell.) is the most important agricultural product of the globe and among the major three cereal crops that provides 20% of the total energy requirement in human food [1]. Our country has witnessed spectacular growth in production and productivity of wheat i.e. 93.50 million tonnes from 30.23 million hectare area with a productivity of 3.43 tonnes/ha [2]. Yield potential of any variety is the result of interaction between genotypes and environment. In the present scenario, climatic conditions are changing due to the effect of global warming and in late February and March during the post anthesis stage of wheat, increased temperature at the time of grain development, terminates grain growth prematurely and affect yield considerably. Elahmadi [3] reported heat stress as one of the main constraints

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Table 1. Mean of parents, their F₁'s and F₂'s for various characters in normal (E₁) and late sown condition (E₂) in bread wheat.

Characters	Environ-	Parents	F ₁ 's	F ₂ 's
	ment			
Days to heading	E ₁	79.10	77.21	78.59
	E ₂	70.20	68.90	69.32
Days to maturity	E ₁	125.66	126.29	126.64
	E ₂	110.83	110.01	106.65
Grain filling period	E ₁	46.56	49.07	48.06
	E ₂	40.63	40.96	37.33
Plant height	E ₁	90.25	92.60	90.63
	E ₂	76.56	74.96	76.28
Flag leaf area	E ₁	24.76	23.65	24.16
	E ₂	20.92	18.78	17.55
Peduncle area	E ₁	30.73	32.36	31.48
	E ₂	25.19	26.45	26.03
Number of tillers per plant	E ₁	7.00	7.39	6.75
	E ₂	5.73	5.58	5.39
Spike area	E ₁	39.33	41.78	39.23
	E ₂	31.75	35.12	32.31
Number of grains per spike	E ₁	49.34	52.85	51.59
	E ₂	40.73	43.73	41.59
Grain yield per spike	E ₁	1.87	2.11	1.90
	E ₂	1.32	1.58	1.46
1000-grain weight	E ₁	38.77	38.83	37.05
	E ₂	33.44	30.33	29.54
Harvest index	E ₁	40.31	40.71	40.16
	E ₂	38.94	38.13	36.23
Grain yield per plant	E ₁	18.68	21.55	21.00
	E ₂	12.59	14.87	13.53

of wheat production and is known to cause stunted plant growth, reduced tillering and accelerated development leading to small heads, shriveled grains and low yield.

Consequently development of heat-tolerant cultivars is a major concern in wheat breeding programs. To increase the production and productivity in wheat cultivation particularly in warmer areas, new set of varieties having heat tolerance are required. Therefore the present research investigation was carried out to understand the effect of yield contributing attributes under high temperature conditions and identification of tolerant genotypes suitable for such environments.

Materials and Methods

The varieties/strains of bread wheat (*Triticum*

aestivum L. em. Thell.) namely: Raj 3765, WH 1021, Raj 3777, Raj 4037, Raj 4120, PBW 343, Raj 4083, Raj 4238, DBW 17 and PBW 550 were crossed in diallel fashion excluding reciprocals (*rabi* 2013-14). After advancing the generation (*rabi* 2014-15), ten genotypes along with their 54 F₁'s and 45 F₂'s progenies were evaluated in 2 environments (two different dates of sowing 15 Nov. and 15 Dec.) timely sown and late sown, with 3 replications at Agricultural Research Farm of RARI Durgapura. Row length was 3 meter. Row to row and plant to plant distance was kept 30 cm and 10 cm, respectively. Observations were recorded for days to heading (75%), days to maturity (75%), grain filled period (days), plant height (cm), flag leaf area (cm²), peduncle area (cm²), number of tillers per plant, spike area (cm²), number of grains per spike, grain yield per spike (g), 1,000-grain weight (g), harvest index (%) and grain yield per plant (g) on 10 randomly selected plants in each of the F₁'s progenies along with each parent while 30 plants were selected in F₂'s population from each replication. Mean values over selected plants was used for analysis of heat susceptibility index.

Heat susceptibility index (HSI) was calculated for grain yield and other attributes over high temperature stress (late sown) and non-stress environment (normal sown) by using the formula as suggested by Fischer and Maurer [4].

$$HSI = [I-YD/YP]/D$$

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

The impact of climate change is clearly evident from recent vagaries across regions in India. Although North-West Plain Zone (NWPZ) has weather conditions more favorable in comparison to Central Zone (CZ), the wheat yield under late sown condition is comparatively lower in this wheat bowl of the country [7]. The results of present investigation demonstrated that the mean performance of parents, F₁'s

Table 2. Heat susceptibility indices for yield and its contributing attributes in E₂ in comparison to E₁ environment.

Parents	Days to heading	Days to maturity	Grain filling period	Plant height	Flag leaf area	Peduncle area	Number of tillers per plant	Spike area	Number of grains per spike	Grain yield per spike	1000-grain weight	Harvest index	Grain yield per plant
Raj 3765 (P1)	1.20	0.95	0.71	0.88	0.71	0.70	1.03	1.31	0.96	0.74	0.88	1.18	1.08
WH 1021 (P2)	1.25	0.85	0.45	0.92	0.50	1.87	0.75	1.37	1.30	1.78	0.33	1.05	1.27
Raj 3777 (P3)	1.29	1.04	0.79	0.70	0.88	0.83	1.02	0.01	0.40	0.61	0.50	-0.84	0.51
Raj 4037 (P4)	0.74	0.73	0.74	0.61	0.80	0.31	0.98	1.43	0.15	0.53	0.37	0.31	0.78
Raj 4120 (P5)	0.76	0.73	0.72	0.97	0.85	0.87	1.04	0.39	0.99	0.74	1.26	0.82	0.93
PBW 343 (P6)	1.10	0.78	0.46	0.99	1.03	1.48	0.43	2.14	1.52	1.11	0.72	0.61	1.62
Raj 4083 (P7)	0.75	0.93	1.11	1.00	1.29	0.47	0.96	0.18	0.88	0.92	0.19	-0.38	0.53
Raj 4238 (P8)	1.05	0.69	0.33	1.08	0.40	0.95	0.75	1.44	0.94	0.83	0.92	0.43	0.82
DBW 17 (P9)	0.87	0.89	0.91	0.81	-0.93	1.59	0.62	1.55	1.34	2.14	0.88	1.20	1.11
PBW 550 (P10)	0.92	0.80	0.67	0.83	0.54	0.74	0.51	1.06	1.01	1.94	0.80	0.13	1.08
F ₁ crosses													
P1 × P2	0.83	0.77	0.69	0.81	1.27	1.55	0.80	1.50	1.44	1.87	0.79	-0.40	0.63
P1 × P3	1.06	0.84	0.63	0.67	1.50	0.74	0.85	1.32	1.01	0.87	0.88	0.31	0.55
P1 × P4	0.74	0.85	0.93	0.61	0.40	0.91	0.95	1.28	0.91	0.21	1.23	1.19	0.83
P1 × P5	0.54	0.78	1.04	0.98	0.23	0.67	1.20	1.66	1.19	0.86	1.33	-0.18	0.74
P1 × P6	1.07	0.90	0.73	0.91	0.98	1.56	0.88	1.69	1.25	0.22	0.93	1.48	1.13
P1 × P7	0.80	0.79	0.79	0.93	0.23	0.69	1.29	0.86	0.93	0.98	1.21	-0.62	0.90
P1 × P8	0.98	0.98	0.93	1.35	0.81	0.62	1.06	0.89	0.82	0.40	1.60	-1.07	1.12
P1 × P9	0.56	0.98	1.33	1.30	0.90	0.12	0.39	1.68	0.88	0.21	1.40	2.62	1.01
P1 × P10	0.92	0.90	0.82	0.82	0.32	0.84	0.97	1.65	1.26	1.43	1.62	0.43	1.38
P2 × P3	1.01	1.08	1.10	0.73	0.57	1.76	0.64	1.20	0.79	0.91	0.78	1.38	0.80
P2 × P4	0.38	1.03	1.49	1.27	-0.32	0.43	1.27	1.07	0.87	1.51	0.47	0.77	1.22
P2 × P5	0.94	0.92	0.90	1.32	0.86	1.34	0.90	1.01	1.19	2.10	1.61	2.99	0.87
P2 × P6	0.99	0.83	0.68	1.21	0.91	1.51	0.75	0.97	0.59	0.27	1.23	0.68	1.55
P2 × P7	0.60	0.99	1.37	1.26	1.27	0.22	0.98	1.10	1.62	1.26	1.34	-0.38	0.84
P2 × P8	0.87	1.20	1.51	1.17	0.70	0.87	0.95	0.91	0.87	0.20	1.48	-0.30	1.32
P2 × P9	1.06	0.99	0.90	1.21	0.65	1.72	0.56	1.86	1.34	0.43	1.17	0.90	0.97
P2 × P10	1.22	1.25	1.24	1.66	0.83	0.56	1.06	1.24	0.62	1.42	0.75	0.90	1.17
P3 × P4	1.18	1.08	1.03	1.20	0.50	1.02	1.44	1.09	1.15	0.69	0.98	-2.84	0.81
P3 × P5	0.98	0.90	0.89	1.57	1.41	0.40	1.13	1.40	0.91	1.90	1.01	-2.18	0.68
P3 × P6	0.66	1.06	1.37	1.51	1.38	0.76	0.61	0.48	0.55	0.79	0.78	0.71	1.00
P3 × P7	0.82	0.92	1.06	1.05	0.64	0.83	1.40	0.49	0.54	1.71	1.15	0.43	0.99
P3 × P8	1.05	0.92	0.79	1.36	1.46	1.21	1.76	1.04	1.22	1.60	0.29	1.06	0.62
P3 × P9	1.07	0.94	0.82	1.26	1.46	1.60	0.64	0.60	0.65	0.60	0.74	2.94	0.84
P3 × P10	0.91	0.99	1.03	0.79	0.67	1.15	1.18	0.37	0.44	0.58	0.80	1.38	0.77
P4 × P5	0.97	0.93	0.96	0.69	1.88	1.49	1.19	0.55	0.49	1.58	1.08	-0.53	0.65
P4 × P6	0.94	0.77	0.61	1.49	-0.15	0.15	0.71	0.45	1.50	1.11	0.86	0.56	0.82
P4 × P7	1.15	0.77	0.40	0.79	0.43	0.41	1.42	-0.44	1.14	0.16	0.72	0.78	1.11
P4 × P8	0.73	0.80	0.90	0.84	0.78	1.42	1.50	1.30	0.99	0.31	0.27	0.00	0.67
P4 × P9	1.17	1.01	0.87	0.87	0.54	0.77	0.84	1.11	0.55	-0.09	1.46	-0.03	0.64
P4 × P10	1.05	0.98	0.90	1.07	1.22	0.41	1.03	1.01	1.00	1.31	0.65	2.42	0.92
P5 × P6	1.05	0.95	0.84	1.39	0.68	1.38	1.08	1.00	1.27	1.30	0.85	2.53	1.27
P5 × P7	1.33	0.81	0.25	0.64	1.26	1.31	1.26	0.60	0.35	1.15	0.78	-0.03	1.41
P5 × P8	1.15	1.10	1.06	0.68	0.76	0.75	1.33	0.19	1.03	0.75	1.01	-1.72	0.64
P5 × P9	0.62	0.71	0.76	0.99	0.58	1.01	1.27	0.46	1.39	0.95	1.73	1.14	1.08
P5 × P10	1.03	0.86	0.69	1.18	-0.17	1.21	1.11	0.54	0.97	0.81	1.44	0.07	0.63
P6 × P7	0.81	0.85	0.91	1.39	0.11	0.42	1.00	0.68	1.38	1.01	0.90	1.72	0.77
P6 × P8	0.87	0.80	0.73	1.08	1.12	1.53	1.35	0.95	0.65	1.47	1.01	1.89	0.96
P6 × P9	0.71	0.95	1.21	1.19	1.86	1.43	1.35	1.47	0.62	1.12	1.51	1.23	0.89
P6 × P10	1.93	0.89	-0.19	1.02	1.28	1.29	0.59	1.48	1.34	0.38	1.15	2.60	0.97
P7 × P8	1.06	0.76	0.46	1.28	1.26	1.33	2.24	1.06	0.73	0.19	0.50	-0.25	0.63
P7 × P9	1.28	0.87	0.49	1.28	1.37	0.70	1.26	0.33	0.73	1.10	1.22	1.40	1.23

Table 2. Continued.

Parents	Days to heading	Days to maturity	Grain filling period	Plant height	Flag leaf area	Peduncle area	Number of tillers per plant	Spike area	Number of grains per spike	Grain yield per spike	1000-grain weight	Harvest index	Grain yield per plant
P7 × P10	0.88	0.86	0.82	1.25	0.93	1.54	1.69	-0.10	0.53	0.42	1.44	3.35	0.88
P8 × P9	0.70	0.69	0.66	1.27	0.68	1.04	1.33	-0.42	1.43	1.62	0.87	0.71	1.00
P8 × P10	1.29	0.74	0.24	1.01	1.46	1.20	1.38	1.18	1.11	2.32	1.15	0.81	1.12
P9 × P10	0.77	1.14	1.48	1.20	0.95	1.20	0.83	0.36	0.70	1.73	1.31	1.34	0.34
F ₂ crosses													
P1 × P2	0.85	0.99	1.13	0.71	1.69	1.69	1.26	0.80	1.41	2.25	1.56	0.28	0.07
P1 × P3	1.23	1.10	0.98	0.62	1.58	0.90	0.98	1.40	1.08	0.38	0.77	-0.37	0.68
P1 × P4	0.91	0.85	0.80	0.61	0.89	0.78	0.40	0.20	0.92	0.36	1.58	0.81	0.95
P1 × P5	0.98	0.83	0.68	0.97	0.70	0.44	-1.00	0.53	1.96	1.57	1.31	1.48	0.79
P1 × P6	0.87	1.34	1.66	1.00	1.71	1.62	0.55	1.49	1.61	1.04	0.92	1.95	1.22
P1 × P7	0.56	0.84	1.17	0.89	0.83	0.63	-0.28	0.86	1.23	1.21	0.55	-0.42	0.87
P1 × P8	1.37	1.22	1.05	1.08	1.01	0.03	1.39	2.03	0.63	-0.42	0.60	0.61	1.05
P1 × P9	0.93	1.02	1.12	0.71	0.87	0.74	-1.20	1.85	1.01	1.05	0.60	1.96	1.18
P1 × P10	1.18	1.20	1.14	0.94	0.68	0.04	1.25	1.53	1.17	0.69	1.95	2.50	1.40
P2 × P3	0.75	1.10	1.41	0.59	1.45	1.26	1.29	1.25	0.74	1.28	0.88	1.74	1.09
P2 × P4	0.78	1.17	1.43	0.92	0.69	0.22	0.66	1.21	1.15	1.75	0.33	-0.15	1.13
P2 × P5	0.67	1.20	1.68	0.89	1.36	1.31	0.78	0.52	1.11	0.97	1.18	2.90	1.31
P2 × P6	1.18	1.25	1.27	0.73	1.15	1.42	0.74	0.86	1.01	1.29	0.29	2.28	1.31
P2 × P7	1.13	0.90	0.69	1.00	1.81	0.28	1.24	1.21	1.75	0.98	0.57	1.26	1.02
P2 × P8	1.20	1.16	1.13	1.08	1.26	0.60	0.82	1.07	0.95	1.18	0.29	0.37	1.41
P2 × P9	1.67	1.20	0.75	1.09	0.91	1.29	0.70	1.81	1.27	-0.60	1.43	2.87	0.72
P2 × P10	1.48	0.99	0.51	1.26	0.91	0.56	0.51	0.75	0.34	0.86	0.55	1.68	1.44
P3 × P4	0.98	1.03	1.18	0.93	0.09	1.01	1.25	1.05	0.85	-0.13	0.71	-0.69	0.33
P3 × P5	0.83	1.04	1.31	1.60	1.05	0.54	0.51	0.57	1.46	0.20	0.95	-0.23	0.98
P3 × P6	0.99	1.10	1.19	0.81	1.87	1.02	0.67	0.43	0.45	-0.05	0.06	0.33	1.37
P3 × P7	1.00	0.89	0.80	0.98	1.64	0.44	0.63	1.37	1.03	2.41	1.57	2.13	1.08
P3 × P8	1.06	1.23	1.41	1.47	1.60	1.27	1.45	1.23	1.47	1.48	0.65	1.41	1.06
P3 × P9	0.84	1.20	1.54	0.80	1.26	1.51	0.79	0.97	1.02	0.71	0.24	2.52	1.35
P3 × P10	1.44	1.33	1.19	0.76	0.73	0.59	1.37	0.66	1.16	0.71	0.35	2.09	1.22
P4 × P5	0.95	0.94	0.98	0.76	1.44	1.72	1.39	0.67	0.90	0.40	1.46	-0.38	0.88
P4 × P6	1.21	1.12	1.08	0.98	0.17	0.46	1.12	1.08	1.82	0.91	1.04	2.14	0.97
P4 × P7	0.99	0.93	0.91	0.65	0.94	0.37	0.85	1.41	0.58	1.16	1.32	0.60	0.80
P4 × P8	1.23	1.13	1.07	1.12	1.35	1.73	1.41	0.95	1.18	1.16	1.17	-0.25	0.99
P4 × P9	0.90	1.21	1.64	1.11	0.81	0.83	1.79	0.73	0.94	0.64	0.87	1.72	0.90
P4 × P10	1.09	1.19	1.31	1.09	0.02	0.57	1.00	0.45	0.64	0.90	0.02	3.34	1.08
P5 × P6	0.96	1.20	1.37	0.74	0.74	1.17	0.46	0.02	1.32	1.53	1.87	2.33	1.11
P5 × P7	1.29	0.98	0.66	0.51	1.25	1.30	1.08	0.45	0.16	0.44	1.77	-0.33	1.14
P5 × P8	1.13	1.26	1.41	0.28	1.04	0.41	1.35	0.99	0.87	1.93	1.43	0.40	0.15
P5 × P9	0.68	1.28	1.80	0.75	1.14	0.82	1.23	1.03	0.99	1.18	1.73	2.02	1.49
P5 × P10	0.75	1.15	1.53	0.58	0.92	1.03	1.19	1.23	1.68	1.26	0.72	1.06	0.68
P5 × P7	0.56	1.21	1.91	0.78	0.99	0.18	0.66	0.44	1.53	0.27	1.02	0.06	1.20
P5 × P8	1.16	1.27	1.46	1.01	1.87	1.16	0.40	1.58	0.37	1.08	0.95	1.70	1.01
P5 × P9	1.58	1.14	0.70	1.00	1.99	1.63	1.21	1.42	1.29	0.91	0.75	2.12	1.34
P5 × P10	1.21	1.13	1.06	1.26	1.78	1.47	0.07	1.16	1.43	-0.06	0.78	2.16	1.35
P7 × P8	0.85	0.99	1.22	1.00	1.93	1.13	1.11	0.72	0.51	1.56	0.74	-1.16	0.68
P7 × P9	0.92	1.35	1.77	0.87	1.77	0.48	0.78	1.11	0.27	0.02	1.07	1.64	1.36
P7 × P10	0.57	1.18	1.68	1.03	0.96	1.53	2.17	0.49	1.19	1.73	1.30	1.87	0.92
P8 × P9	1.62	1.15	0.69	1.24	1.05	1.59	2.02	1.80	1.07	0.26	1.76	0.17	1.02
P8 × P10	0.95	1.21	1.43	1.16	1.61	1.37	0.55	1.62	0.76	1.10	1.36	3.14	1.63
P9 × P10	1.39	1.05	0.71	0.91	1.00	1.35	0.96	0.92	1.36	-1.44	0.31	1.76	1.29
D-value	0.11	0.14	0.19	0.17	0.23	0.18	0.22	0.17	0.18	0.25	0.20	0.08	0.33

and F_2 's under E_2 (late sown) environment reduced in comparison to E_1 environment (normal sown) (Table 1) [5—13].

On the basis of HSI, the parents, F_1 's and F_2 's were classified as highly tolerant, tolerant, moderately tolerant, and susceptible to heat stress. Perusal of Table 2 indicated that parent Raj 4037, Raj 4083 and Raj 4120 for days to heading; Raj 4238, Raj 4037 and Raj 4120 for days to maturity; Raj 4238, WH 1021 and PBW 343 for grain filling period, Raj 3777, Raj 4037 and DBW 17 for plant height; DBW 17, Raj 4238 and WH 1021 for flag leaf area; Raj 4037, Raj 4083 and Raj 3765 for peduncle area; PBW 343, PBW 550 and DBW 17 for tillers per plant; Raj 3777, Raj 4083 and Raj 4120 for spike area; Raj 4037, Raj 3777 and Raj 4083 for number of grains per spike; Raj 4037, Raj 3777 and Raj 4120 for grain yield per spike; Raj 4083, WH 1021 and Raj 4037 for 1,000-grain weight; Raj 3777, Raj 4083 and PBW 550 for harvest index and Raj 3777, Raj 4083 and Raj 4037 for grain yield per plant were least affected under late sown conditions (E_2). An overall assessment of parents for all the studied characters indicated that Raj 4037, Raj 4083 and Raj 3777 were found to be desirable for most of the characters on the basis of HSI.

Considering heat susceptibility index (HSI) in F_1 's (Table 2), the crosses DBW 17 \times PBW 550, Raj 3765 \times Raj 3777 and Raj 3777 \times Raj 4238 for days to heading; WH 1021 \times Raj 3777, Raj 3765 \times Raj 4120 and Raj 3765 \times DBW 17 for days to maturity; Raj 4238 \times DBW 17, Raj 4120 \times DBW 17 and Raj 4238 \times PBW 550 for grain filling period; Raj 3765 \times Raj 4037, Raj 4120 \times Raj 4083 and Raj 3765 \times Raj 3777 for plant height; WH 1021 \times Raj 4037, Raj 4120 \times PBW 550 and Raj 4037 \times PBW 343 for flag leaf area; Raj 3765 \times DBW 17, Raj 4037 \times PBW 343 and WH 1021 \times Raj 4083 for peduncle area; Raj 3765 \times DBW 17, WH 1021 \times DBW 17 and PBW 343 \times PBW 550 for number of tillers per plant; Raj 4037 \times Raj 4083, Raj 4238 \times DBW 17 and Raj 4083 \times PBW 550 for spike area; Raj 4120 \times Raj 4083, Raj 3777 \times PBW 550 and Raj 4037 \times Raj 4120 for number of grains per spike; Raj 4037 \times DBW 17, Raj 4037 \times Raj 4083 and Raj 4083 \times Raj 4238 for grain yield per spike; Raj 4037 \times Raj 4238, Raj 3777 \times Raj 4238 and WH 1021 \times Raj 4037 for 1000-grain weight; Raj 3777 \times Raj 4037, Raj 3777 \times Raj 4120 and Raj 4120 \times Raj 4238 for harvest index and

DBW 17 \times PBW 550, Raj 3765 \times Raj 3777 and Raj 3777 \times Raj 4238 for grain yield per plant exhibited comparatively more tolerance among 45 F_1 's, under late sown conditions (E_2). It is well established that grain yield is primary objective of any breeding program, therefore F_1 crosses DBW 17 \times PBW 550, Raj 3765 \times Raj 3777, Raj 3777 \times Raj 4238, Raj 4083 \times Raj 4238 and Raj 4120 \times PBW 550 which revealed more tolerance for grain yield per plant were considered as desirable for thermal stress tolerance in E_2 .

Perusal of Table 2 revealed that in F_2 's the crosses, PBW 343 \times Raj 4083, Raj 3765 \times Raj 3777 and Raj 3777 \times PBW 550 for days to heading; Raj 3765 \times Raj 4120, Raj 3765 \times Raj 4083 and Raj 3765 \times Raj 4037 for days to maturity; WH 1021 \times PBW 550, Raj 4120 \times Raj 4083 and Raj 3765 \times Raj 4120 for grain filling period; Raj 4120 \times Raj 4238, Raj 4120 \times Raj 4083 and Raj 4120 \times PBW 550 for plant height; Raj 4037 \times PBW 550, Raj 3777 \times Raj 4037 and Raj 4037 \times PBW 343 for flag leaf area; Raj 3765 \times Raj 4238, Raj 3765 \times PBW 550 and PBW 343 \times Raj 4083 for peduncle area; Raj 3765 \times PBW 550, Raj 3765 \times PBW 343 and Raj 3765 \times Raj 4238 for number of tillers per plant; Raj 4120 \times Raj 3765 \times Raj 4037 and Raj 3777 \times PBW 343 for spike area; Raj 4120 \times Raj 4083, Raj 4083 \times Raj 4238 and WH 1021 \times PBW 550 for number of grains per spike; DBW 17 \times PBW 550, WH 1021 \times DBW 17 and Raj 3765 \times Raj 4238 for grain yield per spike; Raj 4037 \times PBW 550, Raj 3777 \times PBW 343 and Raj 3777 \times DBW 17 for 1000-grain weight; Raj 4083 \times Raj 4238, Raj 3777 \times Raj 4037 and Raj 3765 \times Raj 4083 for harvest index and Raj 3765 \times WH 1021, Raj 4120 \times Raj 4238 and Raj 3777 \times Raj 4037 for grain yield per plant showed high heat tolerance under late sown conditions (E_2). On the basis of HSI for grain yield in F_2 generation DBW 17 \times PBW 550, Raj 3765 \times Raj 3777, Raj 3777 \times Raj 4238, Raj 4083 \times Raj 4238 and Raj 4120 \times PBW 550 were considered as desirable for thermal stress tolerance in E_2 . Resemblance across the generations indicated the superiority of the crosses Raj 3777 \times Raj 4037, Raj 3765 \times Raj 4083, Raj 4037 \times Raj 4083, Raj 3765 \times Raj 3777 and Raj 4037 \times DBW 17 under late sown condition (E_2). Low value of heat stress intensity (D - value) indicated that parameters viz., harvest index, days to heading, days to maturity, spike area, plant height and number of grains per spike were less affected while grain yield per plant, grain yield per spike, peduncle area, flag

leaf area, tillers per plant, 1,000-grain weight and grain filling period with high heat stress intensity (D -value) suffered more under E_2 environment.

A overall appraisal of Table 2 indicated that among the parents, Raj 3777, Raj 4083 and Raj 4037; in F_1 crosses DBW 17 \times PBW 550, Raj 3765 \times Raj 3777, Raj 3777 \times Raj 4238, Raj 4083 \times Raj 4238 and Raj 4120 \times PBW 550 and in F_2 , Raj 3765 \times WH 1021, Raj 4120 \times Raj 4238, Raj 3777 \times Raj 4037, Raj 4083 \times Raj 4238 and Raj 4120 \times PBW 550 were least affected under late sown conditions (E_2). VedPrakash [10] also reported higher D -value for grain yield/m².

On the basis of heat susceptibility index, the parents Raj 3777, Raj 4037 and Raj 4083 were most desirable parents in E_2 . As a consequence, it is recommended that these genotypes may perform as potential donor for heat tolerance. These parents should be further exploited for improvement of grain yield under late sown conditions. The HSI should be taken as important criteria for breeding wheat genotypes suitable for thermal stress.

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