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Heat susceptibility index analysis for terminal heat tolerance in Bread wheat (*Triticum aestivum* L. Em. Thell) under high temperature stress

Guman Singh, Dhirendra Singh, Naresh Parashar, DK Gothwal and RK Solanki

Abstract
High temperature is a major abiotic stress factor limiting wheat (*Triticum aestivum* L. em. Thell) productivity. Improvement of heat tolerance in wheat is an important breeding objective. This experiment was conducted using 10 genetically diverse genotypes of wheat were evaluated for heat stress tolerance in two varying environments created by two different dates of sowing *viz.*, normal (E_1) and late (high temperature stress, E_2) for yield and its contributing characters. It could be visualized from heat susceptibility index that parent Raj 3077, Raj 4079 and Raj 3765 were identified as good donors for heat tolerance. Among the crosses, Raj 3765xRaj 3077, Raj 3765xRaj 3777, Raj 3765xRaj 4079, Raj 3077xRaj 4079, Raj 3777xRaj MR-1, Raj 3777xRaj 4120, Raj MR-1xRaj 4120, Raj MR-1xWH 1105, Raj 4079xRaj 4120 and Raj 4079xWH 1105 were most desirable and could be utilized as a promising breeding material for the development of new set of heat stress tolerant wheat varieties.

Keywords: Susceptibility, index, Bread, temperature, *Triticum aestivum* L.

Introduction
Wheat (*Triticum aestivum* L. em. Thell) is one of the most cultivated cereal crops with an acreage of 220 million ha and a total production of 734.0 million tone worldwide (FAO 2018). India reached a landmark achievement in the year 2018–2019 with a total wheat production of 101.2 million t out of a cultivated area of 29.8 million ha (Anonymous, 2019) [3]. Wheat crop grown in Northern India under late sown condition get exposed to very low temperature upto booting stage and at later stages it has to face warm temperature that leads to forced maturity under high temperature conditions leading to poor grain yield. Wheat production is significantly affected by abiotic stresses especially at high temperature after anthesis period or during the grain filling stage (Zhang *et al*., 2017) [12]. Each genotype within a plant species needs an optimum temperature range for growth at different stages such as 20-25 °C for germination, 16-20 °C for tillering and 20-23 °C for grain formation in case of wheat. The best vegetative and reproductive growth stage for wheat plant is between 18-22 °C (Reynolds *et al*., 2010) [8]. Wheat is especially sensitive to temperature that exceeds 32-33 °C for any significant period, plants can be injured at seedling emergence, reproductive development, and stem elongation, heading and flowering by high temperature.
During last decade an increasing attention has been given to the development of short duration varieties with heat tolerance during grain formation stage. Breeding for heat tolerance is an integral component of wheat breeding programme at both national and international levels (Acevedo *et al.*, 1990) [2]. These programmes will help in spreading wheat cultivation to non-traditional warm areas besides optimizing wheat yield in tropical environments under the present situation of multiple cropping systems. Both of these goals require significant breeding efforts to improve high temperature tolerance of cereals for yield and quality. Heat stress is a major challenge to wheat productivity in India. The impact of climate change is clearly evident from recent vagaries across regions in India. Therefore, breeding aimed at selecting genotypes with high temperature stress tolerance is one of the most vital objectives of the wheat breeder.
Keeping the above facts in view, the present study was conducted to magnify the yield level of wheat in high temperature areas by selecting stress tolerant parents and cross combinations for future breeding programme.

Methods and Materials

In the present investigation, ten wheat (*Triticum aestivum.* L. em. Thell). Varieties/genotypes namely: Raj 1482, Raj 3765, Raj 3077, Raj 3777, Raj MR-1, Raj 4238, Raj 4079, Raj 4120, DPW 621-50 and WH 1105 were crossed in half diallel fashion during *rabi* 2015-16. For generation advancement, all the resulting 45 F1's were grown in a single row plot at Wheat Research Station, Wellington (Tamil Nadu) during summer 2016 to get F2 seeds. Heat stress environment in the field condition was created by manipulating the date of sowing. The experimental material consisting ten parents and their resulting 45 F1's and 45 F2's, were evaluated in a randomized block design with three replications under normal and high temperature condition during *rabi* 2016-17 at Agronomy farm, S.K.N. College of Agriculture, Jobner. Sowing was done about 30 days later than normal date of sowing which created heat stress environment at post anthesis. The parents and F1's were grown in a plot of two rows of 2-meter length, while the segregating generation i.e. F2 was sown in a plot of four rows of 2-meter length with row to row distance of 30 cm and plant to plant distance of 10 cm under both normal and heat stress environments. Observations were recorded for days to anthesis, grain filling duration, days to maturity, plant height, number of tillers per plant, flag leaf area, peduncle length, spike length, number of grains per spike, 1000-grain weight, biological yield per plant, grain yield per plant and harvest index, on 10 randomly selected plants in each of the F1's progenies and in each parent while 30 plants were selected in F2's population from each replication. Mean values over selected plants were used for analysis of heat susceptibility index. Heat susceptibility index (HSI) was calculated for grain yield and its attributes over high temperature/heat stress environment (E2) and non-stress environment (E1) by using the formula as suggested by Fisher and Maurer (1978).

HSI = [l-YD/YP]/D

Where,
D = Heat stress intensity
YD = mean of the genotype in stress environment.
YP = mean of the genotype under non-stress environment.
D =1-[mean of all genotypes in stress environment/mean of all genotypes in normal environment].

The HSI values were used to characterize the relative tolerance of genotypes based on minimization of yield losses as compared to normal environmental condition.

Results and Discussion

Increased ambient temperature as a result of global warming and climate changes is emerging as a great threat to the growth and development of most crop plants. A significant reduction was observed in mean performance of the genotypes in late sown condition as compared to timely sown condition for all the traits *viz.*, days to anthesis, grain filling duration, days to maturity, plant height, flag leaf area, number of tillers per plant, peduncle length, spike length, number of grains per spike, 1000-grain weight, grain yield per plant, biological yield per plant and harvest index. When temperatures are elevated from anthesis to grain maturity, grain yield is reduced because of the reduced time to capture resources (Farooq *et al.*, 2011) [5]. The drastic reduction in morphological and yield contributing traits i.e., plant height, number of tillers/plant, spike length, thousand seed weight and plant yield under heat stress conditions could be due to the inhibition of photosynthesis as one of the most striking consequences of heat stress on photosynthetic tissues which is reflected by the reduction in chlorophyll content of the leaves under heat stress conditions (Abou-Elwafa and Amein, 2016). Modhej *et al.* (2015) reported average grain yield reduction in barley and bread wheat genotypes by 17% and 23%, respectively when these crops were exposed to heat stress after anthesis.

The results of present investigation demonstrated that in comparison to normal sown (E_1), mean performance of parents, F_1's and F_2's declined under late sown (E_2) conditions. The mean performance value of grain yield per plant were reduced by 22.47%, 25.55% and 20.89 in Parents, F_1s and F_2s respectively. The results are in agreement with Sikdar *et al.* (2001) [9], Nagarajan and Rane (2002) [7], Singh and Madanpal (2003) [10], Tammam and Abd el-rady (2011) [11], Bala *et al.* (2014) and Bhardwaj *et al*. (2017) [4]. It is fairly accepted that yield is a complex trait and an ultimate product of the action and interaction of a number of component characters. Thus, a selection based on yield *per se* will not be much effective. Therefore, in order to determine the tolerance of different parents and crosses for heat stress, the heat susceptibility indices was worked out based upon the values and direction of desirability of different traits used in the study. In the present study, parents, F_1s and F_2s were classified into 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 results revealed that among the parents, Raj 3077 and Raj 4079; in F_1 crosses Raj 3765xRaj 3077, Raj 3765xRaj 3777, Raj 3765xRaj 4079, Raj 3077xRaj 4079; and in F_2, Raj 1482xRaj 3765, Raj 1482xRaj 3777, Raj 1482xRaj 4238, Raj 3765xRaj 3777, Raj 3077xRaj 4079, Raj 3077xRaj 4120, Raj 4120xWH 1105 and DPW 621-50xWH 1105 showed HSI value less than 0.50, therefore; these crosses were least affected under late sown conditions (E_2) for grain yield per plant.

Raj 3765, Raj 4079 and WH 1105 among the parents, Raj 1482xRaj 4238, Raj 1482xRaj 3777, Raj 1482xWH 1105, Raj 1482xRaj 4079, Raj 4079xWH 1105 and Raj 4079xRaj 4120 in F_1 crosses and Raj 4238xRaj 4079, Raj 4238xWH 1105, Raj MR-1xWH 1105, Raj 3077xDPW 621-50, Raj 3777xRaj MR-1, Raj 3077xDPW 621-50, Raj 1482xDPW 621-50, Raj 3077xRaj 4238, Raj 3765xRaj 4120 and Raj MR-1xDPW 621-50 in F_2 crosses revealed HSI value from 0.50-0.75, therefore, these parents, F_1 and F_2 crosses were considered as moderately tolerant to heat.

Resemblance across the generations for different characters indicated the superiority of the Raj 3765xRaj 3777, Raj 3077xRaj 4079 and Raj 4079xRaj 4120 crosses as they attained high heat tolerance in both the generations.

The overall results indicated that parent; Raj 3077, Raj 4079 and Raj 3765 were the most desirable parents as they possessed high heat tolerance for most of the characters. Among the F_1 crosses, Raj 3765xRaj 3077, Raj 3765xRaj 3777, Raj 3765xRaj 4079, Raj 3077xRaj 4079, Raj 3777xRaj MR-1, Raj 3777xRaj 4120, Raj MR-1xRaj 4120, Raj MR-1xWH 1105, Raj 4079xRaj 4120 and Raj 4079xWH 1105 and in F_2 crosses Raj 1482xRaj 3777, Raj 1482xRaj 3765, Raj 1482xRaj 4238, Raj 3765xRaj 3777, Raj 3765xRj MR-1, Raj

3765xRaj 4120, Raj 3077xRaj 3777, Raj 3077xRaj 4079, Raj 3077xRaj 4120, Raj 3777xRaj 4238, Raj 3777xDPW 621-50, Raj MR-1xRaj 4079, Raj MR-1xDPW 621-50, Raj 4238xRaj 4079 were found to be desirable for more than two characters on the basis of HSI.

An overall results revealed that the crosses Raj 3765xRaj 3777, Raj 3077xRaj 4079, Raj 4079xRaj 4120 were most desirable as they possessed high heat tolerance for more than two characters across the generations.

Table 1: Heat susceptibility indices for yield and its attributes

Parents	Days to heading	Grain filling duration	Days to maturity	Plant ht. (cm)	No. of effective tillers per plant	Flag leaf area (cm^2)	Peduncle length (cm)	Spike length (cm)	Number of grains per spike	1000-grain weight (g)	Biological yield per plant (g)	Grain yield per plant(g)	Harvest index (%)
Raj 1482	0.98	1.20	1.09	1.20	0.88	1.05	1.14	0.70	0.80	0.93	0.68	0.76	0.92
Raj 3765	1.11	0.84	0.99	0.96	0.93	0.95	0.81	0.48	0.66	0.87	0.44	0.75	1.41
Raj 3077	1.07	0.36	0.75	1.20	1.02	0.50	0.72	0.75	0.92	0.86	0.02	0.46	1.29
Raj 3777	1.14	0.64	0.92	-0.19	1.01	0.57	0.76	1.05	1.71	0.74	0.80	1.07	1.72
Raj MR-1	0.79	0.37	0.60	0.85	0.88	1.26	1.34	1.11	1.67	1.49	1.15	1.12	1.06
Raj 4238	1.16	0.83	1.02	0.74	1.10	1.29	1.21	1.34	1.65	0.96	1.42	1.17	0.69
Raj 4079	1.06	0.90	0.99	0.74	0.74	0.38	0.98	-0.15	-0.16	1.40	0.25	0.60	1.28
Raj 4120	0.55	0.86	0.68	0.88	0.75	1.20	0.99	1.04	1.33	1.11	0.52	0.93	1.81
DPW 621-50	1.08	1.13	1.12	1.64	1.27	1.24	0.99	1.21	1.52	1.03	1.33	1.19	1.02
WH 1105	1.10	1.02	1.07	1.57	0.63	1.20	1.02	0.78	0.83	1.23	0.47	0.59	0.85
F_1 crosses													
Raj 1482x Raj 3765	0.80	1.19	0.99	1.41	1.10	0.76	0.73	0.83	0.14	0.67	0.92	0.77	0.33
Raj 1482x Raj 3077	0.91	1.43	1.15	1.07	1.08	1.16	1.01	1.38	0.67	0.90	0.65	0.95	1.62
Raj 1482x Raj 3777	1.01	0.89	0.96	0.83	0.79	0.91	0.81	0.92	0.33	0.72	0.75	0.58	0.12
Raj 1482x Raj MR-1	0.78	1.32	1.01	1.35	0.94	0.95	0.88	1.02	0.61	1.08	0.71	0.94	1.46
Raj 1482x Raj 4238	1.34	0.53	0.99	0.93	0.91	1.58	1.35	0.54	0.11	0.61	0.74	0.52	0.01
Raj 1482x Raj 4079	0.77	1.49	1.12	0.99	0.58	1.22	1.25	1.39	0.50	1.16	-0.11	0.66	2.04
Raj 1482x Raj 4120	0.74	0.95	0.85	1.06	1.03	1.46	0.85	1.48	1.53	1.01	1.25	1.27	1.47
Raj 1482x DPW 621-50	1.16	1.16	1.17	0.89	1.27	1.18	0.98	1.10	1.52	0.54	1.15	1.10	1.07
Raj 1482x WH 1105	1.24	0.57	0.93	1.49	0.40	0.71	1.18	1.92	0.65	1.39	0.43	0.61	0.94
Raj 3765x Raj 3077	0.96	0.94	0.97	1.03	0.69	1.45	1.04	0.43	0.10	0.73	0.15	0.37	0.79
Raj 3765x Raj 3777	0.96	1.09	1.05	0.52	0.34	0.80	0.87	0.17	-0.09	0.83	0.18	0.10	-0.18
Raj 3765x Raj MR-1	0.97	1.08	1.03	1.27	1.12	1.45	1.00	0.89	0.83	1.31	1.50	1.23	0.76
Raj 3765x Raj 4238	1.03	1.44	1.25	0.82	1.18	1.18	1.59	1.10	0.62	1.05	0.51	1.20	2.71
Raj 3765x Raj 4079	0.70	1.71	1.20	1.36	0.74	1.36	1.00	1.49	0.17	0.77	0.15	0.49	1.08
Raj 3765x Raj 4120	0.67	1.19	0.94	1.05	0.88	1.05	0.36	1.06	1.02	0.63	0.67	0.81	1.12
Raj 3765x DPW 621-50	1.11	1.35	1.24	1.17	1.37	0.71	1.11	1.59	1.18	0.56	0.34	1.18	2.89
Raj 3765x WH 1105	1.50	0.86	1.21	1.60	1.01	0.86	1.65	0.82	1.10	0.76	0.85	0.89	0.98
Raj 3077x Raj 3777	0.88	0.77	0.84	0.74	1.27	0.93	0.61	1.08	1.29	0.66	1.23	1.10	0.89
Raj 3077x Raj MR-1	0.84	0.97	0.91	1.24	1.14	0.63	1.34	1.25	1.49	1.21	1.88	1.31	-0.03
Raj 3077x Raj 4238	1.14	1.21	1.19	1.19	1.33	0.97	1.28	1.56	2.07	0.74	1.26	1.43	2.07
Raj 3077x Raj 4079	0.82	1.31	1.06	0.80	0.71	0.77	0.85	-0.28	-0.40	0.61	-0.77	0.10	1.63
Raj 3077x Raj 4120	1.00	0.82	0.92	1.28	1.29	1.01	0.57	0.67	0.51	0.96	1.58	1.19	0.33
Raj 3077x DPW 621-50	1.06	1.94	1.49	1.07	1.37	0.98	0.76	1.46	1.70	0.85	1.78	1.33	0.36
Raj 3077x WH 1105	1.23	0.30	0.81	0.95	0.93	1.88	0.83	0.78	0.88	1.01	0.88	0.90	0.87
Raj 3777x Raj MR-1	1.06	1.23	1.11	-0.05	1.20	0.46	0.97	1.51	1.61	1.08	2.02	1.41	-0.03
Raj 3777x Raj 4238	1.05	0.79	0.93	0.11	1.53	0.45	1.92	0.54	0.61	0.84	1.68	1.38	0.80
Raj 3777x Raj 4079	0.66	1.28	0.95	0.49	0.94	0.76	0.61	1.09	1.49	0.99	1.41	1.16	0.70
Raj 3777x Raj 4120	0.95	0.61	0.80	0.24	1.47	0.43	0.42	1.53	2.31	0.87	1.82	1.73	1.85
Raj 3777x DPW 621-50	0.97	1.28	1.14	0.67	1.38	0.66	0.82	1.51	1.97	0.65	1.87	1.40	0.35
Raj 3777x WH 1105	1.22	0.57	0.92	0.75	0.89	0.81	1.26	1.15	0.99	0.69	0.10	0.80	2.17
Raj MR-1x Raj 4238	0.97	0.31	0.67	0.36	1.07	1.25	0.98	1.74	1.75	1.22	1.56	1.26	0.65
Raj MR-1x Raj 4079	1.00	0.73	0.87	0.74	0.92	0.64	0.35	0.29	0.70	1.42	1.25	1.07	0.59
Raj MR-1x Raj 4120	1.24	0.33	0.85	1.10	0.99	1.12	1.10	0.00	0.06	1.41	1.57	1.10	-0.07
Raj MR-1x DPW 621-50	0.92	1.02	0.98	1.18	1.24	1.13	1.16	1.08	0.81	1.04	1.04	1.17	1.59
Raj MR-1x WH 1105	1.12	0.45	0.81	1.29	0.47	0.93	1.12	1.22	1.50	1.31	1.07	0.82	0.21
Raj 4238x Raj 4079	1.41	0.09	0.82	0.76	1.06	1.09	0.87	0.42	0.26	1.22	0.48	1.09	2.35
Raj 4238x Raj 4120	0.94	0.95	0.96	0.95	1.15	0.89	1.06	1.56	1.88	0.94	1.85	1.40	0.43
Raj 4238x DPW 621-50	0.87	1.33	1.11	1.14	1.23	1.14	1.12	1.49	1.33	0.84	0.96	1.23	1.94
Raj 4238x WH 1105	1.30	0.98	1.15	1.40	0.57	1.14	0.93	1.12	1.47	1.11	0.86	0.78	0.54
Raj 4079x Raj 4120	0.98	0.71	0.86	0.61	0.62	1.04	0.99	0.01	-0.07	1.39	0.97	0.74	0.14
Raj 4079x DPW 621-50	1.03	1.27	1.15	1.41	0.62	0.79	1.18	1.18	1.29	1.26	1.21	0.94	0.36
Raj 4079x WH 1105	1.00	1.07	1.04	0.98	0.87	0.58	0.44	0.38	0.44	1.14	0.99	0.70	0.02
Raj 4120x DPW 621-50	0.51	1.46	1.00	1.40	1.37	0.99	1.10	1.57	1.88	1.35	2.30	1.71	0.42
Raj 4120x WH 1105	0.76	1.15	0.96	0.85	0.81	1.12	1.10	0.79	0.95	1.10	0.75	0.85	1.02

DPW 621-50x WH 1105	1.11	1.14	1.14	1.89	1.18	1.10	0.84	1.26	1.79	1.14	1.79	1.34	0.36
F_2 crosses													
Raj 1482x Raj 3765	0.79	1.53	1.12	1.18	0.83	0.90	0.90	0.39	0.32	0.88	-0.50	0.47	1.34
Raj 1482x Raj 3077	0.85	1.73	1.22	1.03	0.77	1.32	0.88	1.78	1.92	1.34	2.27	1.36	0.36
Raj 1482x Raj 3777	0.88	1.18	0.99	1.08	0.43	1.19	0.91	0.20	0.07	0.97	0.27	0.19	0.11
Raj 1482x Raj MR-1	0.84	1.06	0.93	0.98	1.13	1.09	0.52	1.17	1.12	1.43	2.39	1.42	0.25
Raj 1482x Raj 4238	1.19	0.05	0.73	1.41	1.09	1.39	1.42	0.37	0.45	0.32	0.08	0.34	0.56
Raj 1482x Raj 4079	0.58	1.46	0.99	0.91	0.02	1.58	0.62	2.03	2.12	1.54	2.06	1.16	0.09
Raj 1482x Raj 4120	0.72	1.38	1.02	0.76	1.84	1.69	1.32	2.08	2.33	0.96	3.50	2.30	1.25
Raj 1482x DPW 621-50	1.13	1.26	1.19	1.09	1.23	1.71	1.72	1.25	1.20	0.47	0.41	0.72	1.04
Raj 1482x WH 1105	1.15	0.58	0.93	1.42	1.09	0.41	1.42	1.66	1.80	1.35	1.78	1.56	1.48
Raj 3765x Raj 3077	1.00	1.54	1.23	0.82	0.97	0.94	0.91	-0.10	0.32	0.90	1.47	0.83	0.04
Raj 3765x Raj 3777	1.05	1.19	1.12	0.71	0.17	0.85	0.42	0.18	0.30	0.68	-1.04	-0.31	0.41
Raj 3765x Raj MR-1	1.16	0.82	1.02	1.03	1.00	1.90	1.40	0.42	0.38	1.19	-0.14	0.83	1.68
Raj 3765x Raj 4238	0.92	0.71	0.84	1.43	1.03	1.08	1.16	0.48	0.89	0.83	0.75	1.00	1.30
Raj 3765x Raj 4079	0.78	1.32	1.03	0.88	0.25	1.14	0.68	1.91	2.02	1.01	1.47	0.84	0.08
Raj 3765x Raj 4120	0.63	1.60	1.06	1.09	0.64	0.73	0.76	0.20	0.40	1.11	-0.53	0.74	1.86
Raj 3765x DPW 621-50	1.30	0.23	0.84	1.14	1.68	0.94	1.14	1.05	1.00	0.92	-0.14	1.43	2.95
Raj 3765x WH 1105	1.44	0.35	0.95	1.33	0.56	0.80	1.24	0.41	0.68	1.58	0.84	0.90	0.91
Raj 3077x Raj 3777	0.96	1.09	1.01	1.04	1.99	0.41	0.16	1.59	1.66	0.53	3.58	1.89	-0.18
Raj 3077x Raj MR-1	0.70	1.43	1.03	0.72	1.50	0.61	0.90	0.56	0.59	1.46	3.05	1.67	0.03
Raj 3077x Raj 4238	0.96	1.00	1.00	1.20	1.54	1.34	1.28	1.63	1.61	1.22	1.59	1.81	2.30
Raj 3077x Raj 4079	1.01	0.72	0.89	0.88	0.50	0.59	1.12	-0.39	-0.29	0.60	-1.06	-0.38	0.28
Raj 3077x Raj 4120	0.94	0.90	0.94	1.05	0.86	0.87	0.51	0.22	0.20	0.42	-2.39	0.09	2.16
Raj 3077x DPW 621-50	1.26	1.49	1.36	1.32	0.76	1.33	1.53	1.33	1.13	1.06	0.85	0.65	0.36
Raj 3077x WH 1105	1.12	0.18	0.73	1.17	1.23	1.03	1.42	1.36	0.97	1.35	0.79	1.47	2.23
Raj 3777x Raj MR-1	0.91	0.80	0.88	0.10	1.01	0.09	0.62	0.64	0.54	0.54	0.97	0.69	0.28
Raj 3777x Raj 4238	1.28	0.58	0.99	0.30	1.02	0.69	1.13	0.35	0.45	0.96	0.42	0.73	1.06
Raj 3777x Raj 4079	0.94	1.25	1.07	0.44	0.90	1.03	0.45	2.11	2.22	1.44	2.56	1.72	0.91
Raj 3777x Raj 4120	0.98	0.92	0.96	0.43	1.17	1.09	0.32	1.03	0.97	0.84	0.79	1.15	1.58
Raj 3777x DPW 621-50	1.05	1.69	1.34	0.80	1.38	0.50	1.06	0.72	0.35	0.62	0.14	0.72	1.28
Raj 3777x WH 1105	1.31	1.05	1.20	0.59	1.25	0.30	1.37	1.00	0.88	1.15	1.90	1.28	0.61
Raj MR-1x Raj 4238	0.98	0.20	0.67	0.71	1.00	1.21	1.26	1.46	1.42	0.73	0.53	0.88	1.21
Raj MR-1x Raj 4079	1.12	-0.58	0.44	0.57	0.92	0.45	0.42	0.83	0.88	1.53	0.82	1.32	1.93
Raj MR-1x Raj 4120	1.05	0.54	0.84	0.83	1.07	1.41	1.12	-0.28	-0.49	1.24	0.99	0.80	0.58
Raj MR-1x DPW 621-50	0.79	1.58	1.16	1.04	0.71	1.03	1.10	0.46	0.36	1.50	1.02	0.74	0.43
Raj MR-1x WH 1105	1.07	0.64	0.89	1.40	0.58	1.01	1.67	0.74	0.49	1.17	-1.19	0.62	2.12
Raj 4238x Raj 4079	1.23	0.99	1.13	0.95	0.39	0.84	0.41	1.33	1.41	0.90	-0.04	0.54	1.11
Raj 4238x Raj 4120	1.04	0.81	0.94	0.95	1.13	1.21	0.78	1.37	1.25	1.11	-0.17	1.28	2.66
Raj 4238x DPW 621-50	0.82	1.44	1.10	1.02	1.49	1.23	1.40	0.96	0.89	0.31	1.56	0.83	0.00
Raj 4238x WH 1105	1.12	0.63	0.91	1.64	-0.03	1.73	1.31	1.99	1.74	1.13	-2.41	0.56	2.85
Raj 4079x Raj 4120	0.95	0.67	0.84	0.70	0.34	-0.19	0.84	0.93	0.84	0.77	-0.01	0.29	0.58
Raj 4079x DPW 621-50	1.19	1.40	1.29	1.32	1.54	0.89	0.30	2.08	2.20	0.79	3.30	1.81	0.09
Raj 4079x WH 1105	1.16	0.68	0.97	1.12	1.22	1.10	0.20	1.02	0.66	0.61	1.67	0.88	-0.12
Raj 4120x DPW 621-50	0.65	1.78	1.17	1.29	1.16	0.95	1.21	1.63	1.52	1.27	2.49	1.46	0.20
Raj 4120x WH 1105	0.79	1.23	1.00	0.95	0.27	0.62	1.09	1.22	0.96	0.96	0.59	0.35	0.04
DPW 621-50x WH 1105	1.08	1.12	1.10	1.79	0.88	0.83	1.22	0.95	0.50	0.77	-0.38	0.35	1.06

Summary and Conclusion

On the basis of heat susceptibility index (HSI) of grain yield per plant the parents Raj 3077, WH 1105, Raj 4079 and Raj 3765 emerged as highly heat tolerant genotypes. Similarly, the F1 crosses namely Raj 3765xRaj 3777, Raj 3077xRaj 4079, Raj 3765x Raj 3077 and Raj 3765xRaj 4079 and F_2 crosses Raj 3077xRaj 4079, Raj 3765xRaj 3777, Raj 3077xRaj 4120, Raj 1482xRaj 3777, Raj 4079xRaj 4120, Raj 1482xRaj 4238, Raj 4120xWH 1105 and DPW 621-50xWH 1105were found highly heat tolerant for grain yield per plant. An overall evaluation revealed that the crosses, Raj 3765xRaj 3777, Raj 3077xRaj 4079, Raj 4079xRaj 4120 were most desirable as they possessed high heat tolerance for grain yield and associated characters across the generations.

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 and very late sown conditions. The HSI should be taken as an important criterion for breeding barley genotypes suitable for heat stress environment.

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References

1. Abdel-Nour NAR. Genetic studies on grain yield and earliness components in bread wheat of different photo thermal response. Egyptian Journal of Agricultural Research. 2011;89(4):1435-1460.
2. Acevedo E, Nachit M, Ortiz G. Effect of heat stress on

wheat and possible selection tools for the use in breeding for tolerance. Wheat for non-traditional warm areas. In: Saunders, D.A. (ed.) Proceeding International Conference, Mexico, 1990, 401-402.
3. Anonymous. United States Department of Agriculture. Foreign Agricultural Service. Production Supply and Distribution (PSD), 2019, Pp. 15.
4. Bhardwaj R, Sain RS, Sharma BK, Singh H. Estimation of thermal stress tolerance for yield and its contributing attributes in bread wheat. Environment & Ecology. 2017;35(4B):3142-3147.
5. Farooq J, Khaliq I, Ali MA, Kashif M, Rehman A, Naveed M, *et al*. Inheritance pattern of yield attributes in spring wheat at grain filling stage under different temperature regimes. Australian Journal of Crop Science. 2011;5(13):1745-1753.
6. Fisher RA, Maurer R. Drought resistance in spring wheat cultivars I. Grain yield responses. Australian Journal of Agriculture Research. 1978;29(5):897-912.
7. Nagarajan S, Rane J. Physiological traits associated with yield performance of spring wheat (*Triticum aestivum* L.) under late sown condition. Indian Journal of Agricultural Sciences. 2002;72:135-140.
8. Reynolds M, Bonnett D, Scott CC, Robert TR, Mane Y, Mather ED, Parr JM. Raising yield potential of wheat. I. Overview of a consortium approach and breeding strategies. Journal of Experimental Botany. 2010;62(2):439-452.
9. Sikdar S, Ahmad JU, Hossain T. Heat tolerance and relative yield performance of wheat varieties under late sown seeded conditions. Indian Journal of Agricultural Research. 2001;35:141-148.
10. Singh S, Madan Pal. Growth, yield and phenological response of wheat cultivars to delayed sowing. Indian Journal of Plant Physiology. 2003;8(3):277-286.
11. Tammam AM, Abd El-Rady AG. Genetical studies on some morpho-physiological traits in some bread wheat crosses under heat stress conditions. Egyption Journal of Agricultural Research. 2011;89(2):589-604.
12. Zhang Y, Pan J, Huang X, Huang X, Guo D, Lou H, *et al*. Differential effects of a postanthesis heat stress on wheat (*Triticum aestivum* L.) grain proteome determined by iTRAQ. Scientific Report. 2017;7:3468.