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Documentation of Parents and Hybrids Tolerant to Terminal Heat Stress in *Brassica juncea* L.

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ABSTRACT

Background: Fluctuations in temperature during the growth period can damage the inter-molecular interactions needed for proper growth, thus impairing plant development and fruit set, which leads to significant yield loss with greater risks for future global food availability, food accessibility, food utilization and food systems stability. Keeping these in mind present investigation was done to identify of parents and hybrids for terminal heat tolerance.

Methods: Nine lines and three testers were crossed in line × tester fashion to develop hybrids. F_1s were evaluated under timely and late sown conditions to study the effect of terminal heat stress by calculating, heat susceptibility index (HSI), heat tolerance efficiency (HTE) and stress tolerance index (STI) on yield and yield traits and to characterize parents and crosses on the basis of their relative tolerance against heat stress at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during *Rabi* 2017-18 and 2018-19.

Result: Observations were made for different yield and yield related traits. Genotypes such as BPR 541-4 was found to be tolerant to heat stress at terminal stage and crosses such as Vardan × PM 30, Kranti × RH 406 and Kranti × Urvashi were found to be tolerant to heat stress for seed yield per plant at terminal stage during 2017-18 and 2018-19. Genotypes and crosses that were found to have minimum reduction in seed yield manifested tolerance to heat stress in terminal stage (had lowest HSI, Highest HTE and Highest STI).

Key words: Heat susceptibility index (HSI), Heat tolerance efficiency (HTE), Indian mustard, Stress tolerance index (STI), Terminal heat stress.

INTRODUCTION

It is known that phenotype is a function of the genotype and environment and this is germane to all the individuals subjected to a particular environment so, when the same individual is subjected to more than one kind of environment, its phenotypic expression for any trait changes accordingly. According to, National oceanic and atmospheric administration's "Global climate report" of 2019 the average temperature across global land and ocean surfaces was 1.71°F (0.95°C) higher than the 20th century average. Furthermore, it was revealed that the five warmest years have occurred since 2015; nine of the 10 warmest years have occurred since 2005. These suggests that climate change is happening due to global warming of 1.5°C above pre-industrial levels. These differences include increases in mean temperature in most land and ocean regions, hot extremes in most inhabited regions, heavy precipitation in several regions and the probability of drought and precipitation deficits in some regions which will have major impact on biodiversity, ecosystem, food security *etc*. It is factual that fluctuations in temperature occur naturally during plant growth and reproduction. However, extreme changes during the growth period can damage the inter-molecular interactions needed for proper growth, thus impairing plant development and fruit set, which leads to significant yield loss with greater risks for future global food availability, food accessibility, food utilization and food systems stability. For this reason, it turns out to be critical that plant breeders make available such genotypes that can withstand climate change, to a certain extent.

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As much as the rapeseed-mustard crop is important to the economy of India, it is not immune to the changing climate. Studies have shown that though Indian mustard (*Brassica juncea*) is relatively tolerant to biotic and abiotic stresses in comparison with other oilseed *Brassica* species reports have shown that high temperature stress in *Brassica* enhanced plant development and caused flower abortion and poor grain filling with appreciable loss in seed yield. When temperatures above 32°C occur, on average for about seven consecutive days in a given growing season it can cause substantial yield losses in *Brassica* species (Angadi *et al*. 2000; Morrison and Stewart 2002). Angadi *et al*. (2000) suggested that earlier the occurance of stress, greater the opportunity to recover, so, a plant stressed during bud formation may recover more easily than a plant stressed during the pod development stage *i.e.,* terminal growth period. Flowering is the most sensitive stage for temperature stress damage, probably due to susceptibility of pollen development, anthesis and fertilization (asynchrony of stamen and gynoecium development) to heat damage (Hall 1992). More reports suggests that high temperatures accelerate plant development but reduces the growing period and also reduce the yield potential (Entz and Fowler 1991). Mendham and Salisbury (1995) reported that seed yield potential in *Brassica* crops depends on the events occurring prior to and during the flowering in addition Hall (1992) and Paulsen (1994) also stated that the reproductive period is most susceptible to stress. In India, Indian mustard, has gained on productivity part but area in which it is cultivated has not changed much and so increase in production from the existing area does not give the desired yield even after growing improved varieties. Therefore, breeding for such genotypes which are adapted to wide range of environments and specifically for terminal heat stress tolerance is vital at this point of changing climate. Keeping these in mind present investigation was done to identify of parents and hybrids for terminal heat tolerance.

MATERIALS AND METHODS

The present investigation was carried out for the duration of three years during *Rabi* season, 2017-2018 and 2018-2019 at the Agriculture Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. Varanasi experiences a humid subtropical climate with large variations between summer and winter temperatures. The dry summer starts in April and lasts until June followed by the monsoon season from July to September. The temperature ranges between 22 and 46°C in the summers. Winters in Varanasi experience very large diurnal variations with warm days and downright cold nights. The average annual rainfall is 1100mm. The nine lines *viz.,* PM 25, PM 26, PM 30, RH 406, BPR 541-4, SEJ 2, Urvashi, Giriraj, Pusa Bold and three testers Kranti, Vardan and NRCHB 101 were crossed in line × tester fashion to get twenty-seven F_1s which were evaluated for heat stress parameters, yield and related traits along with some physiological and biochemical parameters such as test weight, yield per plant, harvest index, area under canopy temperature depression curve, area under chlorophyll depression curve, membrane thermostability at vegetative and reproductive stage and oil content in randomized block design in three replications under timely and late sown condition during 2017-18 and 2018-19.

ANOVA was carried-out to test the differences amongst the parents and crosses by using randomised block design as per model given by Panse and Sukhatme (1985). Mean was used to compare individual genotypes. The screening was done using heat stress parameters such as Heat susceptibility index, heat tolerance efficiency and tolerance against stress. For heat susceptibility index (HSI) the mean value of all the traits under optimum and heat stress conditions was used to estimate the heat susceptibility index and calculated by the formula of Fischer and Maurer (1978). HTE will be calculated by the equation of Fischer and Wood (1981). Tolerance against stress (TOL) was calculated according to Fernandez (1992) equation.

Heat tolerance index (HTI) indices were

$$HTI = 1 - \left[\frac{(y_{pi}) - (y_{si})}{y_p} \right]$$

Where,

y_{pi} = Yield of individual genotype without stress.

y_{si} = Yield of individual genotype with stress.

y_p = Average yield of all genotype without stress, Higher rate for the stress tolerance index indicates higher potential yield.

Classification of genotypes on the basis of heat susceptibility parameters *viz.,* heat susceptibility index (HSI), heat tolerance efficiency (HTE) and stress tolerance index (STI) are given below.

Range	Heat susceptibility index (HSI)	Heat tolerance efficiency (HTE)	Heat stress tolerance index (STI)
Susceptible	HSI > 1	HTE = 0 to 30	STI = 0 to 0.5
Moderately tolerant	HSI = 0.76 to 1	HTE =31-70	0.5-0.9
Tolerant	HSI = 0.51 to 0.75	HTE =70-80	STI >= 1

RESULTS AND DISCUSSION

Evaluation of selected parents and their crosses for heat tolerance

Performance of parents and hybrids

Average performance during both the years (2017-18 and 2018-19) revealed that average percent reduction in test weight due to late sowing was recorded to be 8.71% and 4.44% during 2017-18 and 2018-19 respectively, with minimum reduction in genotype BPR 541-4. Similarly, when seed yield per plant was considered, that mean yield reduction was 16.16% with least reduction in PM 26 (-7.24%) during 2017-18 and during 2018-19 it was observed that mean yield reduction was 30.15% with least reduction in Pusa Bold (5.18%). In the same way, average reduction of 15.60% was seen when oil content was considered and Hybrid mustard PRO AGRO 5222 recorded least reduction (1.92%) in oil content during 2017-18 while during 2018-19 average reduction of 3.69% was seen when oil content was considered and genotype PM 26 recorded least reduction (-4.16%) in oil content. During first year average reduction in harvest index was 43.14% with minimum reduction in Hybrid mustard PRO AGRO 5222 (-64.10 and during next year average reduction in harvest index was 43.14% with minimum reduction in Hybrid mustard PRO AGRO 5222 (-64.10%) when all the genotypes taken for evaluation were considered. Least reduction for AUCTDC and AUCDC was seen in PM 25 (-98.70%) and Sej 2 (-47.704%) respectively, with average reduction of -25.20% and 10.44% for AUCTDC and AUCDC respectively during the first year similarly during second year also least reduction for AUCTDC and AUCDC was seen in PM 25 (-98.70%) and Sej 2 (-47.704%) respectively, with average reduction of -25.20% and 10.44% for AUCTDC and AUCDC respectively. During the first-year average percent reduction in membrane thermostability at vegetative and reproductive stages was noted to be 36.65% and 42.57% respectively with minimum reduction in genotype Urvashi and Sej 2 in the same way during second year also minimum reduction was noted in genotypes Urvashi and Sej 2 with average percent reduction in membrane thermostability of 36.65% and 42.57% at vegetative and reproductive stages respectively.

Among hybrids reduction in harvest index ranged from -131.71% in Vardan × PM 30 to 35.46% in Kranti × PM 25, with mean reduction of -16.91% in the year 2017-18 while during the year 2018-19 it ranged from -104.43% in Vardan × PM 26 to 82.26% in NRCHB 101 × RH 406. In the same way, average reduction of 10.38% and 8.30% was recorded for test weight during 2017-18 and 2018-19. Genotypes which manifested least reduction for test weight are Vardan × PM 26 and Kranti × Sej 2 during 2017-18 and 2018-19 respectively. Average reduction in seed yield per plat was recorded to be 17.51% and 24.76% during 2017-18 and 2018-19. The crosses which recorded least reduction for seed yield per plant were NRCHB 101 × Pusa bold and Kranti × Sej 2 during 2017-18 and 2018-19 respectively. For AUCTDC least reduction among crosses was seen in cross Kranti x Giriraj and Vardan x Sej 2 during 2017-18 and during 2018-19 respectively with average reduction of 12.90% and -10.97% during 2017-18 and 2018-19 respectively. For AUCDC least reduction among crosses was seen in cross NRCHB 101 × Urvashi and Vardan × PM 26 during 2017-18 and during 2018-19 respectively with average reduction of -2.70% and 5.98% during 2017-18 and 2018-19 respectively. For membrane thermostability at vegetative and reproductive stage, least reduction among crosses was seen in cross NRCHB 101 × PM 25 and Kranti × RH 406 during 2017-18 and during 2018-19 respectively with average reduction of 23.69% and 6.05% during 2017-18 and 2018-19 respectively. Similarly, for oil content, least reduction among crosses was seen in cross Vardan × Sej 2 during 2017-18 and 2018-19 with average reduction of 14.55% and 4.66% during 2017-18 and 2018-19 respectively.

Identification of heat tolerant parents and hybrids

For identification of parents and hybrids for heat stress tolerance, stress parameters such as heat susceptibility index, heat tolerance efficiency and stress tolerance index were taken into consideration and parents and crosses found to be either moderately tolerant or tolerant to heat stress, during both the years 2017-18 and 2018-19, according the classification mentioned above, were identified as heat tolerant. By perusal of Table 1, for test weight, genotypes such as Giriraj and Pusa Bold were found to be heat tolerant during both the years whereas, genotype BPR 451-4 was found to be heat tolerant during both the years for seed yield per plant. When oil content was considered genotypes such as PM 25, PM 30, RH 406, Urvashi, Giriraj, Pusa bold and Kranti were found to be heat tolerant during both the years. Similarly, genotypes such as RH 406, Giriraj and Vardan were considered to be heat tolerant for harvest index on the basis of two years data. In the same way for AUCTDC genotypes such as RH 406, NRCHB 101, RH 749 and PRO 5222 were found to be heat tolerant and for AUCDC genotypes *viz.,* PM 30, RH 406, Urvashi, RH 749 and PRO 5222 were observed to be heat tolerant during both the evaluation years. None of the parental genotypes showed tolerance for membrane thermostability at both vegetative and reproductive stages during both the years.

Parental genotypes and hybrids which showed least reduction in test weight, harvest index, seed yield per plant, AUCTDC, AUCDC and membrane thermostability were identified as heat tolerant parents and crosses. Hybrids which were found to be moderately tolerant and tolerant to heat stress according to the three heat stress parameters during the years 2017-18 and 2018-19 were identified as heat stress tolerant hybrids. According to Table 2, 3 and 4 it was observed that crosses NRCHB 101 × PM 25, Kranti × BPR 541-4, Kranti × Sej 2, Vardan × Urvashi and Kranti × Giriraj, Kranti × Pusa Bold were found to be heat tolerant during both the years 2017-18 and 2018-19 for harvest index, whereas crosses *viz.,* Vardan × PM 25, NRCHB 101 × PM 25, NRCHB 101 × PM 26, Vardan × RH 406, NRCHB 101 × RH 406, Kranti × BPR 541-4, NRCHB 101 × Sej 2, NRCHB 101 × Urvashi, Kranti × Giriraj and Vardan × Pusa Bold manifested tolerance to heat stress for test weight. When seed yield per plant was considered crosses such as Vardan × PM 30, Kranti × RH 406 and Kranti × Urvashi, were noted as heat tolerant hybrids. Among all the 27 hybrids considered crosses like NRCHB 101 × PM 25, Kranti × Sej 2 and NRCHB 101 × Sej 2, were identified as heat tolerant for AUCTDC while crosses such as NRCHB 101 × PM 26, Kranti × PM 30, Vardan × PM 30, NRCHB 101 × PM 30, Vardan × BPR 541-4, NRCHB 101 × Sej 2 and Kranti × Urvashi, were found to be heat stress tolerant for AUCDC. None of the crosses were found to be heat stress tolerant for membrane thermostability when both the years were considered however during 2018-19 crosses such as NRCHB 101 × PM 25, NRCHB 101 × PM 26, Vardan × RH 406 and Kranti × Urvashi, for membrane thermostability at reproductive stage and crosses like Vardan × RH 406, Vardan × BPR 541-4 and Kranti × Urvashi for membrane thermostability at vegetative stage were found to be tolerant according to all the three heat stress parameters. When oil content was taken into consideration crosses such as Vardan × PM 26, Kranti × PM 30, NRCHB 101 × RH 406, Vardan × BPR 541-4, NRCHB 101 × BPR 541-4, Kranti × Sej 2, Kranti × Urvashi and Kranti × Giriraj, manifested tolerance to heat stress.

It was observed that crosses which showed tolerance to heat stress had either one or both the parents manifesting heat tolerance during 2017-18 or 2018-19 or both the years. In addition, genotypes and crosses that were found to have

Table 1: Showing mean performances of twelve parental genotypes along with two checks (RH 749 and hybrid mustard 5222) in timely and late sown condition along with heat stress parameters for AUCTDC, AUCDC, membrane thermostability at vegetative and reproductive stages.

Genotypes	AUDCTDC						AUCDC						MT (V)						MT (R)					
	Timely	Late		HSI	HTE	STI	Timely	Late		HSI	HTE	STI	Timely	Late		HSI	HTE	STI	Timely	Late		HSI	HTE	STI
2017-18																								
PM25	110.78	145.83	-31.64	1.40	131.60	1.30	561.50	554.50	1.25	1.00	98.80	1.00	45.79	36.68	19.90	1.20	80.10	0.80	47.92	31.98	33.26	1.10	66.70	0.60
PM26	88.93	107.50	-20.88	1.30	120.90	1.20	615.50	512.00	16.82	0.80	83.20	0.80	39.84	8.74	78.06	0.30	21.90	0.20	40.44	9.20	77.25	0.40	22.70	0.20
PM30	125.67	113.33	9.82	1.00	90.20	0.90	581.50	582.50	-0.17	1.00	100.20	1.00	50.13	22.80	54.52	0.60	45.50	0.30	51.47	16.81	67.34	0.50	32.70	0.10
RH406	128.57	113.33	11.85	1.00	88.20	0.90	581.75	519.50	10.70	0.90	89.30	0.90	43.52	17.13	60.64	0.60	39.40	0.30	45.40	13.82	69.56	0.50	30.40	0.20
BPR541-4	100.53	72.08	28.30	0.80	71.70	0.80	608.00	684.25	-12.54	1.10	112.50	1.10	8.18	41.82	-411.25	7.50	511.00	1.90	5.95	42.99	-622.52	12.30	722.20	2.00
SEJ2	98.12	126.25	-28.67	1.40	128.70	1.20	640.50	571.50	10.77	0.90	89.20	0.90	42.26	20.68	51.06	0.70	48.90	0.40	43.89	16.57	62.25	0.60	37.80	0.30
Urvashi	124.70	134.17	-7.59	1.20	107.60	1.10	600.75	569.50	5.20	0.90	94.80	0.90	30.80	41.43	-34.51	2.00	134.50	1.30	32.11	41.82	-30.24	2.20	130.30	1.30
Giriraj	111.17	105.42	5.17	1.00	94.80	1.00	489.50	645.00	-31.77	1.30	131.80	1.30	64.61	10.45	83.83	0.20	16.20	-0.40	65.45	8.13	87.58	0.20	12.40	-0.50
Pusa Bold	99.18	125.42	-26.46	1.40	126.50	1.20	642.00	638.50	0.55	1.00	99.50	1.00	43.75	19.14	56.25	0.60	43.80	0.30	45.31	13.90	69.32	0.50	30.70	0.20
Kranti	105.85	116.67	-10.22	1.20	110.20	1.10	517.75	554.00	-7.00	1.10	107.00	1.10	39.71	16.97	57.27	0.60	42.70	0.40	40.91	12.23	70.11	0.50	29.90	0.30
Vardan	62.45	116.25	-86.15	2.00	186.20	1.40	646.75	594.00	8.16	0.90	91.80	0.90	31.70	25.74	18.80	1.20	81.20	0.80	33.04	23.28	29.54	1.20	70.50	0.70
NRCHB101	151.67	122.50	19.23	0.90	80.80	0.80	574.75	620.00	-7.87	1.10	107.90	1.10	53.26	38.17	28.33	1.00	71.70	0.60	54.25	35.00	35.48	1.10	64.50	0.50
RH749	174.97	145.42	16.89	0.90	83.10	0.80	677.00	544.25	19.61	0.80	80.40	0.80	53.47	20.35	61.94	0.50	38.10	0.10	48.87	42.10	13.85	1.50	86.10	0.80
PRO AGRO5222	150.32	107.08	28.77	0.80	71.20	0.60	600.50	548.50	8.66	0.90	91.30	0.90	64.20	43.43	32.35	1.00	67.70	0.40	65.60	15.24	76.77	0.40	23.20	-0.30
Mean	116.64	117.95	-1.12				595.55	581.29	2.40				43.66	25.97	40.52				44.33	23.08	47.94			
Range lowest	62.45	72.08	-86.15	0.80	71.20	0.60	489.50	512.00	-31.77	0.80	80.40	0.80	8.18	8.74	-411.25	0.20	16.20	-0.40	5.95	8.13	-622.52	0.20	12.40	-0.50
Range highest	174.97	145.83	28.77	2.00	186.20	1.40	677.00	684.25	19.61	1.30	131.80	1.30	64.61	43.43	83.83	7.50	511.00	1.90	65.60	42.99	87.58	12.30	722.20	2.00
2018-19																								
PM25	109.00	216.58	-98.70	1.70	198.70	1.70	753.00	436.28	42.06	0.60	57.90	0.50	73.35	49.62	32.35	0.80	67.60	0.60	68.75	45.95	33.16	0.90	66.80	0.60
PM26	107.36	183.50	-70.92	1.50	170.90	1.50	448.50	608.50	-35.67	1.50	135.70	1.30	27.73	57.51	-107.39	2.50	207.40	1.50	22.73	55.24	-143.03	3.10	243.00	1.60
PM30	148.50	244.44	-64.61	1.40	164.60	1.60	687.50	577.18	16.05	0.90	84.00	0.80	76.20	27.80	63.52	0.40	36.50	0.10	74.93	23.80	68.24	0.40	31.80	0.00
RH406	164.00	189.84	-15.76	1.00	115.80	1.20	662.00	535.93	19.04	0.90	81.00	0.80	72.62	24.34	66.48	0.40	33.50	0.10	68.36	17.67	74.15	0.30	25.80	0.00
BPR541-4	149.80	185.62	-23.91	1.10	123.90	1.20	616.50	454.55	26.27	0.80	73.70	0.70	74.14	27.72	62.61	0.40	37.40	0.20	71.54	16.72	76.63	0.30	23.40	-0.10
SEJ2	154.96	225.50	-45.52	1.30	145.50	1.40	421.45	622.50	-47.70	1.60	147.70	1.30	23.34	55.27	-136.80	2.90	236.80	1.60	18.67	52.33	-180.29	3.60	280.30	1.70
Urvashi	178.50	182.76	-2.39	0.90	102.40	1.00	638.50	532.93	16.53	0.90	83.50	0.80	57.60	20.79	63.91	0.40	36.10	0.30	54.67	10.12	81.49	0.20	18.50	0.10
Giriraj	164.00	231.92	-41.41	1.20	141.40	1.40	647.00	591.08	8.64	1.00	91.40	0.90	73.18	32.69	55.33	0.50	44.70	0.30	72.25	24.69	65.83	0.40	34.20	0.10
Pusa Bold	194.50	197.50	-1.54	0.90	101.50	1.00	564.00	572.73	-1.55	1.10	101.50	1.00	72.53	29.44	59.41	0.50	40.60	0.20	66.93	25.44	61.99	0.50	38.00	0.20
Kranti	142.50	128.00	10.18	0.80	89.80	0.90	546.50	579.23	-5.99	1.10	106.00	1.10	56.53	22.79	59.69	0.50	40.30	0.40	53.60	16.79	68.68	0.40	31.30	0.30
Vardan	127.50	201.90	-58.35	1.40	158.40	1.50	804.00	454.75	43.44	0.60	56.60	0.40	84.31	39.25	53.45	0.60	46.60	0.20	83.05	35.92	56.75	0.60	43.20	0.10
NRCHB101	174.96	170.00	2.83	0.80	97.20	1.00	624.08	631.50	-1.19	1.10	101.20	1.00	44.99	73.12	-62.53	2.00	162.50	1.50	36.66	70.85	-93.26	2.50	193.30	1.70
RH749	204.00	203.40	0.29	0.90	99.70	1.00	654.50	586.55	10.38	1.00	89.60	0.90	53.47	43.75	18.18	1.00	81.80	0.80	48.87	37.08	24.13	1.00	75.90	0.80
PRO AGRO 5222	188.50	203.58	-8.00	0.90	108.00	1.10	600.50	579.13	3.56	1.00	96.40	1.00	64.20	37.00	42.37	0.70	57.60	0.50	65.60	30.66	53.26	0.60	46.70	0.30
Mean	157.72	197.47	-25.20				619.15	554.49	10.44				61.01	38.65	36.65				57.62	33.09	42.57			
Range lowest	107.36	128.00	-98.70	0.80	89.80	0.90	421.45	436.28	-47.70	0.60	56.60	0.40	23.34	20.79	-136.80	0.40	33.50	0.10	18.67	10.12	-180.29	0.20	18.50	-0.10
Range highest	204.00	244.44	10.18	1.70	198.70	1.70	804.00	631.50	43.44	1.60	147.70	1.30	84.31	73.12	66.48	2.90	236.80	1.60	83.05	70.85	81.49	3.60	280.30	1.70

Note: AUCTDC (area under canopy temperature depression curve), AUCDC (area under chlorophyll depression curve) (mg/g fresh leaf weight), MT (v) (membrane thermostability at vegetative stage), MT (r) (membrane thermostability at reproductive stage).*Highlighted part denotes genotypes which were found to be either moderately tolerant or tolerant to heat stress.

Table 2: Showing mean performances of twelve parental genotypes along with two checks (RH 749 and hybrid mustard 5222) in timely and late sown condition along with heat stress parameters for harvest index, test weight and seed yield per plant.

Entry	HI										TW										SYPP									
	2017-18					2018-19					2017-18					2018-19					2017-18					2018-19				
	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI
Kranti × PM 25	24.90	16.07	0.6	64.5	0.5	83.70	66.03	1.3	105	1.1	5.33	5.64	1.3	105	1.1	4.60	4.30	1	93.2	0.9	18.43	12.22	0.8	66.3	0.6	14.73	10.97	1.1	74.4	0.6
Vardan × PM 25	16.87	20.8	1.3	123.3	1.2	54.77	37.20	0.8	73.1	0.7	4.73	3.48	0.8	73.1	0.7	3.97	3.43	0.9	87	0.9	16.33	15	1.1	91.8	0.9	10.77	9.40	1.2	87.1	0.9
NRCHB 101 × PM 25	23.03	16.85	0.7	73.2	0.7	82.30	27.33	0.8	76.7	0.8	4.73	3.62	0.8	76.7	0.8	4.23	3.10	0.7	72.3	0.7	18.97	15.89	1	83.6	0.8	12.17	9.57	1.1	78.5	0.8
Kranti × PM 26	15.97	12.62	0.8	78.9	0.8	49.50	21.37	1.4	123.8	1.2	4.07	5.06	1.4	123.8	1.2	4.00	3.27	0.8	81.6	0.8	14.57	9.67	0.8	66.4	0.7	12.00	6.87	0.8	57.2	0.5
Vardan × PM 26	19.37	20.15	1.1	104.1	1	43.60	89.13	1.8	153.7	1.4	3.47	5.38	1.8	153.7	1.4	4.80	3.83	0.9	80.6	0.8	18.00	16.7	1.1	92.8	0.9	9.97	9.20	1.3	92.6	0.9
NRCHB 101 × PM 26	11.37	23.38	2.1	205.7	1.7	59.83	37.27	1	90.3	0.9	4.27	3.86	1	90.3	0.9	3.50	3.27	1	94.9	1	15.10	13.66	1.1	90.4	0.9	11.83	10.23	1.2	86.6	0.9
Kranti × PM 30	14.83	21.5	1.5	145.1	1.4	23.83	19.37	1	87.4	0.9	5.07	4.43	1	87.4	0.9	3.60	3.83	1.1	104.2	1	13.67	11	1	80.5	0.8	8.67	5.47	0.8	63.2	0.7
Vardan × PM 30	11.10	25.72	2.4	231.8	1.8	59.50	86.43	0.9	83.3	0.8	4.23	3.5	0.9	83.3	0.8	4.00	3.33	0.9	83.8	0.8	17.13	14.33	1	83.8	0.8	16.60	11.63	1	70.1	0.5
NRCHB 101 × PM 30	16.63	25.83	1.6	155	1.5	32.73	36.13	0.7	67.9	0.7	4.80	3.24	0.7	67.9	0.7	3.50	3.60	1.1	102.5	1	17.00	14.33	1	84.3	0.8	9.40	8.23	1.2	87.4	0.9
Kranti × RH406	15.07	24.02	1.6	159.5	1.5	38.63	44.20	1	93.4	0.9	4.33	4.04	1	93.4	0.9	4.00	4.23	1.2	104.7	1	17.57	14.67	1	83.5	0.8	12.17	8.80	1	72.2	0.7
Vardan × RH406	26.07	33.13	1.3	127.1	1.4	33.03	22.53	1	88.4	0.9	5.00	4.42	1	88.4	0.9	4.03	3.53	0.9	87.9	0.9	20.57	18.33	1.1	89.2	0.9	11.93	6.73	0.7	56.4	0.5
NRCHB 101 × RH406	17.33	23.09	1.4	133.2	1.3	86.07	15.27	1	89.2	0.9	4.67	4.14	1	89.2	0.9	3.97	3.63	1	92.7	0.9	21.77	20.67	1.2	94.9	0.9	13.40	9.63	1	71.9	0.7
Kranti × BPR 541-4	14.73	15.15	1	102.7	1	62.13	35.30	0.9	81.7	0.8	5.17	4.24	0.9	81.7	0.8	3.93	3.27	0.8	82.4	0.8	13.37	10.44	0.9	78.3	0.8	12.13	8.50	1	69.9	0.7
Vardan × BPR 541-4	18.50	23.41	1.3	126.4	1.3	57.57	33.70	1	90.9	0.9	4.80	4.34	1	90.9	0.9	3.90	4.27	1.2	109.9	1.1	15.90	14.44	1.1	90.9	0.9	12.17	7.63	0.8	62.7	0.6
NRCHB 101 × BPR 541-4	13.47	27.56	2.1	204.7	1.8	34.37	44.13	1.2	100.6	1	4.77	4.76	1.2	100.6	1	3.50	3.63	1.1	103.9	1	15.57	14	1.1	90	0.9	11.40	9.07	1.1	79.7	0.8
Kranti × SEJ 2	16.07	16.47	1	102.7	1	36.03	32.37	0.9	80.7	0.8	5.43	4.38	0.9	80.7	0.8	3.50	3.87	1.2	110.9	1.1	14.67	11	0.9	75	0.8	7.73	8.73	1.6	113.5	1.1
Vardan × SEJ 2	19.50	16.68	0.9	85.5	0.8	26.07	29.47	1.2	103	1	4.47	4.62	1.2	103	1	5.13	4.23	0.9	82.3	0.8	17.00	13.78	1	81	0.8	8.87	7.03	1.1	79.6	0.8
NRCHB 101 × SEJ 2	15.13	16.68	1.1	110	1.1	48.87	18.67	0.8	78.4	0.8	4.70	3.7	0.8	78.4	0.8	3.67	3.63	1	98	1	14.20	11.22	0.9	78.9	0.8	10.60	6.37	0.8	60.2	0.6
Kranti × Urvashi	14.43	16.5	1.2	114.4	1.1	30.10	25.03	0.7	64.1	0.6	5.30	3.4	0.7	64.1	0.6	3.93	3.40	0.9	87.1	0.9	10.63	8.33	0.9	78.1	0.9	12.17	7.67	0.9	63.3	0.6
Vardan × Urvashi	19.37	19.87	1	102.5	1	56.37	17.77	0.9	78.8	0.8	5.30	4.2	0.9	78.8	0.8	5.00	5.37	1.3	108.6	1.1	17.00	13	0.9	76.5	0.7	11.20	7.70	0.9	68.9	0.7
NRCHB 101 × Urvashi	17.27	18.88	1.1	109.2	1.1	62.23	51.80	0.9	85	0.8	5.00	4.25	0.9	85	0.8	4.67	3.57	0.8	75.9	0.7	18.00	15.11	1	84	0.8	11.27	9.20	1.1	81.7	0.8
Kranti × Giriraj	18.73	15.58	0.8	83.1	0.8	36.33	18.63	1	89.5	0.9	5.10	4.58	1	89.5	0.9	3.67	3.20	0.9	87.4	0.9	17.67	12.56	0.9	71.1	0.7	11.40	8.37	1	73.6	0.7
Vardan × Giriraj	16.17	18.85	1.2	116.8	1.1	24.50	25.77	0.7	69.8	0.7	4.97	3.48	0.7	69.8	0.7	5.03	4.43	1	88.4	0.9	17.57	14.11	1	80.4	0.8	8.77	8.03	1.2	91.6	0.9
NRCHB 101 × Giriraj	22.40	26.95	1.2	120.3	1.2	52.03	19.90	1.6	139.5	1.3	3.33	4.6	1.6	139.5	1.3	4.13	3.57	0.9	84.9	0.8	18.43	14.22	0.9	77.1	0.7	11.10	8.97	1.1	80.8	0.8
Kranti × Pusa Bold	14.67	13.89	0.9	94.6	1	36.77	42.00	1	85.2	0.8	5.47	4.64	1	85.2	0.8	3.60	3.63	1.1	100.6	1	11.67	8.33	0.8	71.4	0.8	10.77	7.00	0.9	65	0.6
Vardan × Pusa Bold	12.27	13.43	1.1	109.3	1.1	53.40	18.50	1	87.8	0.9	5.00	4.38	1	87.8	0.9	4.20	4.03	1	94.6	0.9	13.87	11.78	1	84.8	0.9	11.73	9.13	1.1	77.8	0.8
NRCHB 101 × Pusa Bold	12.07	11.59	0.9	96.1	1	76.97	25.27	1.1	97.6	1	4.47	4.32	1.1	97.6	1	4.17	3.63	0.9	86.2	0.9	11.77	11.22	1.1	95.3	1	12.00	10.83	1.3	89.9	0.9

Note: HI (harvest index), TW (test weight), SYPP (seed yield per plant). *Highlighted part denotes genotypes which were found to be either moderately tolerant or tolerant to heat stress.

Table 3: Showing mean performances of twelve parental genotypes along with two checks (RH 749 and hybrid mustard 5222) in timely and late sown condition along with heat stress parameters for AUCTDC, AUCDC, membrane thermostability at stage.

Entry	AUCTDC										AUCDC										MT v									
	2017-18					2018-19					2017-18					2018-19					2017-18					2018-19				
	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI
Kranti×PM 25	147.90	93.33	0.7	63.1	0.5	168.80	232.00	1.2	137.4	1.4	579.03	660	1.1	114	1.1	598.10	566.50	1	94.7	0.9	31.83	26	1.2	81.8	0.8	39.83	76.03	2.3	190.9	1.7
Vardan×PM 25	155.63	108.33	0.8	69.6	0.6	171.00	179.63	0.9	105.1	1.1	604.27	653	1.1	108.1	1.1	718.50	558.57	0.8	77.7	0.7	39.53	40.09	1.5	101.4	1	26.50	38.37	1.7	144.8	1.2
NRCHB 101×PM 25	116.50	111.25	1	95.5	1	189.00	176.47	0.8	93.4	0.9	554.50	604.75	1.1	109.1	1.1	546.50	465.70	0.9	85.2	0.9	26.20	42.4	2.4	161.8	1.4	63.53	58.43	1.1	92	0.9
Kranti×PM 26	84.10	116.67	1.5	138.7	1.3	208.00	234.53	1	112.8	1.2	607.27	618	1	101.8	1	703.00	462.23	0.7	65.8	0.6	46.93	39.61	1.2	84.4	0.8	68.80	40.73	0.7	59.2	0.5
Vardan×PM 26	105.37	101.25	1	96.1	1	107.87	224.50	1.8	208.1	1.7	660.30	596	0.9	90.3	0.9	468.77	694.50	1.6	148.2	1.4	41.60	16.79	0.6	40.4	0.3	34.30	57.60	2	167.8	1.4
NRCHB 101×PM 26	179.80	115.83	0.7	64.4	0.5	188.00	176.53	0.8	93.9	0.9	572.77	577.5	1	100.8	1	581.50	493.73	0.9	84.9	0.9	34.33	54.29	2.3	158.1	1.5	56.40	49.37	1.1	87.7	0.9
Kranti×PM 30	67.67	107.92	1.7	159.5	1.3	219.50	154.50	0.6	70.4	0.6	552.77	576.5	1	104.3	1	605.27	549.70	1	90.8	0.9	47.60	40.19	1.2	84.5	0.8	59.37	33.60	0.7	56.6	0.5
Vardan×PM 30	105.37	112.92	1.2	107.2	1.1	185.00	153.97	0.7	83.2	0.8	564.77	579	1	102.5	1	701.77	641.43	1	91.4	0.9	32.20	5.93	0.2	18.4	0.3	61.50	26.17	0.5	42.6	0.4
NRCHB 101×PM 30	150.80	97.92	0.7	64.9	0.6	162.50	189.23	1	116.4	1.2	641.03	586	0.9	91.4	0.9	685.50	517.87	0.8	75.5	0.7	31.70	41.79	1.9	131.9	1.3	59.37	41.57	0.8	70	0.7
Kranti×RH406	106.33	98.75	1	92.9	0.9	159.13	218.00	1.2	137	1.4	638.77	623.5	1	97.6	1	580.50	716.50	1.3	123.4	1.2	36.13	39.77	1.6	110	1.1	34.53	67.33	2.4	194.8	1.6
Vardan×RH406	137.27	89.17	0.7	65	0.6	156.00	162.23	0.9	104	1	612.77	576	0.9	94	0.9	706.23	439.97	0.7	62.3	0.6	34.90	7.29	0.3	20.9	0.3	61.80	50.77	1	82.1	0.8
NRCHB 101×RH406	192.37	115.42	0.7	60	0.4	171.10	197.00	1	115.1	1.2	529.27	521.5	1	98.5	1	589.53	581.00	1.1	98.6	1	34.93	16.18	0.6	46.3	0.5	52.10	50.70	1.2	97.3	1
Kranti×BPR 541-4	73.47	98.75	1.5	134.4	1.2	222.00	148.07	0.6	66.7	0.6	567.80	616	1.1	108.5	1.1	662.27	473.03	0.8	71.4	0.7	36.97	17.34	0.7	46.9	0.5	71.37	42.53	0.7	59.5	0.5
Vardan×BPR 541-4	95.70	104.17	1.2	108.8	1.1	158.50	168.83	0.9	106.5	1.1	629.77	648.5	1	103	1	563.00	527.03	1	93.6	0.9	33.33	29.54	1.3	88.6	0.9	63.07	44.77	0.9	71	0.7
NRCHB 101×BPR 541-4	162.40	107.92	0.7	66.5	0.5	166.50	178.63	0.9	107.3	1.1	591.27	653	1.1	110.4	1.1	612.27	445.90	0.8	72.8	0.7	35.43	22.31	0.9	63	0.6	47.63	50.00	1.3	104.9	1
Kranti×SEJ 2	124.70	105.42	0.9	84.5	0.8	193.00	164.27	0.7	85.1	0.8	633.27	556.5	0.9	87.9	0.9	577.00	609.03	1.1	105.6	1.1	36.23	13.39	0.5	36.9	0.4	47.67	42.17	1.1	88.5	0.9
Vardan×SEJ 2	102.87	95.42	1	92.8	0.9	87.33	222.00	2.2	254.2	1.8	598.53	665.5	1.1	111.2	1.1	564.53	713.50	1.4	126.4	1.2	32.30	40.16	1.8	124.3	1.2	36.77	54.10	1.8	147.2	1.3
NRCHB 101×SEJ 2	165.30	117.08	0.8	70.8	0.6	168.00	175.80	0.9	104.6	1	589.27	574.5	1	97.5	1	577.77	544.33	1	94.2	0.9	31.63	36.59	1.7	115.7	1.1	57.50	73.63	1.6	128.1	1.3
Kranti×Urvashi	105.37	105	1.1	99.7	1	183.00	204.80	1	111.9	1.1	640.77	594.5	0.9	92.8	0.9	736.77	526.57	0.8	71.5	0.7	31.60	9.29	0.4	29.4	0.4	71.40	58.83	1	82.4	0.8
Vardan×Urvashi	87.00	92.92	1.2	106.8	1	173.50	175.27	0.9	101	1	630.30	642.5	1	101.9	1	555.27	648.73	1.3	116.8	1.2	31.47	7.92	0.3	25.2	0.4	65.27	36.67	0.7	56.2	0.5
NRCHB 101×Urvashi	124.73	127.08	1.1	101.9	1	165.00	155.53	0.8	94.3	0.9	457.50	531.75	1.2	116.2	1.1	547.00	649.73	1.3	118.8	1.2	33.57	32.69	1.4	97.4	1	46.00	68.00	1.8	147.7	1.4
Kranti×Giriraj	58.97	119.17	2.2	202.1	1.5	207.00	144.23	0.6	69.7	0.6	547.53	580	1	105.9	1.1	587.27	584.37	1.1	99.5	1	33.43	38.31	1.7	114.6	1.1	64.47	15.47	0.3	24	0.1
Vardan×Giriraj	116.97	86.25	0.8	73.7	0.7	114.93	200.00	1.5	174	1.5	555.27	645	1.2	116.2	1.2	560.57	577.00	1.1	102.9	1	29.60	16.75	0.8	56.6	0.7	37.13	68.47	2.3	184.5	1.6
NRCHB 101×Giriraj	137.27	104.58	0.8	76.2	0.7	153.00	220.90	1.2	144.4	1.4	531.03	577	1.1	108.7	1.1	544.50	558.27	1.1	102.5	1	29.27	22.36	1.1	76.4	0.8	60.60	54.10	1.1	89.3	0.9
Kranti×Pusa Bold	115.60	113.75	1.1	98.4	1	191.00	179.97	0.8	94.2	0.9	546.03	575	1	105.3	1	657.50	661.93	1.1	100.7	1	30.03	12.49	0.6	41.6	0.5	57.00	25.60	0.5	45	0.4
Vardan×Pusa Bold	124.30	101.67	0.9	81.8	0.8	115.53	203.50	1.5	176.2	1.5	639.77	609.5	0.9	95.3	0.9	631.67	680.00	1.2	107.7	1.1	29.47	8.05	0.4	27.3	0.4	38.27	54.07	1.7	141.3	1.3
NRCHB 101×Pusa Bold	146.53	117.92	0.9	80.5	0.8	154.00	195.50	1.1	126.9	1.3	591.00	654	1.1	110.7	1.1	656.07	643.00	1.1	98	1	29.97	26.21	1.3	87.5	0.9	40.30	57.33	1.7	142.5	1.3

Note: AUCTDC (area under canopy temperature depression curve), AUCDC (area under chlorophyll depression curve) (mg/g fresh leaf weight), MT (v) (membrane thermostability at vegetative stage). *Highlighted part denotes genotypes which were found to be either moderately tolerant or tolerant to heat stress.

Table 4: Showing mean performances of twelve parental genotypes along with two checks (RH 749 and hybrid mustard 5222) in timely and late sown condition along with heat stress parameters for membrane thermostability at reproductive stage and oil content.

Entry	MT r										Oil content									
	2017-18					2018-19					2017-18					2018-19				
	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI	Timely	Late	HSI	HTE	STI
Kranti × PM 25	32.77	21.05	1.1	64.3	0.7	28.83	71.77	3.2	248.8	1.8	41.97	41.33	1.2	98.4	1	41.07	40.50	1	98.6	1
Vardan × PM 25	40.30	37.36	1.6	92.8	0.9	22.90	34.70	1.9	151.6	1.2	42.03	39.24	1.1	93.4	0.9	41.13	41.53	1.1	100.9	1
NRCHB 101 × PM 25	29.57	43.53	2.5	147.2	1.4	57.93	47.10	1	81.3	0.8	38.27	25.53	0.8	66.7	0.7	41.20	40.33	1	97.9	1
Kranti × PM 26	48.50	33.83	1.2	69.8	0.6	64.53	29.73	0.6	46	0.3	42.23	38.34	1.1	90.8	0.9	42.03	38.30	1	91.3	0.9
Vardan × PM 26	42.20	12.4	0.5	29.4	0.2	30.97	57.00	2.4	183.9	1.5	41.87	35.05	1	83.8	0.8	41.97	37.97	0.9	90.4	0.9
NRCHB 101 × PM 26	35.50	50	2.4	140.9	1.4	54.80	39.70	0.9	72.6	0.7	40.23	36.43	1.1	90.5	0.9	40.70	40.97	1.1	100.6	1
Kranti × PM 30	48.60	34.38	1.2	70.8	0.6	57.77	24.60	0.5	42.6	0.4	41.70	33.72	1	81	0.8	39.90	38.60	1	96.7	1
Vardan × PM 30	34.23	9.71	0.4	28.4	0.4	60.90	21.50	0.4	35.4	0.2	41.13	39.44	1.1	96	1	41.07	38.10	1	92.9	0.9
NRCHB 101 × PM 30	33.00	37.2	1.9	112.9	1.1	53.43	30.90	0.7	57.8	0.6	39.30	31.42	0.9	79.9	0.8	39.10	38.37	1	98.1	1
Kranti × RH406	37.83	34.55	1.5	91.3	0.9	23.20	66.07	3.7	284.4	1.8	42.03	33.69	0.9	80.2	0.8	42.27	37.67	0.9	89	0.9
Vardan × RH406	36.50	2.66	0.1	7.3	0.1	60.87	45.43	1	74.6	0.7	41.03	39.5	1.1	96.3	1	40.87	38.90	1	95.2	1
NRCHB 101 × RH406	36.47	11.78	0.5	32.3	0.4	43.43	49.10	1.5	113.1	1.1	40.33	33.35	1	82.7	0.8	41.43	38.27	1	92.4	0.9
Kranti × BPR 541-4	37.00	14.75	0.6	39.9	0.4	68.43	33.87	0.6	49.4	0.3	41.47	37.63	1.1	90.8	0.9	40.97	39.47	1	96.4	1
Vardan × BPR 541-4	35.10	26.84	1.3	76.4	0.8	57.13	33.10	0.7	58	0.5	41.27	36.32	1	88	0.9	41.93	37.33	0.9	89.1	0.9
NRCHB 101 × BPR 541-4	36.97	16.75	0.7	45.4	0.5	44.70	41.67	1.2	93.2	0.9	39.43	33	1	83.7	0.8	40.63	37.43	1	92.2	0.9
Kranti × SEJ 2	37.30	8.67	0.4	23.2	0.3	42.73	36.83	1.1	86.2	0.9	41.13	33.41	1	81.3	0.8	41.97	40.60	1	96.9	1
Vardan × SEJ 2	33.67	35.71	1.8	106	1.1	33.10	50.17	2	151.6	1.3	40.30	40.42	1.2	100.3	1	38.50	39.60	1.1	102.8	1
NRCHB 101 × SEJ 2	33.17	31.51	1.6	95	1	51.57	69.63	1.8	135.1	1.4	41.37	40.44	1.2	97.7	1	42.07	38.47	1	91.6	0.9
Kranti × Urvashi	32.53	12.39	0.6	38.1	0.5	68.13	53.83	1	79	0.7	42.23	31.7	0.9	75.1	0.7	41.47	38.37	1	92.5	0.9
Vardan × Urvashi	33.43	10.04	0.5	30	0.4	62.67	31.00	0.6	49.5	0.4	40.57	36.47	1.1	89.9	0.9	41.30	41.03	1	99.5	1
NRCHB 101 × Urvashi	31.67	32.9	1.8	103.9	1	41.40	65.00	2	156.9	1.5	41.43	26.44	0.7	63.8	0.6	41.47	40.20	1	97.1	1
Kranti × Giriraj	34.20	35.17	1.7	102.8	1	62.87	9.03	0.2	14.4	0	41.40	32.39	0.9	78.3	0.8	41.47	40.53	1	97.8	1
Vardan × Giriraj	31.27	12.65	0.6	40.5	0.5	29.13	64.20	2.9	220.6	1.7	41.53	41.12	1.2	99	1	40.97	38.10	1	92.9	0.9
NRCHB 101 × Giriraj	30.90	19.07	1	61.7	0.7	57.67	50.77	1.1	88.1	0.9	39.53	26.6	0.8	67.3	0.7	42.13	41.00	1	97.3	1
Kranti × Pusa Bold	31.70	12.86	0.7	40.6	0.5	55.73	20.27	0.5	36.4	0.3	40.10	34.4	1	85.7	0.9	41.70	41.80	1.1	100.3	1
Vardan × Pusa Bold	31.37	4.22	0.2	13.4	0.3	33.93	49.47	1.9	145.8	1.3	41.37	40.66	1.2	98.3	1	42.30	38.07	0.9	89.8	0.9
NRCHB 101 × Pusa Bold	31.17	23.78	1.3	76.3	0.8	29.63	52.40	2.3	177.1	1.4	40.10	26.45	0.8	66	0.7	42.37	40.53	1	95.8	1

Note: MT (r) (membrane thermostability at reproductive stage) oil % (oil content).

*Highlighted part denotes genotypes which were found to be either moderately tolerant or tolerant to heat stress.

minimum reduction in seed yield manifested tolerance to heat stress in terminal stage (had lowest HSI, Highest HTE and Highest STI). It may be mentioned here that heat tolerance in crop plants is developmentally regulated and is known to be stage specific phenomena, meaning tolerance at one stage of plant development may not be correlated with tolerance at the other developmental stages (Wahid *et al.* 2007). Results of the present study showed similarities with the findings of Sharma *et al.* 2013 who reported that minimum yield reduction was realized in the genotypes which had the highest HTE and the lowest HSI. In similar studies, most of the findings (Sio-Se *et al.*, 2006) showed that genotypes with lowest HSI was most tolerant than the highest HSI. In the same way Sharma *et al.* (2011, 2012) reported heat susceptible varieties had high values (HSI >1) while resistant varieties had lower values.

CONCLUSION

Genotypes such as BPR 541-4 was found to be tolerant to heat stress at terminal stage and crosses such as Vardan × PM 30, Kranti × RH 406 and Kranti × Urvashi were found to be tolerant to heat stress for seed yield per plant at terminal stage. These parents and F1s would serve as useful donors and hybrids respectively, in mustard breeding programmes for improving heat tolerance. Conclusively, HSI, THE and STI are the most important heat stress parameters to evaluate genotypes under high temperature. These indices can be easily used to find heat tolerant/ resistant genotypes in the mustard breeding programmes.

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