

Assessment of terminal heat tolerance ability of Indian mustard genotypes based on morpho-physiological traits

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Abstract

Indian mustard (*Brassica juncea*) is a vital oilseed crop of the nation, contributing significantly to the agricultural economy. The growth of this crop, however, faces challenges due to changing climate conditions, particularly the increasing prevalence of heat stress during reproductive stages. This research was aimed to explore the impact of terminal heat stress on Indian mustard and to identify sources of terminal heat tolerance in Indian mustard germplasm for utilization in the breeding scheme. Therefore, a study on screening of Indian mustard genotypes against heat tolerance is conducted and total 200 Indian mustard genotypes were evaluated in augmented block design in two different sowing dates (14 November and 10 December 2021) at Rani Lakshmi Bai Central Agricultural University, Jhansi. Based on estimation of percent yield change, heat susceptibility index (HSI) and yield stability index (YSI) or heat tolerance index (HTI), nine genotypes viz. NDRE-4, EC-399300, DRMR-13, DRMR-9, DRMR-7, DRMR-357, DRMR-6, EC-766423 and IM-76 were identified as promising accessions against heat tolerance. The study focuses on the agro-morphological traits influencing heat tolerance and proposes measures to ensure sustainable production under evolving climatic scenario.

Keywords: *Brassica juncea*, heat tolerance, phenotyping, terminal heat stress

Introduction

Indian mustard (*Brassica juncea*) stands as a cornerstone in India's agricultural landscape, playing a crucial role in oilseed production. Oleiferous brassicas (rapeseed and mustard) are the major contributor of edible oil globally and ranks third after soybean and oil palm. At national level, rapeseed-mustard is second major oilseed crop in terms of area and production after soybean. *Brassica juncea* (L.) Czern & Coss (AABB, 2n=36) is a premier oilseed crop and most dominating species of this group and occupies more than 90 % of total acreage of Oleiferous brassicas. In terms of cultivating rapeseed-mustard, India is the second-largest country in the world, followed by China and ranks third in production after China and Canada. India's contribution to global acreage and production of rapeseed-mustard is 19.8% and 9.8%, respectively (USDA, 2020). In India, rapeseed-mustard is grown on 8.06 million hectares area, having annual production of 11.75 million tonnes with an average productivity of about 1458 kg/ha (DES, DA&FW, 2021-22). The top most rapeseed- mustard producing states of the country are Rajasthan (46.63 %) followed by Madhya Pradesh (14.36 %), Haryana (11.63 %), Uttar Pradesh (8.81 %) and West Bengal (6.5 %). (DES, DA&FW, 2021-22).

The crop faces a formidable challenge in the form of changing climate conditions, particularly the rising threat of heat stress during reproductive stages. This research delves into the complexities of heat stress on Indian mustard, aiming to unravel key agro-morphological traits that influence heat tolerance. The ultimate goal is to devise strategies for sustainable production, ensuring resilience in the face of evolving climatic challenges. India's oilseed production, with Indian mustard as a significant contributor, has witnessed steady growth over the last three decades. However, the country's dependence on imported vegetable oil, exacerbated by a consumption surge, raises concerns about economic stability. The domestic production of edible oil in 2021-22 stands at 12.55 million tonnes, while the domestic demand for the same is 26.62 million tonnes, meeting only 52.85 % of the total demand for edible oils. To bridge this gap between demand and production, India is importing 14.07 million tonnes of edible oil of worth Rs. 1,41,000 Crores (ICVO, 2023).

To address this, a deeper understanding of the impact of heat stress on Indian mustard becomes imperative. Indian mustard, predominantly grown in diverse agro-ecological conditions, faces various stresses, including biotic and abiotic factors. Heat stress, particularly during

the terminal stages, adversely affects seed filling and reduces overall seed yield. The global context of rising temperatures, as highlighted by the Intergovernmental Panel on Climate Change in 2018, adds urgency to addressing the challenges posed by heat stress in crops.

This research was aimed to assess the extent of heat tolerance in Indian mustard, with a specific focus on the agro-morphological traits that contribute to resilience under high-temperature conditions. By identifying these traits, the study intends to provide a foundation for developing thermo-tolerant genotypes that can withstand terminal heat stress. Such genotypes would play a crucial role in stabilizing mustard productivity and meeting the escalating national demand for edible oil. In summary, this research was designed to deepen our understanding of heat tolerance in Indian mustard, providing valuable insights into agro-morphological and physiological changes induced by heat stress. By elucidating the complex interplay of factors influencing heat tolerance, the study aims to pave the way for sustainable and climate-resilient Indian mustard production.

Materials and Methods

The study was aimed to evaluate Indian mustard genotypes for comparative phenotyping against terminal heat. The experiment took place at Seed and Research Farm, Rani Lakshmi Bai Central Agricultural University (RLBCAU), Jhansi, during the *Rabi* season of 2021-2022. RLBCAU, Jhansi, is located at 25°31'02.5"N latitude, 78°33'05.11" E longitude, at an altitude of 271 meters above mean sea level. The region experiences a sub-tropical climate with cool winters, hot summers and semi-humid weather. The study utilized 200 Indian mustard genotypes, including 7 checks (NRCHB-101, NRCDR-2, Krishna, Pusa Agrani (Sej-2), PM-25 (NPJ-112), PM-26 (NPJ-113), Radhika). The germplasms were sourced from ICAR-National Bureau of Plant Genetic Resources, New Delhi, and ICAR-Directorate of Rapeseed and Mustard Research, Bharatpur (Rajasthan). A set of two hundred genotypes with seven checks of Indian mustard were sown in augmented block design at two different sowing dates (14 November and 10 December 2021) for comparative phenotyping by calculating the heat stability index (HSI), yield stability index (YSI), percent mean change and association analysis is carried out in both the situations. For the estimation of above parameters, observations on 12 agro-morphological traits [number of days to 50 % flowering (FW50), number of days to maturity (DM), plant height (cm, PH), number of primary branches per plant (PB), Number of secondary branches per plant (SB), main shoot length (cm, MAL), number of siliquae on the main shoot (SAM), silique length (cm, SL), number of silique per plant (TS), number of seeds per

silique (SSQ), seed yield per plant (g, YP) and 1000-seed weight (g, SW) and 3 physiological parameters [chlorophyll content (CC) by Model- MC-100 make Apogee Instruments, chlorophyll fluorescence (FLU) by chlorophyll fluorometer model OS 30 p+ of Opti sciences USA and leaf area index (LAI) by SunScan plant canopy analyzer (SS1-COM) of Delta- T devices Cambridge, United Kingdom system] were recorded. The recorded data were utilized to estimate heat susceptibility parameters like yield stability index (YSI) as per formula given by Lewis (1954), heat stability index (HSI) as formula given by Fisher and Maurer (1978) and percent mean change. The meteorological data for the cropping season *Rabi* 2021-22 is presented in Table 1 and temperature during reproductive phase is also presented in Fig. 1.

Results and Discussion

The terminal heat stress particularly at flowering, is highly susceptible to temperature fluctuations, with even slightly increases in maximum daily temperatures reflected in significant reduction in seed yield. High temperatures directly influence chlorophyll content and impair pigment synthesis in plants, slowing down various physiological processes and ultimately leading to substantial yield reductions. The current study intended to investigate the effect of heat stress during reproductive stage in Indian mustard through several agro-morphological and physiological traits in addition to yield parameters. Two sowing dates were used during study, normal sowing is done on 14 November 2021 for normal crop growth and to avoid terminal heat stress and delayed sowing is done at 10 December 2021 to expose different mustard genotypes to heat stress at reproductive stage and comparative picture provides the tolerance level in the mustard genotypes. The increased temperature at reproductive stage during the late sown condition decreases the yield attributing traits except in tolerant genotypes. Thus, the primary objective of evaluating 200 mustard genotypes along with seven checks is to identify sources of terminal heat tolerance in Indian mustard germplasm for efficient utilization in the breeding scheme. The results of percent yield change, heat susceptibility index (HSI) and yield stability index (YSI) are presented in the Table 2.

Yield reduction percentage (%)

Under the heat stress, in general yield reduction was noticed and the average yield reduction was 50.4 % whereas, maximum yield reduction of 87.9 % was observed in (EC-766311) and the yield increment was observed under heat tolerant genotypes and maximum increment was observed for NDRE-4 (50.9%).

Heat susceptibility index (HSI)

Table 1: The meteorological data for the cropping season *Rabi* 2021-22

Standard meteorological week	Duration	Temperature (°C)		Rainfall (mm)	Relative humidity (%)	
		Max.	Min.		Max.	Min.
46	12- 18 Nov.	27.9	10.6	0	84	50
47	19- 25 Nov.	28.1	12.0	0	85	49
48	26 Nov.- 2 Dec.	27.5	9.3	0	85	57
49	03 -0 9 Dec. 6	24.7	11.2	0	88	56
50	10- 16 Dec.	23.4	7.8	0	89	60
51	17 - 23 Dec.	22.9	4.4	0.0	88	61
52	24- 31 Dec.	22.3	8.4	12.0	90	65
1	01- 07 Jan.	20.9	7.7	18.0	91	71
2	08- 14 Jan.	19.2	10.4	23.8	91	71
3	15- 21 Jan.	18.3	5.8	0.0	91	72
4	22- 28 Jan.	19.9	7.6	3.6	91	71
5	29 Jan. - 04 Feb.	26.4	7.3	0.0	89	59
6	05- 11 Feb.	24	7.5	0.0	88	47
7	12- 18 Feb.	25.8	8	0.0	87	46
8	19- 25 Feb.	28	11.3	0.0	84	46
9	26 Feb. - 04 Mar.	28.5	11.3	0.0	84	45
10	05- 11 Mar.	30	12.6	0.4	81	44
11	12- 18 Mar.	35.2	16	0.0	80	38
12	19- 25 Mar.	38	17.4	0.0	79	38
13	26 Mar. - 01 Apr.	38.8	16.8	0.0	76	34
14	02- 08 Apr.	40.4	17.4	0.0	60	30
15	09- 15 Apr.	42.7	20.4	0.0	53	29
16	16- 22 Apr.	40.5	20.5	0.0	52	29
17	23 - 29 Apr.	42.3	21.3	0.0	49	26

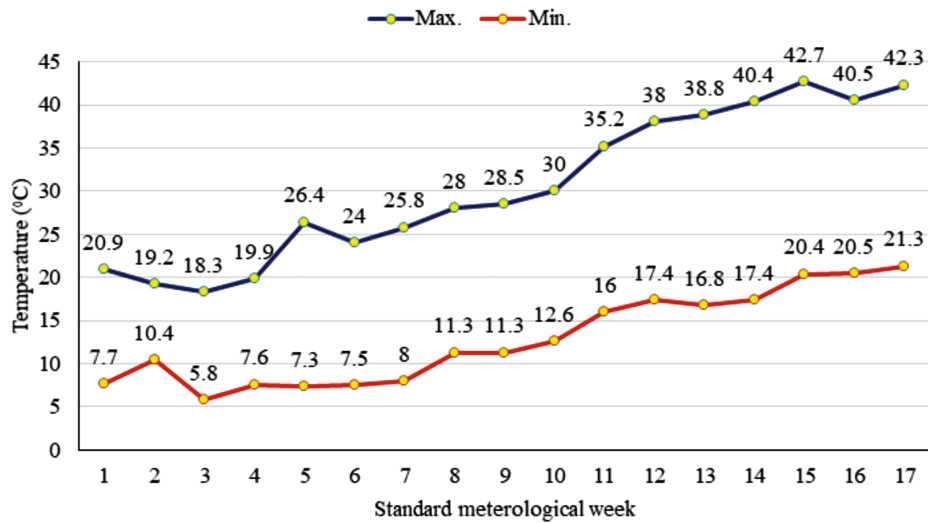


Fig. 1: Graphical representation of maximum and minimum temperature during the flowering and reproductive phase of crop (01 January- 29 April, 2022)

Table: 2 Percent yield change, heat susceptibility index (HSI) and yield stability index (YSI) of each genotype of Indian mustard

S.No.	Genotypes	% yield change	HSI	YSI	S.No.	Genotypes	% yield change	HSI	% yield change
1	DRMR - 2	54.7	1.0	0.5	105	PCR - 9403	57.5	1.0	0.4
2	DRMR - 8	28.8	0.5	0.7	106	PM - 67	78.0	1.4	0.2
3	DRMR - 4	57.1	1.0	0.4	107	PM -30	68.2	1.2	0.3
4	DRMR - 5	46.6	0.8	0.5	108	CN -101845	25.3	0.5	0.8
5	DRMR - 6	-5.9	-0.1	1.1	109	IC - 122137	68.1	1.2	0.3
6	DRMR - 7	-21.4	-0.4	1.2	110	IC - 11721	53.8	1.0	0.5
7	DRMR - 9	-23.4	-0.4	1.2	111	IC -206741	27.8	0.5	0.7
8	DRMR - 11	12.4	0.2	0.9	112	IC - 372259	74.0	1.3	0.3
9	DRMR - 12	45.3	0.8	0.6	113	IC - 341108	49.5	0.9	0.5
10	DRMR - 13	-28.3	-0.5	1.3	114	IC - 491455	37.9	0.7	0.6
11	DRMR - 33	40.1	0.7	0.6	115	IC - 491175	72.8	1.3	0.3
12	DRMR - 46	61.9	1.1	0.4	116	IC - 491485	76.4	1.4	0.2
13	DRMR - 48	72.8	1.3	0.3	117	IC - 531377	52.7	1.0	0.5
14	DRMR - 136	62.1	1.1	0.4	118	IC -589676	61.2	1.1	0.4
15	DRMR - 137	33.4	0.6	0.7	119	IC - 589683	69.8	1.3	0.3
16	DRMR - 138	76.8	1.4	0.2	120	IC - 497904	54.9	1.0	0.5
17	DRMR - 264	76.4	1.4	0.2	121	IC - 70302	13.9	0.3	0.9
18	DRMR - 266	87.2	1.6	0.1	122	IC - 491348	69.8	1.3	0.3
19	DRMR - 357	-14.8	-0.3	1.2	123	IC - 375924	38.5	0.7	0.6
20	DRMR - 358	72.8	1.3	0.3	124	IC - 422156	60.3	1.1	0.4
21	DRMR - 359	73.5	1.3	0.3	125	IC -422172	37.6	0.7	0.6
22	DRMR - 360	70.4	1.3	0.3	126	IC - 481011	39.0	0.7	0.6
23	DRMR - 361	10.1	0.2	0.9	127	IC - 73225	73.8	1.3	0.3
24	DRMR - 362	39.4	0.7	0.6	128	IC - 766313	25.1	0.5	0.8
25	DRMR - 364	78.4	1.4	0.2	129	IC -766377	73.9	1.3	0.3
26	DRMR - 574	69.7	1.3	0.3	130	EC -399300	-46.4	-0.8	1.5
27	DRMR - 576	66.9	1.2	0.3	131	EC -766423	-3.6	-0.1	1.0
28	DRMR - 577	56.6	1.0	0.4	132	EC -766110	29.3	0.5	0.7
29	DRMR - 578	49.8	0.9	0.5	133	EC -766234	37.4	0.7	0.6
30	DRMR - 579	61.2	1.1	0.4	134	EC -766127	72.4	1.3	0.3
31	DRMR -582	44.9	0.8	0.6	135	EC -766134	6.7	0.1	0.9
32	DRMR - 610	47.3	0.9	0.5	136	EC -766136	78.8	1.4	0.2
33	DRMR - 611	39.8	0.7	0.6	137	EC -766141	81.3	1.5	0.2
34	DRMR - 624	50.1	0.9	0.5	138	EC - 66431	38.4	0.7	0.6
35	DRMR - 625	65.4	1.2	0.4	139	EC -766402	45.7	0.8	0.5
36	DRMR - 626	78.5	1.4	0.2	140	EC -766401	73.3	1.3	0.3
37	DRMR -669	75.5	1.4	0.2	141	EC -766611	42.5	0.8	0.6
38	DRMR - 680	33.3	0.6	0.7	142	EC -766576	43.6	0.8	0.6
39	DRMR - 683	72.5	1.3	0.3	143	EC -766571	49.2	0.9	0.5
40	DRMR - 686	48.3	0.9	0.5	144	EC -766560	62.1	1.1	0.4
41	DRMR - 689	71.0	1.3	0.3	145	EC -766391	42.7	0.8	0.6
42	DRMR - 691	53.3	1.0	0.5	146	EC -766381	28.1	0.5	0.7
43	DRMR -692	54.8	1.0	0.5	147	EC -766335	79.7	1.4	0.2
44	DRMR - 693	69.9	1.3	0.3	148	IC - 766334	49.4	0.9	0.5
45	DRMR -710	58.5	1.1	0.4	149	EC -766322	12.9	0.2	0.9
46	DRMR - 711	19.6	0.4	0.8	150	EC -766311	87.9	1.6	0.1

47	DRMR - 726	43.1	0.8	0.6	151	EC - 766310	41.5	0.8	0.6
48	DRMR - 731	18.2	0.3	0.8	152	EC - 766296	65.0	1.2	0.4
49	DRMR - 900	79.3	1.4	0.2	153	EC - 766292	32.1	0.6	0.7
50	DRMR - 906	43.1	0.8	0.6	154	EC - 766276	68.1	1.2	0.3
51	DRMR - 909	36.7	0.7	0.6	155	EC - 766278	74.9	1.4	0.3
52	Sitara Sagar	31.7	0.6	0.7	156	EC - 766270	80.9	1.5	0.2
53	Pusa Bahar	71.3	1.3	0.3	157	EC - 766234	41.2	0.7	0.6
54	BASANTI	21.0	0.4	0.8	158	EC - 766211	12.8	0.2	0.9
55	RHUR - 2 -1	28.5	0.5	0.7	159	EC - 766207	19.5	0.4	0.8
56	RC -371-1	73.9	1.3	0.3	160	EC - 766557	54.0	1.0	0.5
57	RC -371	53.0	1.0	0.5	161	EC - 766124	11.1	0.2	0.9
58	RC - 132	68.9	1.2	0.3	162	EC - 766060	20.7	0.4	0.8
59	RC - 571	46.0	0.8	0.5	163	EC -766204	64.3	1.2	0.4
60	RC - 891-1	65.7	1.2	0.3	164	EC - 766487	34.6	0.6	0.7
61	RC - 1271	80.0	1.4	0.2	165	EC - 766344	39.1	0.7	0.6
62	RC - 1270	27.7	0.5	0.7	166	EC - 766200	75.8	1.4	0.2
63	RLC - 3	47.4	0.9	0.5	167	EC - 766069	58.9	1.1	0.4
64	NC - 37362	39.2	0.7	0.6	168	EC - 766576	42.1	0.8	0.6
65	NC - 660	52.1	0.9	0.5	169	EC - 399318	75.5	1.4	0.2
66	CN - 105257	36.9	0.7	0.6	170	EC - 399293	75.0	1.4	0.3
67	CN - 105312	56.5	1.0	0.4	171	EC - 571648	81.6	1.5	0.2
68	CN - 105309	52.4	0.9	0.5	172	EC - 399308	73.8	1.3	0.3
69	CN - 34005	78.3	1.4	0.2	173	EC - 399302	87.6	1.6	0.1
70	CN - 113780	10.2	0.2	0.9	174	EC - 764501	66.0	1.2	0.3
71	CN - 34008	19.6	0.4	0.8	175	EC - 766622	53.7	1.0	0.5
72	CN - 105364	60.0	1.1	0.4	176	EC - 766325	58.6	1.1	0.4
73	CN - 101813	78.0	1.4	0.2	177	EC - 766115	56.4	1.0	0.4
74	CN - 105233	32.7	0.6	0.7	178	EC - 766498	60.1	1.1	0.4
75	CN - 105379	65.4	1.2	0.4	179	EC - 766564	26.8	0.5	0.7
76	AJ - 11	72.6	1.3	0.3	180	EC -766489	59.7	1.1	0.4
77	AJ - 3	34.2	0.6	0.7	181	EC - 766393	61.7	1.1	0.4
78	DJ - 5	0.5	0.0	1.0	182	EC - 766470	69.6	1.3	0.3
79	DJ - 12	50.9	0.9	0.5	183	EC - 766616	28.7	0.5	0.7
80	DJ - 65	32.5	0.6	0.7	184	EC - 766594	42.3	0.8	0.6
81	RJ - 10	63.1	1.1	0.4	185	EC - 766555	71.8	1.3	0.3
82	DTM - 50	35.3	0.6	0.7	186	EC - 766094	75.8	1.4	0.2
83	PTJ - 3-89	36.8	0.7	0.6	187	EC - 766312	69.6	1.3	0.3
84	PTJ - 3-64	64.9	1.2	0.4	188	EC -766095	72.3	1.3	0.3
85	NPJ - 161	52.4	0.9	0.5	189	EC - 564649-1	81.8	1.5	0.2
86	KDM - 49-1	79.9	1.4	0.2	190	EC - 766207	44.0	0.8	0.6
87	RB - 60	64.4	1.2	0.4	191	EC - 766322	15.9	0.3	0.8
88	PR - 2001-42	68.4	1.2	0.3	192	IC - 320378	66.5	1.2	0.3
89	EM - 1	80.3	1.4	0.2	193	IC - 766214	53.1	1.0	0.5
90	GR-325	78.1	1.4	0.22	194	IC - 766098	59.5	1.1	0.4
91	IM - 108	55.2	1.0	0.5	195	IC -766029	64.5	1.2	0.4
92	IM - 76	-0.5	0.0	1.0	196	IC - 766614	71.2	1.3	0.3
93	IM - 152	68.0	1.2	0.3	197	IC - 766129	72.3	1.3	0.3
94	IM - 3	45.7	0.8	0.5	198	IC - 766299	50.8	0.9	0.5
95	IM - 170	47.4	0.9	0.5	199	IC - 399318	84.0	1.5	0.2
96	PBR - 97	16.4	0.3	0.8	200	IC - 321424	84.5	1.5	0.2

97	RE - 44	42.7	0.8	0.6	C 1	NRCHB-01	49.2	1.0	0.5
98	RGN - 34	66.8	1.2	0.3	C 2	NRCDR-2	36.5	0.8	0.6
99	RH - 30	54.4	1.0	0.5	C 3	Krishna	69.6	1.5	0.3
100	NPJ- 113	51.2	0.9	0.5	C 4	SEJ-2	32.9	0.7	0.7
101	RCQR-9901	40.9	0.7	0.6	C 5	PM-25	59.9	1.3	0.4
102	RNN - 505	40.3	0.7	0.6	C 6	PM-26	-4.4	-0.1	1.0
103	NDRE - 4	-50.9	-0.9	1.5	C 7	Radhika	51.6	1.1	0.5
104	I - 79	49.2	0.9	0.5					

The lowest value of HSI was reported by NDRE-4 (-0.9) followed by the EC-399300 (-0.8), DRMR- 13 (-0.5), DRMR-9 (-0.4), DRMR-7 (-0.4), DRMR- 357 (-0.3), DRMR- 6 (-0.1), EC- 766423 (-0.1) and IM-76 (-0.01) and these genotypes are categorized as the promising genotypes for heat tolerance. Whereas, highest HSI was observed for the genotypes EC-766311 (1.6) followed by EC-399302 (1.6), DRMR- 266 (1.6) and IC-321424 (1.5) and these genotypes are categorized as susceptible genotypes. It was estimated for all test genotypes under heat stress condition. The HSI ranged from -0.9 to 1.6 and average value of HSI was 0.9. Under the checks, PM-26 showed minimum heat susceptibility value (-0.1) in all checks.

Yield stability index (YSI) or heat tolerance index (HTI)

Yield stability ratio or yield stability index (YSI) is also a good criterion for selecting the tolerant genotype under stressed condition. Under present study, YSI is ranged from 0.1 to 1.5 and average value for YSI was 0.5. The high value of YSI is considered promising with respect to heat tolerance and vice versa. The highest value for YSI was recorded by the genotype NDRE-4 (1.5) followed by EC-399300 (1.5), DRMR-13 (1.3), DRMR-9 (1.2), DRMR-7 (1.2), DRMR-357 (1.2), DRMR-6 (1.1), PM-26 (1.0), EC-766423 (1.0) and IM-76 (1.0) and these values were generally in the same direction as observed under HSI. Low values for YSI were recorded for the genotypes such as EC -766311 (0.1), EC -399302 (0.1), DRMR - 266 (0.1) and IC - 321424 (0.2) etc. In case of checks, maximum value for YSI was recorded for PM-26 (1.0) followed by Pusa Agrani (0.7) and NRCDR-2 (0.6) etc.

Based on all three indicators, nine tolerant genotypes were identified for heat stress conditions which showed low reduction in yield, low HSI and high YSI than other genotypes under heat stress condition. Best tolerant genotypes were NDRE-4, EC-399300, DRMR-13, DRMR-9, DRMR-7, DRMR-357, DRMR-6, EC-766423 and IM-76. The above results suggested that adequate differences were observed among the mustard germplasm in terms of heat tolerance based on HSI and YSI/HTI. The germplasms with lower values (<1) of HSI are more stable in both the sowing conditions and

can be used in developing heat tolerant Indian mustard genotype to maintain yield stability under climate change scenario. These results are in close agreement with the findings of earlier researchers Sharma *et al.* (2022), Sandhu *et al.* (2019), Ram *et al.* (2017), Sharma and Sardana, (2014), Sharma, (2014) and Chauhan *et al.* (2009).

Yield attributes

The impact of terminal heat stress was also seen on various agro-morphological and physiological traits. Number of primary branches per plant was decreased by 1.7 % in late sown as compare to timely sown conditions. In late sown, SEJ-2 found best in among all checks for number of primary branches per plant (4.5) and reduction percent was just 1.7% under stress. Promising genotypes for heat tolerance showed minimum reduction in number of primary branches per plant and it was recorded by the genotype DRMR-357 with only 4.5% reduction due to stress. The per cent mean reduction in late sown with respect to timely sown condition for number of secondary branches was 45.5%. Radhika was found as best check for number of secondary branches per plant (9.3) with only reduction of 11.8%. DRMR-7 found as best line for number of secondary branches per plant (11.9) among promising genotypes with 18.5 % increment in late sown compare to timely sown. The reduction in number of secondary branches leads to reduction in yield per plant as these branches are silique bearing branches. The percent increment in late sown condition with respect to timely sown condition for main shoot length was 3.1%. In late sown environment, genotype Radhika was found as best check for main shoot length (91.5 cm) with 51.4% increment among all checks. Best genotype in late sown for main shoot length was DRMR-7 (83.3 cm) with 70.1% increment over best check. The per cent mean reduction for total siliqua was 31.9% due to heat stress. The genotype, SEJ-2 was found as best check in stress condition for total siliqua per plant (260.0) with minimum reduction of 14.4%. The genotype, EC-399300 with minimum reduction in total siliqua per plant (6.0%) was found promising under late sown and it recorded 328.0 siliqua per plant under stress. Due to heat stress maximum reduction was found for yield per plant (50.4%) followed by leaf area index (45.6%), number of

secondary branches per plant (45.5%), total siliqua per plant (31.9%), chlorophyll content (15.7%) and seeds per siliqua (11.30%). The character wise percent mean

change under heat stress at reproductive stage and comparison of promising genotype with checks are presented in Table 3.

Table: 3 Character wise percent mean change under heat stress at reproductive stage and comparison of promising genotype with checks

Trait	% mean change for genotype	Best check	% change for check	Promising genotype	% change for promising genotype	Superiority for promising genotype over best check (%)
FW50	-10.2	Radhika	-4.6	EC-399300	-1.6	3.0
DM	3.5	SEJ-2	1.7	EC-766423	5.6	3.8
PH	-6.2	NRCDR-2	-7.1	DRMR-9	-45.9	38.7
PB	1.7	SEJ-2	1.7	DRMR-357	4.5	2.8
SB	45.5	Radhika	11.8	DRMR-7	-18.5	30.3
CC	15.7	NRCDR-2	-11.7	EC-766423	-32.9	21.2
LAI	45.6	NRCHB-101	28.9	EC-766423	-67.4	96.3
FLU	4.6	NRCHB-101	0	IM-76	-8.7	8.7
MAL	-3.1	Radhika	-51.4	DRMR-7	-70.1	30.6
TS	31.9	SEJ-2	14.4	EC-399300	6.0	8.4
SAM	5.2	NRCDR-2	-6.3	NDRE-4	-44.0	37.7
SSQ	11.3	PM-26	6.0	DRMR-13	-9.4	15.4
SL	-5.1	NRCDR-2	-5.8	DRMR-357	-36.7	30.9
SW	7.5	Krishna	-2.7	DRMR-13	-24.4	21.8
YP	50.4	PM-26	-4.4	NDRE-4	-50.8	46.4

Based on percent change in yield per plant, HSI, YSI, percent change in all characters; nine genotypes viz., NDRE-4, EC-399300, DRMR-13, DRMR-9, DRMR-7, DRMR-357, DRMR-6, EC-766423 and IM-76 were identified as promising for the terminal heat tolerance. Among all, most tolerant genotype was NDRE-4 and best check was PM-26 whereas, most susceptible genotype was EC-766311 among all test genotypes. Performance of promising genotypes of Indian mustard genotypes against heat tolerance at reproductive phase are given in Table 4. The heat stress at all crop growth stages obstructs the mustard productivity but it is causing considerable yield losses at reproductive stage. Heat stress during the reproductive stage or grain filling stage affects photosynthate and its translocation and deposition in developing grain, thereby lowering the 1000- seed weight and altering the seed quality and ultimately affecting the yield. Similar kind of impact of heat stress is also seen in present study and most influenced traits were yield per plant, number of secondary branches, leaf area index, chlorophyll content, seeds per siliqua and seed weight. Based on performance of heat tolerant genotypes, the genotypes DRMR-357, EC-766423, DRMR-6 and DRMR-7 also recorded good seed yield and can be preferred for introgression of heat tolerance. These results are in line with the findings of Sharma *et al.* (2022), Mohan *et al.* (2020), Sandhu *et al.* (2019), Singh *et al.* (2014), Sharma and Sardana, (2014), Sharma, (2014) and Chauhan *et al.* (2009).

Conclusion

Under present study most of the mustard genotypes were more affected when exposed to heat stress during reproductive phase. However, the genotypes vary in their ability to tolerate terminal heat stress. This study revealed that nine genotypes viz. NDRE-4, EC-399300, DRMR-13, DRMR-9, DRMR-7, DRMR-357, DRMR-6, EC-766423, and IM-76 were identified as promising for heat tolerance at the reproductive stage, providing valuable candidates for further breeding efforts for development of Indian mustard varieties having heat tolerance at terminal growth stage in the context of climate change. The contrasting genotypes can be utilized to develop mapping population to identify candidate genes/QTLs responsible for heat tolerance.

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Table: 4 Performance of promising genotypes of Indian mustard genotypes against heat tolerance at reproductive phase

Traits	Sowing	DRMR-6	DRMR-7	DRMR-9	DRMR-13	DRMR-357	IM-76	NDRE-4	EC-399300	EC-766423
FW50	Timely	58.0	58.0	58.0	61.0	57.0	62.0	68.0	62.0	56.0
	Late	59.0	60.0	59.0	63.0	63.0	68.0	72.0	63.0	64.0
DM	Timely	122.0	122.0	123.0	127.0	125.0	133.0	140.0	133.0	125.0
	Late	119.0	117.0	121.0	123.0	121.0	128.0	135.0	130.0	118.0
PH	Timely	186.3	168.3	157.7	191.0	210.0	217.3	225.7	186.7	185.7
	Late	216.7	235.0	230.0	213.0	217.7	218.3	227.7	218.3	205.0
PB	Timely	5.7	6.3	6.0	8.0	7.3	6.3	7.0	7.7	8.7
	Late	5.0	5.7	5.0	6.0	7.0	5.3	6.3	5.3	7.0
SB	Timely	12.7	10.0	12.0	16.7	17.7	10.0	13.0	13.0	13.7
	Late	13.5	11.9	12.5	17.9	18.0	10.0	13.4	13.5	13.4
CC	Timely	30.4	30.8	30.7	32.6	24.1	24.0	24.5	28.5	26.1
	Late	26.9	28.6	27.7	26.7	22.6	25.4	22.5	28.7	34.7
LAI	Timely	3.6	3.0	2.7	2.1	4.0	4.0	3.9	3.9	2.7
	Late	3.9	3.2	3.2	2.9	3.9	4.3	4.0	4.1	4.6
FLU	Timely	0.8	0.8	0.7	0.8	0.7	0.7	0.7	0.7	0.8
	Late	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
MAL	Timely	79.0	49.0	61.3	53.3	89.7	74.3	43.0	57.3	56.0
	Late	83.7	83.3	67.7	63.0	85.0	76.7	53.3	68.3	59.7
TS	Timely	269.0	264.0	341.0	345.3	394.0	291.0	262.7	349.7	440.0
	Late	223.3	243.3	319.7	286.7	346.7	250.7	214.3	328.7	376.7
SAM	Timely	41.0	41.7	45.7	39.0	53.7	45.7	30.0	41.0	56.7
	Late	44.7	49.7	45.3	48.0	51.0	48.3	43.3	42.3	55.7
SSQ	Timely	14.7	15.4	13.5	12.1	15.3	15.0	14.5	15.2	15.2
	Late	14.7	15.5	13.6	13.2	14.9	15.8	14.5	15.4	15.0
SL	Timely	4.0	3.6	4.3	3.7	3.7	3.8	3.4	3.5	3.4
	Late	4.9	4.2	4.2	3.6	5.1	4.0	3.6	3.8	4.0
SW	Timely	4.9	4.0	4.5	3.2	4.3	3.2	2.5	2.5	3.6
	Late	5.4	4.3	4.9	3.9	4.2	3.1	2.9	3.1	3.6
YP	Timely	11.8	9.8	7.7	6.2	13.1	10.0	6.9	7.2	12.9
	Late	12.5	11.9	9.5	7.9	15.0	10.0	10.4	10.5	13.4
HSI		-0.1	-0.4	-0.4	-0.5	-0.3	0.0	-0.9	-0.8	-0.1
YSI		1.1	1.2	1.2	1.3	1.2	1.0	1.5	1.5	1.04

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