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Genetic Analysis of Diallel Crosses of Rapeseed (*B. rapa*) for Screening High Temperature Tolerant Genotypes under Phytotron Facility and Late Field Sown Condition

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PKB, RNS and AP conceptualized the research. Authors PKB and AT contributed to experimental materials. Authors AP, AK and SS did data collection. All authors read and approved the final manuscript.

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ABSTRACT

High temperature tolerance is assuming importance in breeding rapeseed-mustard. In the present investigation attempt was made to study genetic variation for traits in response to high temperature and screened during flowering to pod formation stage. Populations of diallel crosses involving three

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yellow sarson and two toria varieties were used in this study. The diallel populations were exposed to high temperature at National Phytotron Facility, IARI, New Delhi and also grown in late sown field conditions which generally experience high temperature terminal stress. The temperature treatment was given only to the crosses as the parents did not come to flowering in the normal growth chamber. B9 x Jeuti, B9 x TS46, YSH401 x Jeuti and NRCYS05-03 x Jeuti were found to be promising for yield attributes under phytotron facility. In field experiments, Jeuti, B9 x NRCYS05-03, B9 x YSH401, B9 x Jeuti, NRCYS05-03 x Jeuti, YSH401 x Jeuti and YSH401 x NRCYS05-03 were found promising for seed yield and its attributes. Main shoot length, siliquae on main shoot, seeds per siliqua, percent flower drop, siliqua density and biological yield per plant showed high to moderate heritability with high genetic advance.

Keywords: High temperature; heat susceptibility index; oil content; combining ability.

1. INTRODUCTION

Breeding for abiotic stress tolerance is a challenging task as the traits are mostly governed by more than one gene. Among the abiotic stress, high temperature stress is one of the most important but least studied issue which affects plant productivity around the world [1,2]. High temperature during plant growth and development disturbs the plants in various ways such as expansion of leaf blades, internode elongation and flower bud abortion [3]. In some important crops viz. wheat [4,5], Argentine canola [6,7,2] and rice [1], infertility and yield loss have been reported due to heat stress. Indian rapeseed (*Brassica rapa* L.) and mustard [*B. juncea* (L) Czern. & Coss.] are major oilseed crops of India and ranks second after soybean. Rapeseed is the predominant oilseed crop in Assam as it has many agronomic advantages. Short stature and short life cycle are the major advantageous factors that farmers prefer it more than mustard. People generally grow this crop after harvesting of rice and is sown in the mid-month of October to mid-November. Therefore, it is recognised as a cool season crop and temperatures that are moderately high, during sensitive stages of development can reduce yield. It has been reported that for canola (*B. napus*), 25 to 27°C [8,7] and 30 to 32°C [9,6] observed as critical temperatures. With this view the present investigation was undertaken to study the genetics and response of *B. rapa* lines to high temperature.

2. MATERIALS AND METHODS

Diallel populations of rapeseed consisting of three yellow sarson (B9, YSH401 and NRCYS05-03) and two toria (Jeuti and TS46) parental lines were used for studying the genetic variation. During Rabi 2018-19, the experiment was conducted. Total fifteen entries were sown in pot culture at IARI using the phytotron facility on 26th September, 2018. During pod formation stage, the F_1 plants were shifted from the growth chamber to the controlled chamber (Temperature 32/28/15 ˚C for 9/4/11 hrs at RH 70 % and photoperiod of 10 hrs).

In field condition, the parents and the crosses were tested in the same Rabi season, 2018-19 in normal and late sowing dates. The parameters days to 50% flowering, days to 50% flowering, days to maturity, main shoot length (cm), number of flowers on main shoot, number of siliquae on main shoot, siliqua density on main shoot, number of flowers on terminal 15 cm of main shoot, number of siliquae on terminal 15 cm of main shoot, percent flower drop, number of seeds per siliqua, 1000 grain weight (g), biological yield/ plant (g) and seed yield per plant were recorded as per standard procedure. Other characters such as oil content and heat susceptibility index were recorded as follows:

2.1 Oil Content (%)

Oil content was determined by using Nuclear Magnetic Resonance (NMR) Spectroscopy and expressed in percentage at the ICAR- Indian Institute of Oilseeds Research, Hyderabad. Oil content of the samples was determined only for field grown samples.

2.2 Heat Susceptibility Index

Heat susceptibility index was calculated by the following formula given by Fisher and Maurer [10] as follows.

$$HSI = \frac{(1-Y/Yp)}{(1-X/Xp)}$$

Where,

Y = mean seed yield of a genotype in a stress environment,
Yp = mean seed yield of a genotype in a stress free environment,
X = mean seed yield of all genotypes in stress environment,
Xp = mean seed yield of all genotypes in normal environment.
HSI ≤ 0.5 = Tolerant,
HSI > 0.5 –1.0 = Moderately tolerant,
HSI > 1.0 = Susceptible

Analysis of variance of each character in each environment (normal and late sowing) was done as well as pooled analysis of variance of the field experiments was performed following Gomez and Gomez [11]. Genetic parameters were estimated for each character from the pooled ANOVA. Genotypic variances (σ^2_g) and environmental variance (σ^2_e) were computed according to Singh [12] in fixed model.

2.3 Combining Ability Analysis

Analysis of combining ability of the half diallel population was done following model I, method 2 of Griffing [13]. Then a pooled analysis over environments was carried out according to the method given by Singh [13,14]. General combining ability and specific combining ability effects were estimated from the pooled analysis.

3. RESULTS AND DISCUSSION

3.1 Evaluation under Phytotron Facility

Analysis of variance showed that the genotypes differed significantly for main shoot length, flowers on main shoot, siliquae on main shoot, flower drop, flowers on terminal shoot, siliquae on terminal shoot and seeds per siliqua.

Mean performance of the genotypes is presented in Table 1. The genotypes NRCYS05-03 x Jeuti and B9 x TS46 exhibited longer main shoots with higher number of flowers on terminal shoot, flowers on main shoot, siliquae on terminal shoot, number of siliquae on main shoot and seeds per siliqua. B9 x Jeuti exhibited high number of flowers on main shoot, siliquae on main shoot, flowers on terminal shoot and siliquae on terminal shoot with relatively longer main shoot. YSH401 x Jeuti showed high number of siliquae on main shoot, less flower drop and high number of seeds per siliqua with relatively longer main shoot. Therefore the crosses B9 x Jeuti, B9 x TS46, YSH401 x Jeuti and NRCYS05-03 x Jeuti were found promising for high temperature tolerance.

Young et al. [3] suggested that one week of heat treatment in *B. napus*, did not affect production of flowers, but affected siliquae formation. Annisa et al. [15] observed that most buds developed into flowers and pods. The greatest impact of high temperature was a reduction in development of mature seeds in pods. Many physiological traits have been suggested for heat tolerance in other crops but the information for Brassica is very meagre [16]. From present experiment, flower number, flower drop, siliqua number and seeds per siliqua produced under high temperatures, might be useful in screening for high-temperature tolerance in *B. rapa*. Temperature stress affects various physiological parameters of plants like relative water content, membrane stability index and chlorophyll content [16]. Marchand et al. [17] suggested that increased leaf temperatures influenced the thermo-tolerance adjustments in photosynthesis, ultimately leading to reduced seed set.

3.2 Combining Ability Analysis

Analysis of variance of combining ability revealed significant variation for general combining effects as well as specific combining ability effects for all the characters viz. main shoot length, flowers on main shoot, siliquae on main shoot, flower drop, flowers on terminal shoot, siliquae on terminal shoot and seeds per siliqua. The GCA: SCA predictability ratio was high for siliquae on main shoot, main shoot length, flowers on main shoot, percent flower drop and seeds per siliqua.

General combining ability effects of the parents were estimated (Table 2). The parent B9 showed good GCA effects for main shoot length, flowers on main shoot, siliquae on main shoot, flowers on terminal shoot and siliquae on terminal shoot. YSH401 showed positive GCA effects for seeds per siliqua but negative effects for main shoot length, flowers on main shoot, siliquae on main shoot, flowers on terminal shoot siliquae on terminal shoot and flower drop. NRCYS05-03

Table 1. Mean values of diallel cross populations tested in phytotron facility

Population	Main shoot length (cm)	No. of flowers on MS	No. of siliquae on MS	Flower drop (%)	No. of flowers on terminal 15 cm shoot	No. of siliquae on 15 cm terminal shoot	No. of seeds per siliqua
B9 x YSH401	20.70	25.80	12.80	13.00	20.60	9.00	6.80
B9 x NRCYS05-03	23.90	43.00	25.00	18.00	25.80	14.20	5.60
B9 x Jeuti	21.30	51.80	22.20	29.60	34.20	17.60	7.60
B9 x TS46	26.20	50.60	18.40	32.20	36.40	15.00	9.40
YSH401 x NRCYS05-03	16.90	40.60	18.80	21.80	32.60	16.40	7.80
YSH401 x Jeuti	19.30	28.80	20.00	8.80	24.40	11.60	15.40
YSH401 x TS46	16.20	37.80	10.60	27.20	17.00	5.60	11.40
NRCYS05-03 x Jeuti	28.30	42.40	19.20	23.20	36.00	9.00	3.20
NRCYS05-03 x TS46	21.70	40.00	12.80	27.20	21.20	8.40	3.20
Jeuti x TS46	15.20	38.40	20.00	18.40	26.60	10.20	3.00
Mean	20.97	39.92	17.98	21.94	27.48	11.70	7.34
SE(m)	1.46	2.32	1.26	2.10	1.56	1.03	0.60
CD(P=0.05)	4.17	6.62	3.59	6.01	4.46	2.94	1.71
CD(P=0.01)	5.58	8.86	4.81	8.05	5.96	3.93	2.28

Table 2. General combining ability effects for characters tested under high temperature condition in phytotron facility

Parents	MSL	FMS	SMS	FD	FTS	STS	SPS
B9	2.740**	3.840**	2.160**	1.680	2.360**	3.000**	0.013
YSH401	-3.593**	-8.893**	-3.240**	-5.653**	-5.107**	-1.400*	4.013**
NRCYS05-03	2.307**	2.107	1.293	0.813	1.893*	0.400	-3.187**
Jeuti	0.073	0.573	3.160**	-2.587*	3.760**	0.533	-0.053
TS46	-1.527*	2.373	-3.373**	5.747**	-2.907**	-2.533**	-0.787*
SE(gi)	0.754	1.197	0.650	1.086	0.805	0.531	0.308
SE(gi-gj)	1.192	1.892	1.027	1.718	1.273	0.840	0.487

** Significant at P=0.05 and ** Significant at P=0.01*

showed positive GCA effects for main shoot length and flowers on terminal shoot and negative effects for seeds per siliqua. Jeuti exhibited good GCA effects for siliquae on main shoot, flowers on terminal shoot and flower drop percentage. GCA effects of the parent TS46 were undesirable direction for flower drop, main shoot length, siliquae on main shoot, flowers on terminal shoot, siliquae on terminal shoot and seeds per siliqua.

The estimates of specific combining ability effects are presented in Table 3. SCA effect of B9 x YSH401 was good for only flower drop percentage. Its SCA effects were negative for flowers on main shoot, siliquae on main shoot, flowers on terminal shoot, siliquae on terminal shoot and seeds per siliqua. SCA effects of B9 x NRCYS05-03 were good for siliquae on main shoot and seeds per siliqua and flower drop. Its SCA effects were negative for main shoot length and flowers on terminal shoot. B9 x Jeuti showed good SCA effects for flowers on main shoot and siliquae on terminal shoot, but undesirable for flower drop and main shoot length. The cross B9 x TS46 exhibited good SCA effects for main shoot length, flowers on main shoot, flowers on terminal shoot, siliquae on terminal shoot and seeds per siliqua. YSH401 x NRCYS05-03 showed good SCA effects for flowers on main shoot, siliquae on main shoot, flowers on terminal shoot, siliquae on terminal shoot but negative for flower drop and main shoot length. YSH401 x Jeuti exhibited positive SCA effects for siliquae on main shoot and seeds per siliqua, and good SCA effects for flower drop. YSH401 x TS46 exhibited positive SCA effects for flowers on main shoot but undesirable effects for flower drop, flowers on terminal shoot and siliquae on terminal shoot. NRCYS05-03 x Jeuti showed positive effects for main shoot length and flowers on terminal shoot but negative effects for flower drop siliquae on main shoot and siliquae on terminal shoot. NRCYS05-03 x TS46 showed only negative SCA effects for flowers on main shoot, siliquae on main shoot and flowers on terminal shoot. Jeuti x TS46 showed good SCA effects for siliquae on main shoot and flower drop percentage, but negative effects for main shoot length, flowers on main shoot and seeds per siliqua.

3.3 Evaluation under Field Condition

Pooled analyses of variance showed significant variation for all the characters in both the environments (sowing dates) except siliqua density and siliquae on terminal shoot. Genotypes, crosses and parents differed significantly for all characters except parent variation for seed yield per plant. Mean squares due to parent vs. crosses were also significant for all the traits which indicated presence of significant average heterosis for all the traits except days to maturity. Genotypes × sowing date interactions were significant for all the characters except main shoot length, oil content and seed yield per plant. Crosses x sowing date interactions were significant for all characters except main shoot length, flower drop and biological yield per plant. However, parents x sowing date interactions were significant for days to 50% flowering, flowers on main shoot, seeds per siliqua and thousand seed weight. Parents vs. crosses x sowing dates interactions were found significant for days to maturity, main shoot length, number of flowers on main shoot, number of siliquae on main shoot, percent flower drop, number of siliquae on terminal shoot and biological yield per plant.

Mean performances of the diallel populations over the two sowing dates are presented in Table 4. The cross Jeuti x TS46 was the earliest to 50% flowering and maturity (41.3 days, 86.5 days). Following this Jeuti and TS46 were earlier in maturity. Long main shoots were exhibited by B9 x TS46 (70.28 cm) and NRCYS05-03 x Jeuti (66.63 cm). The two crosses NRCYS05-03 x Jeuti (69.5) and NRCYS05-03 x TS46 (64.5) exhibited higher number of flowers on main shoot while the former exhibited the highest number of siliquae on main shoot (64). Lesser percent flower drop was shown by NRCYS05-03 x Jeuti (7.9%), B9 x TS46 (12.51%), NRCYS05-03 x TS46 (13.12%), YSH401 x NRCYS05-03 (14.26%), YSH401 x Jeuti (14.68%), B9 x YSH401 (14.89%), and B9 x NRCYS05-03 (16.63%). Higher siliqua density was exhibited by Jeuti x TS46 (0.98 no/cm), NRCYS05-03 x Jeuti (0.97 no/cm), NRCYS05-03 x TS46 (0.90 no/cm), YSH401 x NRCYS05-03 (0.89 no/cm) and YSH401 x Jeuti (0.83 no/cm). Higher number of siliquae on terminal shoot was exhibited by B9 x Jeuti (17.25), B9 x TS46 (16.75), YSH401 x Jeuti (16.75), YSH401 x NRCYS05-03 (16.5), YSH401 x TS46 (16.25) and B9 x NRCYS05-03 (14.75). The parents Jeuti (22.25) and NRCYS05-03 (20.75) exhibited higher number of seeds per siliqua. Oil content was higher in YSH401 (40.27%), B9 x NRCYS05-03 (40.23%), Jeuti x TS46 (39.67%), B9 x YSH401 (39.39%), Jeuti (39.31%), B9 (38.85%), NRCYS05-03 x Jeuti (38.61%), TS46 (37.64) and NRCYS05-03 x TS46 (37.38%). Thousand seed weight was the highest in YSH401 x NRCYS05-03 (3.678 g). B9 x YSH401 (33.008 g) and TS46 (28.515 g) showed higher biological yield per plant. B9 x NRCYS05-03 (8.63 g), B9 x YSH401 (7.87 g), B9 x Jeuti (7.58 g), NRCYS05-03 x Jeuti (7.55 g), Jeuti (7.375 g),YSH401 x Jeuti (7.325 g) and YSH401 x NRCYS05-03 (7.125 g) exhibited higher seed yield per plant.

3.4 Combining Ability Analysis

Pooled analysis of variance for combining ability showed significant variation for GCA effects for all the characters except siliqua density and siliquae on terminal shoot. Variation for SCA effects was also significant for all characters except siliqua density. Significant variations for sowing dates were observed for all except siliquae on main shoot, siliqua density and siliquae on terminal shoot. GCA x environment interactions were found significant for days to 50% flowering, number of flowers on main shoot, number of siliquae on main shoot, percent flower drop, siliquae on terminal shoot, oil content and thousand seed weight. SCA x environment interactions were significant for all except main shoot length, siliqua density and seed yield per plant. GCA: SCA ratio was high for days to 50% flowering (0.98) and days to maturity (0.97). The ratio was also high for thousand seed weight (0.75) and seed yield per plant (0.76). Thus, for these characters progeny performance was highly predictable by GCA effects. GCA effects of the parents pooled from the two sowing dates are presented in Table 5a and 5b. Again the SCA effects are presented in Table 6a and 6b. Considering the combining ability effects NRCYS05-03, Jeuti, B9 x YSH401, B9 x NRCYS05-03, B9 x Jeuti, B9 x TS46, YSH401 x TS46 and NRCYS05-03 were found promising for yield attributing characters.

3.5 Assessment of Genetic Parameters in Field Conditions

Genetic parameters were estimated from the pooled analysis of variance of the diallel populations and presented in Table 7. High to moderate level of GCV and PCV was observed for main shoot length, flower drop, siliqua density, seeds per siliqua, siliquae on main shoot, siliquae on terminal shoot, thousand seed weight, flowers on main shoot, biological yield per plant and seed yield per plant. This indicated the presence of genetic variation for these characters. Main shoot length, siliquae on main shoot, seeds per siliqua, percent flower drop, siliqua density and biological yield per plant showed high to moderate heritability with high genetic advance. This showed the effect of additive gene action for these traits and therefore improvement through direct selection could be effective [18,19,20]. However, siliquae on terminal shoot and seed yield per plant showed moderate heritability with moderate genetic advance. This indicated the presence of non additive gene action and for improvement of such characters breeding procedure like biparental mating will be effective for improvement of rapeseed [21;20.22] reported that wide ranges of genetic advance (%) with high heritability indicated the better scope of genetic improvement through selection.

Table 3. Specific combining ability effects for characters tested under high temperature condition in Phytotron facility

Cross	MSL	FMS	SMS	FD	FTS	STS	SPS
B9 x YSH401	0.583	-9.067**	-4.100**	-4.967**	-4.133**	-4.300**	-4.567**
B9 x NRCYS05-03	-2.117*	-2.867	3.567**	-6.433**	-5.933**	-0.900	1.433**
B9 x Jeuti	-2.483*	7.467**	-1.100	8.567**	0.600	2.367**	0.300
B9 x TS46	4.017**	4.467**	1.633	2.833	9.467**	2.833**	2.833**
YSH401 x NRCYS05-03	-2.783*	7.467**	2.767**	4.700**	8.333**	5.700**	-0.367
YSH401 x Jeuti	1.850	-2.800	2.100*	-4.900**	-1.733	0.767	4.100**
YSH401 x TS46	0.350	4.400*	-0.767	5.167**	-2.467*	-2.167**	0.833
NRCYS05-03 x Jeuti	4.950**	-0.200	-3.233**	3.033*	2.867*	-3.633**	-0.900*
NRCYS05-03 x TS46	-0.050	-4.400*	-3.100**	-1.300	-5.267**	-1.167	-0.167
Jeuti x TS46	-4.317**	-4.467**	2.233*	-6.700**	-1.733	0.500	-3.500**
SE(sij)	1.032	1.639	0.889	1.488	1.103	0.727	0.422
SE(sij-skl)	1.192	1.892	1.027	1.718	1.273	0.840	0.487
SE(sij-sik)	1.686	2.676	1.452	2.429	1.801	1.188	0.689

** Significant at P=0.05 and ** Significant at P=0.01*

Table 4. Mean performance of diallel genotypes of rapeseed pooled from two sowing dates in the field

Genotype	DF (days)	DM (days)	MSL (cm)	FMS	SMS	FD (%)	SD(No/ cm)	STS	SPS	OC(%)	TSW(g)	BYP(g)	SYP(g)
B9 x YSH401	50.3	97.0	58.48	43.50	37.00	14.89	0.63	11.50	15.50	39.39	3.365	33.008	7.870
B9 x NRCYS05-03	50.5	101.0	63.80	52.25	43.50	16.63	0.68	14.75	15.25	40.23	2.880	25.270	8.630
B9 x Jeuti	47.3	92.3	63.98	51.25	42.25	18.22	0.66	17.25	7.95	36.98	2.833	22.105	7.580
B9 x TS46	47.3	92.5	70.28	59.50	52.50	12.51	0.74	16.75	9.00	36.83	2.870	21.093	5.375
YSH401 x NRCYS05-03	49.3	99.0	50.55	52.25	44.75	14.26	0.89	16.50	14.00	37.37	3.678	20.240	7.125
YSH401 x Jeuti	47.3	97.0	55.75	54.25	46.25	14.68	0.83	16.75	11.25	37.51	2.805	20.473	7.325
YSH401 x TS46	45.5	96.5	58.93	59.75	47.50	20.16	0.81	16.25	11.75	34.54	3.218	21.965	5.680
NRCYS05-03 x Jeuti	48.3	100.0	66.63	69.50	64.00	7.90	0.97	12.25	14.75	38.61	2.995	26.720	7.550
NRCYS05-03 x TS46	46.5	98.5	62.30	64.50	56.00	13.12	0.90	14.00	12.25	37.38	2.975	23.828	5.250
Jeuti x TS46	41.3	86.5	46.98	59.50	45.75	22.78	0.98	10.50	15.75	39.67	2.948	8.825	5.555
B9	50.5	101.3	50.93	54.25	29.00	43.42	0.57	10.50	18.25	38.85	2.650	11.025	5.525
YSH401	49.8	101.8	49.83	56.75	34.75	36.95	0.70	11.50	18.00	40.27	2.650	11.863	6.300
NRCYS05-03	54.0	105.0	50.13	50.00	28.25	42.44	0.56	13.00	20.75	39.31	3.160	18.890	5.525
Jeuti	44.0	88.3	41.78	58.25	29.25	48.39	0.70	14.00	22.25	36.50	2.495	18.875	7.375
TS46	44.3	88.0	40.78	45.50	27.25	39.64	0.67	12.00	19.00	37.64	2.168	28.515	6.075
Mean	47.7	96.3	55.41	55.40	41.87	24.40	0.75	13.83	15.05	38.07	2.913	20.846	6.583
CD(P=0.05)	1.8	2.6	3.49	4.03	4.79	6.76	0.11	2.11	2.26	2.04	0.159	4.228	1.569
CD(P=0.01)	2.4	3.5	4.71	5.43	6.47	9.12	0.16	2.85	3.05	2.75	0.214	5.704	2.117

Table 5a. General combining ability effects for different characters in Indian rapeseed evaluated on two sowing dates in the field

Parent	Days to 50% flowering (DF)	Days to maturity (DM)	Main shoot length (MSL)	No. of flowers on main shoot (FMS)	No. of siliquae on main shoot (SMS)	Flower drop on MS (FD)
B9	1.421**	1.064**	3.706**	-2.486**	-2.564**	-2.486**
YSH401	0.779**	2.171**	-1.297**	-1.307**	-0.886	-1.307**
NRCYS05-03	2.314**	4.386**	1.585**	0.871	1.936**	0.871
Jeuti	-2.043**	-3.650**	-2.222**	2.657**	0.793	2.657**
TS46	-2.471**	-3.971**	-1.772**	0.264	0.721	0.264
SE (gi)	0.207	0.302	0.408	0.470	0.560	0.789
SE (gi-gj)	0.327	0.477	0.645	0.743	0.885	1.247
r (mean, gca)	0.985	0.987	0.759	0.033	-0.371	0.033

** Significant at P=0.05; ** Significant at P=0.01*

Table 5b. General combining ability effects for different characters in Indian rapeseed evaluated on two sowing dates in the field

Parent	Siliqua density on MS (SD)	Seeds per siliqua (SPS)	Oil content (OC)	1000 seed weight (TSW)	Biological yield per plant (BYP)	Seeds yield per plant (SYP)
B9	-2.564**	-0.869**	0.386	-0.034	-0.222	0.144
YSH401	-0.886**	-0.254	0.130	0.126**	-0.810	0.158
NRCYS05-03	1.936**	1.067**	0.539*	0.197**	1.252*	0.016
Jeuti	0.793**	0.560*	-0.380	-0.128**	-1.315*	0.466*
TS46	0.721**	-0.504	-0.675**	-0.162**	1.095*	-0.784**
SE(gi)	0.013	0.264	0.238	0.019	0.493	0.183
SE(gi-gj)	0.021	0.417	0.376	0.029	0.780	0.290
r (mean, gca)	-0.371	0.799	0.709	0.880	0.560	0.389

** Significant at P=0.05; ** Significant at P=0.01*

Table 6a. Specific combining ability effects for different characters in Indian rapeseed evaluated on two sowing dates in the field

Cross	Days to 50% flowering	Days to maturity	Main shoot length (cm)	No. of flowers on main shoot	No. of siliquae on main shoot	Flower drop on MS (%)	Siliqua density on MS (No./cm)
B9 x YSH401	0.333	-2.536**	0.661	-8.107**	-1.417	-8.107**	-1.417
B9 x NRCYS05-03	-0.952	-0.750	3.104**	-1.536	2.262	-1.536	2.262
B9 x Jeuti	0.155	-1.464	7.086**	-4.321**	2.155	-4.321**	2.155
B9 x TS46	0.583	-0.893	12.936**	6.321**	12.476**	6.321**	12.476**
YSH401 x NRCYS05-03	-1.560**	-3.857**	-5.143**	-2.714**	1.833	-2.714*	1.833
YSH401 x Jeuti	0.798	2.179**	3.864**	-2.500*	4.476**	-2.500*	4.476**
YSH401 x TS46	-0.524	2.000*	6.589**	5.393**	5.798**	5.393**	5.798**
NRCYS05-03 x Jeuti	0.262	2.964**	11.857**	10.571**	19.405**	10.571**	19.405**
NRCYS05-03 x TS46	-1.060	1.786*	7.082**	7.964**	11.476**	7.964**	11.476**
Jeuti x TS46	-1.952**	-2.179**	-4.436**	1.179	2.369	1.179	2.369
SE(sij)	0.534	0.780	1.053	1.213	1.445	2.037	0.035
SE(sij-sik)	0.801	1.169	1.579	1.820	2.167	3.055	0.052
SE(sij-skl)	0.731	1.067	1.442	1.662	1.979	2.789	0.047
r (mean,sca)	0.382	0.333	0.915	0.963	0.976	0.963	0.976

** Significant at P=0.05; ** Significant at P=0.01*

Table 6b. Specific combining ability effects for different characters in Indian rapeseed evaluated on two sowing dates in the field

Cross	No. of siliquae on terminal shoot (STS)	No. of seeds per siliqua (SPS)	% Oil content (OC)	Thousand seed weight (g) (TSW)	Biological yield per plant (g) (BYP)	Seed yield per plant (g) (SYP)
B9 x YSH401	-2.226**	1.576**	0.803	0.358**	13.193**	0.985*
B9 x NRCYS05-03	1.095	0.005	1.234	-0.198**	3.394*	1.888**
B9 x Jeuti	3.417**	-6.790**	-1.094	0.082	2.795*	0.387
B9 x TS46	3.381**	-4.674**	-0.952	0.151**	-0.627	-0.568
YSH401 x NRCYS05-03	2.452**	-1.860*	-1.375*	0.442**	-1.048	0.369
YSH401 x Jeuti	2.524**	-4.102**	-0.311	-0.108*	1.751	0.118
YSH401 x TS46	2.488**	-2.538**	-2.986**	0.341**	0.834	-0.277
NRCYS05-03 x Jeuti	-1.905**	-1.924**	0.375	0.017	5.937**	0.485
NRCYS05-03 x TS46	0.310	-3.360**	-0.552	0.025	0.635	-0.565
Jeuti x TS46	-3.369**	0.648	2.650**	0.325**	-11.801**	-0.710
SE(sij)	0.637	0.680	0.614	0.048	1.274	0.473
SE(sij-sik)	0.955	1.021	0.921	0.072	1.911	0.709
SE(sij-skl)	0.872	0.932	0.841	0.066	1.745	0.648
r (mean,sca)	0.995	0.944	0.935	0.764	0.978	0.936

Table 7. Estimates of genetic parameters for different characters in Indian rapeseed evaluated on two sowing dates in the field

Character	Genotypic coefficient of variation (%)	Phenotypic coefficient of variation (%)	Heritability$_{bs}$ (%)	Genetic advance (%)
Days to 50% flowering (DF)	6.57	7.40	78.94	12.03
Days to maturity (DM)	5.74	6.17	86.61	11.01
Main shoot length (MSL) (cm)	16.10	16.25	98.16	32.85
No. of flowers on main shoot (FMS)	12.07	18.46	42.70	16.24
No. of siliquae on main shoot (SMS)	25.85	28.60	81.70	48.13
Flower drop (FD) (%)	55.03	57.56	91.39	108.37
Siliqua density (SD) (No./cm)	17.24	20.02	74.12	30.57
No. of siliquae on terminal shoot (STS)	16.70	19.63	72.38	29.28
No. of seeds per siliqua (SPS)	27.08	28.23	92.06	53.54
Oil content (OC) (%)	3.74	4.75	62.00	6.07
Thousand seed weight (TSW) (g)	12.32	15.73	61.36	19.88
Biological yield per plant (BYP) (g)	30.68	32.28	90.30	60.06
Seed yield per plant (SYP) (g)	14.54	18.17	63.99	23.96

4. CONCLUSION

Temperature at reproductive stage more than 32°C was injurious to all plants of rapeseed in phytotron facility. B9 x Jeuti, B9 x TS46, YSH401 x Jeuti and NRCYS05-03 x Jeuti showed desirable yield adaptive traits at 32/28/15 ˚C for 9/4/11 hrs of temperature treatment. More study is needed at physiological level for understanding the tolerance in brassica. In field experiment, Jeuti, B9 x NRCYS05-03, B9 x YSH401, B9 x Jeuti, YSH401 x NRCYS05-03, YSH401 x Jeuti and NRCYS05-03 x Jeuti were found promising for yield adaptive traits both at normal and late sowing. In future, these lines can be used for development of heterotic populations. Further, these crosses can be used for studying the heat tolerance ability and physiological behavior at various growth stages. This can pave the way for development of climate smart varieties for the farmers to enable them for high oil production.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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