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Combining Ability Analysis: Physiological Traits for High Temperature Stress Tolerance in Indian Mustard [*Brassica juncea* (L.) Czern & Coss.]

Baldeep Singh*, N. K. Thakral, Renu Munjal and Geeta Boken

Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar

*Corresponding Author E-mail: baldeep55@pau.edu

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ABSTRACT

The Effects of high temperature stress during terminal stage were investigated on canopy temp. (^{0}C) at 40 DAS, 50 DAS, 60 DAS, 70 DAS, chlorophyll fluorescence at 40 DAS, 50 DAS, 60 DAS, 70 DAS and seedling mortality (%) of 36 Indian mustard [B. juncea (L.) Czern & Coss.] genotypes along with their $F_{1s.}$ during rabi, 2014-15. The genotypes were grown in randomized complete block design with three replications in two environments, viz., E1 (31st October sowing) and E2 (17th November sowing). Half diallel crosses of Indian mustard [B. juncea (L.) Czern & Coss.] genotypes along with their F_{1s} were evaluated for analysis of variance based on Griffing's method revealed significant mean squares of general combining ability (gca) and specific combining ability (sca) for all most the traits. Mean squares due to parent v/s crosses were also significant for all the traits which depicted presence of heterosis for all the traits, except for canopy temperature at 50 DAS, chlorophyll fluorescence(Fv/Fm)at 40 DAS, chlorophyll fluorescence(Fv/Fm) at 50DAS and 60 DAS in timely sown condition and canopy temperature at 50 DAS and 70DAS in late sown condition. In the present study, an overall appraisal of gca effects revealed that parent RH0735 and BPR349-9 in timely sown condition and RH0116 and RH0555A late sown condition were good combiners for the majority of characters. High gca effects are related to additive gene effects or additive x additive interaction effects which represent the fixable genetic component of variation. Hence these parents could be efficiently used for exploiting seed yield. For seed yield the crosses RH 8814 x RH0555A, RH0644 x BPR543-3 and BPR 349-9 x RH0644 in normal environment and crosses RH0555A x RH0644, RH 0735 x RH 0116and BPR 349-9 x RH0644 were identified as promising on the basis of their high significant SCA effects. These crosses could be extensively used in breeding programme to develop superior segregants could be derived in further breeding programmes.

Key words: *Brassica Juncea, Half Diallel, Gca, Sca, Yield Components Physiological Traits.*

INTRODUCTION

Rapeseed- mustard constitutes an important group of oilseed Brassica crops, and of these, Indian mustard [*Brassica juncea* (L.) Czern and Coss] is an important edible oil yielding crop accounting for about 80% of the cultivated area in North- Western parts of India[22].

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In India the area of rape and mustard 5.7 Mha, Production 5.74 MT and yield 1007 kg/ha in 2014-15. Rapeseed-mustard has now become the second largest produced edible oilseed crop in the world after soybean[9]. Being a C_3 plant, it has efficient photosynthetic response at 15 °C – 20 °C temperatures[6]. High temperature stress causes loss of chlorophyll content and canopy temperature disruptions. Hall[12] reported that flowering is the most sensitive stage for temperature stress damage probably due to vulnerability during pollen development, anthesis and fertilization leading to reduce crop yield. So, the uniqueness of Indian mustard growing environments (early sowing and late sowing) and constantly increasing global temperature necessitates the search for effective selection criteria involving- morphological (yield), physiological parameters. Therefore, improving seed yield of Indian mustard under late sown conditions by genetic up scaling of thermo tolerance at terminal stage would be vital for the sustainability in oilseed production.

To estimate nature and magnitude of general combining ability (additive gene actions) and specific combining ability (non-additive gene actions), two approaches are very common i.e. top-crosses and diallel crosses for conducting a successful breeding program[2]. Estimation of genetic constitution of parents for seed yield and it components can be important for indirect selection for high seed yield in rapeseed[15,23]. Although combining ability studies in oilseed *Brassica* are scanty, most of these studies emphasized the preponderance effect of gca for yield and its components indicating the importance of additive gene action[27]. On the other hand, Teklewold *et al*[25]., reviewed evidences for the presence of significant sca effects for yield and yield components. Ramsay *et al*[18]., reported that variation for both gca and sca were responsible for dry matter yield and other quantitative traits in *B. napus*.

The present investigation is an attempt to analyze the effects of high temperature on seed yield, its components and growth parameters in 28 F_1s by sca and also characterize 8 genotypes by gca for high temperature tolerance to identify suitable donors for utilization in the breeding program.

MATERIALS AND METHODS

This study was carried out at the research area of the Oilseeds Section, Department of Genetics & Plant Breeding, CCS HAU, Hisar (29°10N′ lat., 75°46′E long., 215 m alt.) during 2013-2015. Eight diverse mustard genotypes namely RH8814, RH0735, RH0116, BPR349-9 (Tolerant genotypes), and RH0952, RH0555A, RH0644, BPR543-3 (Susceptible genotypes) were selected as parents on the basis of their origin, adaptability, diversity, yield potential, heat tolerance traits. Crosses were attempted during *rabi*, 2013-14 in a diallel fashion (excluding reciprocals). Further the F_1s were grown during *rabi*, 2014-15. The eight parents along with 28 F_1s were evaluated during *rabi*, 2014-15 in randomized block design with three replications having plot size of two row of three-meter length under two environments (normal and late sown) with two dates of sowing 31.10.2014 (normal environment) and 17.11.2014 (late sown). The data was recorded on ten characters, form five competitive plants excluding border plants in each F_{1s} and parents which were randomly selected from each replication. Chlorophyll fluorescence(Fv/Fm) was calculated by portable handy chlorophyll fluoremeter (model OS-30 p, Opti sciences,USA) at anthesis stage and canopy temperature was estimated by infrared thermometer (IRT), model AG-42,Tele temp crop, Fullerton, for rapid indirect determination, was used for instantaneous measurement of canopy temperature at different stages after sowing in both the environments (normal and late sown). All the recommended cultural practices were followed throughout the crop season to raise a good crop. Irrigations were given as per the schedule to avoid any water stress. Following statistical model for combining ability was followed.

$$X_{ij} = \mu + g_i + g_j + s_{ij} + 1/r \sum_{K} e_{ijk}$$

Where,

μ = Population mean

g_i = General combining ability (gca) effects of i^{st} parent

g_j = General combining ability effects of j^{th} parent

s_{ij} = Specific combing ability (SCA) effect of ij^{th} cross/ hybrid

e_{ijk} = Environmental component pertaining to ijk^{th} observation

i and j = Female & male parents responsible for producing ij^{th} cross/hybrid

r = Number of replications

Estimation of the combining ability sum of squares, effects and their testing was done by the procedure given by Griffing[11].

RESULTS AND DISCUSSION

Mean squares due to genotypes and F_1s revealed significant differences for all the physiological traits in both the environments (normal and late sown), indicating presence of adequate genetic variation among the genotypes and F_1s. Mean squares due to parent v/s crosses were also significant for all the traits which depicted presence of heterosis for all the traits, except for canopy temperature at 50 DAS, chlorophyll fluorescence(Fv/Fm) at 40 DAS, chlorophyll fluorescence(Fv/Fm) at 50DAS and chlorophyll fluorescence (Fv/Fm) at 60 DAS in timely sown condition and canopy temperature at 50 DAS and canopy temperature at 70 DAS in late sown condition. In the present study higher mean values of the hybrids over parents revealed superiority and presence of sufficient amount of heterosis in F_1s in both the environments. Superiority of F_1s was also reported by Karthikeyan *et al*[13]., Shanthi *et al*[20]., in rice and Vaghela *et al*[26]., and Arifullah[3] in Mustard. In the present study, an overall appraisal of gca effects revealed that RH0735 and BPR349-9 in normal environments and RH0116 and RH0555A in late sown environment emerged as good general combiners for seed yield/plant and most of the yield component physiological characters, thus, these genotypes probably possessed the desirable genes for high temperature tolerance during seed filling period. High gca effects are related to additive gene effects or additive x additive interaction effects[24] which represent the fixable genetic component of variation. Hence RH0555A, RH0116, BPR349-9 and RH0735 in both the environments could be efficiently used for exploiting seed yield. Similar results in *brassica juncea* were also revealed by Patel *et al*[16]., Yadava *et al*[28]., Singh *et al*[22]., and Gami and Chauhan[10]. Considering the negative values of gca, an indication of minimum temperature of canopy of the plant, the parents RH0952 for canopy temperature at 40 DAS, parents RH0952 and RH8814 for canopy temperature at 50 DAS, parents RH0735 and RH8814 for canopy temperature at 60 DAS and parents RH0952 and RH8814 for canopy temperature at 70 DAS in both the environments, had significant negative gca effects and thus, for these traits, turned out to be the best combiner for heat tolerance. Such parents may be used to generate desirable genetic variability and these crosses may be exploited for selecting genotypes with decreased canopy temperature at 40, 50, 60 and 70 DAS. Radin *et al*[17]., Ayeneh *et al*[4]., also observed similar results for canopy temperature. Out of 28 cross combinations, only one cross, i.e. RH0735 x BPR349-9 in both the environments exhibited negative and significant sca effects for canopy temperature (^{0}C) at 40 DAS and thus, were good cross combinations for initial heat tolerance. There were four crosses namely; RH8814 x RH0116, RH8814 x RH0644, RH0735 x BPR543-3 and BPR349-9 x RH0644 which exhibited negative and significant sca effects in both the environments, suggesting that they were good hybrids for minimum canopy temperature (^{0}C) at 50 DAS. Significant negative sca effects in both the environments for canopy temperature (^{0}C) at 60 DAS were exhibited by cross combination, namely; RH8814 x RH0644, RH8814 x BPR543-3 and RH0735 x RH0952. Significant negative sca effects in both the environments for canopy temperature (^{0}C) at 70 DAS were exhibited by two cross combinations, namely; RH0116 x RH0952 and BPR349-9 x RH0555A. Therefore, it is suggested that these crosses are to be advanced through pedigree selection or through intermating followed by selection in successive segregating generations to develop genotypes resistant to high temperature tolerance having low canopy temperature (^{0}C) at 40, 50, 60 and 70 DAS**.** Young *et al*[29]., Balota *et al*[5]., and Madan *et al*[14]., also observed similar results for canopy temperature. Positive and significant gca effects were recorded for the parent RH0644 for chlorophyll fluorescence (Fv/Fm) at 40 DAS, parent BPR543-3 chlorophyll fluorescence (Fv/Fm) at 50 DAS, parents RH8814 and RH0735 for chlorophyll fluorescence (Fv/Fm) at 60 DAS and the parent RH0735 for chlorophyll fluorescence (Fv/Fm) at 70 DAS were recorded in both the environments and thus, this parent was found to be the best general combiner for this trait. Such parents may be used to create desirable genetic variability and these crosses may be exploited for selecting genotypes with increased chlorophyll fluorescence (Fv/Fm) at 40, 50, 60 and 70 DAS. Significant positive sca effects in both the environments for chlorophyll fluorescence (Fv/Fm) at 40 DAS were exhibited by two cross combinations, namely; RH8814 x RH0555A and RH0735 x RH0116, three cross combinations, namely; RH8814 x BPR349-9, RH0735 x RH0952 and RH0116 x BPR349-9 for chlorophyll fluorescence (Fv/Fm) at 50 DAS, for chlorophyll fluorescence (Fv/Fm) at 60 DAS were exhibited by four cross combinations, namely; RH8814 x RH0555A, RH8814 x BPR543-3, RH0735 x RH0555A and RH0116 x BPR349-9 and Significant positive sca effects in both the environments for chlorophyll fluorescence (Fv/Fm) at 70 DAS were exhibited by four cross combinations, namely; RH8814 x BPR543-3, RH0735 x RH0116, RH0735 x RH0644 and RH0952 x RH0555A indicating good sca for this trait. These crosses can be exploited for selecting genotypes with increased chlorophyll fluorescence (Fv/Fm) at 40, 50, 60 and 70 DAS. Sharma and Tondon[21] and Abderrahmane *et al*[1]., also observed similar results for chlorophyll fluorescence in wheat. Negative and significant gca effects were recorded for the parent RH0116 in both the environments and thus, this parent was found to be the best general combiner for seedling mortality (%). The magnitude of sca effects for seed seedling mortality (%) revealed by five crosses viz., RH0735 x RH0555A, RH0735 x BPR543-3, RH0116 x RH0644, RH0952 x RH0644 and RH0952 x BPR543-3 showed significant negative sca effects in both the environments. These crosses can be exploited for selecting genotypes with reduced seedling mortality (%) particularly in stress condition where seedling mortality increased drastically. These findings are in agreement with Chhabra and Promila[7], Chhabra[8] and Rapaport and Ferereas[19] in mustard for heat stress.

Table 1: Analysis of variance for different physiological characters under normal and late sown condition in Indian mustard

Source	d.f.	Canopy temperature at 40 DAS (^{0}C)	Canopy temperature at 50 DAS (^{0}C)	Canopy temperature at 60 DAS (^{0}C)	Canopy temperature at 70 DAS (^{0}C)	Chlorophyll fluorescence (Fv/Fm) at 40DAS	Chlorophyll fluorescence (Fv/Fm) at 50DAS	Chlorophyll fluorescence (Fv/Fm) at 60DAS	Chlorophyll fluorescence (Fv/Fm) at 70DAS	Seeding mortality (%)	Seed yield/ plant(g)
Timely sown condition											
Replications	2	0.909	2.810 **	0.032	0.316	NA	NA	NA	NA	0.051	3.538
Genotypes	35	24.961 **	6.746 **	3.012 **	12.165 **	0.001 **	0.003 **	0.004 **	0.004 **	35.332 **	28.864**
Parents	7	19.507 **	4.870 **	1.911 **	12.018 **	0.002 **	0.004 **	0.008 **	0.008 **	25.280 **	16.508**
Crosses	27	27.045 **	7 482**	3.144 **	11.988 **	0.001 **	0.002 **	0.003 **	0.002 **	39.204 **	27.100**
Parents v/s crosses	1	6.881 **	0.001	7.153 **	17.962 **	NA	NA	NA	0.005 **	1.145	162.971**
Error	70	0.971	0.506	0.586	0.407	NA	NA	NA	NA	0.970	1.714
Late sown condition											
Replications	2	0.078	6.168 **	2.155	0.111	NA	NA	NA	NA	0.108	1.718
Genotypes	35	2 927 **	2.405 **	6.289 **	4.226 **	0.002 **	0.002 **	0.004 **	0.002 **	41.531 **	29.562**
Parents	7	3.419 **	1.497 *	4.794 **	5.085 **	NA	0.002 **	0.002 **	0.001 **	19.281 **	14.995**
Crosses	27	2.618 **	2.703 **	6.700 **	4.063 **	0.002 **	0.002 **	0.005 **	\0.003 **	44.424 **	31.759**
Parents v/s crosses	1	7.815 **	0.720	5.671 *	2.608	NA	0.005 **	0.010 **	0.006 **	119.180**	72.198**
Error	70	0.832	0.620	1.204	1.017	NA	NA	NA	NA	0.822	2.546

*, ** significant at P=0.05 and 0.01, respectively.

Table 2: Analysis of variance for combining ability for different physiological traits under normal and late sown condition in Indian mustard (Griffing's Method 2, Model I)

Source	d.f.	Environment	Mean squares									
			Canopy temperature at 40 DAS (^{0}C)	**Canopy temperature at 50 DAS** (^{0}C)	**Canopy temperature at 60 DAS** (^{0}C)	**Canopy temperature at 70 DAS** (^{0}C)	**Chlorophyll fluorescence (Fv/Fm) at 40 DAS**	**Chlorophyll fluorescence (Fv/Fm) at 50 DAS**	**Chlorophyll fluorescence (Fv/Fm) at 60 DAS**	**Chlorophyll fluorescence (Fv/Fm) at 70 DAS**	**Seeding mortality (%)**	**Seed yield/ plant (g)**
gca	7	Normal	17.61**	0.79 **	2.34**	3.72**	0.00070**	0.0021**	0.0020**	0.0020**	13.93**	7.15**
		Late	1.30**	0.87**	4.11**	2.94**	0.00008**	0.0011**	0.0014**	0.0012**	6.76**	4.79**
sca	28	Normal	5.99**	2 61**	0.67**	4.14**	0.00030**	0.0006**	0.0012**	0.0010**	11.24**	10.23**
		Late	0.89**	0.79**	1.59**	1.03**	0.00060**	0.0006**	0.0015**	0.0007**	15.62**	11.11**
Error	70	Normal	0.32	0.17	0.19	0.14	0.00005	0.00003	0.00003	0.00005	0.32	0.57
		Late Late	0.28	0.21	0.40	0.34	0.00002	0.00005	0.00003	0.00003	0.27	0.84

*,**significant at P=0.05 and 0.01, respectively.

Table 3: Estimates of gca effects for differents physiological characters under normal and late sown condition in mustard (Grifling, 1956)

Components	Environment	Canopy temperature at 40 DAS (^{0}C)	Canopy temperature at 50 DAS (^{0}C)	Canopy temperature at 60 DAS (^{0}C)	Canopy temperature at 70 DAS (^{0}C)	Chlorophyll fluorescence (Fv/Fm) at 40 DAS	Chlorophyll fluorescence (Fv/Fm) at 50 DAS	Chlorophyll fluorescence (Fv/Fm) at 60 DAS	Chlorophyll fluorescence (Fv/Fm) at 70 DAS	Seeding mortality (%)	Seed yield/ plant (g)
RH8814	Normal	-1.800 *	-0.336 **	-0.657 **	-0.334 **	-0.010 **	-0.006 **	0.018 **	-0.023 **	-0.248	-0.085
	Late	-0.057	-0.290 *	-0.954 **	-0.566**	-0.018**	-0.010**	0.014**	-0.007**	-1.808**	0.781**
RH0735	Normal	-1.663 **	0.161	-0.457 **	0.229 *	0.006 *	0.010 **	0.003*	0.021 **	-1.458 **	1.358**
	Late	0.196	-0.313 *	-0.571 **	-0.599**	0.003	-0.004	0.014**	0.009**	0.632**	-0.018
RH0116	Normal	0.183	-0.209	0.057	1.099 **	-0.013 **	-0.017 **	-0.014 **	-0.003	-1.09**	0.935**
	Late	0.179	0.190	-0.258	0.711**	0.000	0.019**	0.012 *	0.017**	-0.372*	1.019**
BPR349-9	Normal	-0.007	0.077	-0.443 **	0.259 *	0.002	-0.013 **	-0.012 **	0.008 **	-0.082	1.178**
	Late	-0.294	-0.113	-0.094	-0.102	-0.003 *	-0.005 *	-0.003	-0.003	0.165	-0.911**
RH0952	Normal	-0.577 **	-0.249 *	-0.027	-1.064 **	0.003	-0.013 **	0.009 **	-0.016 **	1.55* *	-0.595**
	Late	-0.741 **	-0.320 *	0.232	-0.616**	-0.001	-0.004	-0.003 *	0.001	-0.005	-0.444
RH0555A	Normal	1.917 **	-0.036	0.613 **	-0.168	-0.004	0.002	-0.011 **	0.007 **	1.94** *	0.582*
	Late	0.336 *	0.280 *	1.183 **	0.321	0.004**	0.002	-0.011 *	-0.015**	0.115	0.752**
RH0644	Normal	0.533 **	0.544 **	0.513 **	0.013	0.005 *	0.023 **	0.019 **	0.003	-0.242	-0.435
	Late	0.102	0.413 **	0.296	0.334	0.014**	-0.011**	-0.017**	0.008**	0.825**	0.043
BPR543-3	Normal	1.413 **	0.048	0.400 **	-0.034	0.011 **	0.014 **	-0.012 **	0.002	-0.365 *	0.095
	Late	0.279	0.153	0.166	0.517**	0.002	0.012**	-0.006 *	-0.008**	0.448**	0.339
S.E. (gi)	Normal	0.168	0.121	0.130	0.108	0.002	0.001	0.002	0.002	0.168	0.223
	Late	0.156	0.134	0.187	0.172	0.001	0.002	0.002	0.002	0.154	0.272
S.E. (gi-gj)	Normal	0.516	0.184	0.197	0.164	0.003	0.002	0.002	0.003	0.254	0.338
	Late	0.235	0.203	0.283	0.260	0.002	0.003	0.002	0.002	0.475	0.412
C.D. at 5% (gi-gj)	Normal	0.507	0.366	0.394	0.328	0.006	0.005	0.004	0.006	0.507	0.674
	Late	0.469	0.405	0.565	0.519	0.004	0.006	0.004	0.005	0.467	0.821
C.D. at 1% (gi-gj)	Normal	0.657	0.473	0.510	0.425	0.008	0.006	0.006	0.008	0.656	0.872
	Late	0.608	0.524	0.731	0.672	0.006	0.008	0.006	0.006	0.604	1.063

*,**significant at P=0.05 and 0.01, respectively.

Table 4: Estimates of sca effects for different characters under normal and late sown condition in Indian mustard (Griffing, 1956)

Components	Environment	Canopy temperature at 40 DAS (°C)	Canopy temperature at 50 DAS (°C)	Canopy temperature at 60 DAS (°C)	Canopy temperature at 70 DAS) (°C)	Chlorophyll fluorescence (Fv/Fm) at 40 DAS	Chlorophyll fluorescence (Fv/Fm) at 50 DAS	Chlorophyll fluorescence (Fv/Fm) at 60 DAS	Chlorophyll fluorescence (Fv/Fm) at 70 DAS	Seeding mortality (%)	Seed yield/ plant (g)
RH 8814 x RH 0735	Normal	1.819**	-0.298	0.295	1.493**	-0.001	-0.022**	0.018**	0.007	-3.017**	0.289
	Stress	1.294**	-0.386	0.387	0.447	-0.042**	0.024**	0.010	0.022**	-0.496	2.26**
RH 8814 x RH 0116	Normal	-2.661**	-0.795*	-0.185	-0.910	0.012*	0.023**	0.022**	-0.036**	0.519	4.089**
	Stress	0.244	-1.156**	-0.460	-1.296	-0.051**	-0.014**	0.005	-0.005	-5.726**	-1.143
RH8814xBPR 349-9	Normal	1.529**	-0.315	-0.219	0.696*	0.015*	0.012**	-0.033**	0.030**	0.439	-2.798**
	Stress	-2.51**	-0.352	-0.256	-0.316	0.005	0.020**	-0.002	-0.036**	0.338	3.987**
RH 8814 x RH0952	Normal	1.032**	0.345	-0.335	1.320**	-0.028**	0.003	-0.015**	0.055**	5.543**	-1.118
	Stress	0.331	0.454	-1.050	-0.269	-0.019**	-0.015*	-0.023**	-0.043**	6.608**	0.420
RH8814 xRH0555A	Normal	0.939	0.432	1.325**	0.756*	0.016*	0.006	0.021**	0.033**	3.549**	6.042**
	Stress	1.087*	0.988*	1.334*	0.461	0.023**	0.015*	0.015**	-0.022**	0.021	3.524**
RH 8814 x RH0644	Normal	-3.244**	-0.981*	-1.242**	0.956**	-0.002	-0.015**	-0.010**	0.033**	-4.167**	-2.738**
	Stress	-0.613	-1.379**	-1.413*	0.514	0.003	-0.015*	-0.011**	0.003	-0.556	-1.96*
RH8814x BPR543-3	Normal	-4.791	-1.051**	-0.962**	0.623	0.004	0.017**	0.030**	0.034**	-0.744	3.959**
	Stress	-0.056	-0.752	-1.883**	-0.769	0.015**	-0.022**	0.023**	0.017**	-3.212**	-2.130
RH 0735 x RH 0116	Normal	-0.898	-1.225	-0.319	-5.007**	0.015*	-0.015**	-0.010*	0.019**	-2.171**	0.039
	Stress	-1.109*	-0.799	0.557	-0.763	0.012**	0.007	0.001	0.011*	2.001**	4.160**
RH0735xBPR 349-9	Normal	-1.208*	2.589**	-0.752	0.633	-0.004	-0.020**	-0.060**	-0.014**	2.916**	-1.98**
	Stress	-0.969*	-0.729	-0.506	-0.449	-0.008	0.008	-0.001	-0.040**	5.564**	-4.543**
RH 0735 x RH0952	Normal	1.629**	2.815**	-1.069**	1.823**	0.011	0.021**	-0.027**	-0.027**	1.853**	-0.335
	Stress	-0.356	-0.022	-1.733**	-0.536	0.058**	0.023**	-0.063**	-0.013*	-4.966**	0.557
RH0735x RH0555A	Normal	0.536	0.102	0.858**	0.293	0.010	0.009*	0.031**	-0.013*	-1.841**	-2.808**
	Stress	0.601	1.678**	1.850**	1.094*	-0.026**	0.004	0.030**	-0.009	-1.452**	-7.206**
RH 0735 x RH0644	Normal	-0.181	2.489**	1.325**	0.246	0.007	0.046**	0.015**	0.013*	3.076**	-1.82**
	Stress	-0.033	1.411**	0.870	0.181	0.016**	0.000	-0.009	0.010*	-2.596**	3.970**
RH 0735xBPR543-3	Normal	-0.194	-2.681**	-0.662	0.260	-0.032**	0.054**	-0.006	0.009	-3.534**	1.542*
	Stress	-0.709	-1.229**	-0.233	0.597	-0.20**	0.012	0.029**	-0.014**	-1.319**	-0.593
RH0116xBPR 349-9	Normal	0.712	0.992	0.701	1.263**	0.019**	0.022**	0.034**	0.015*	-0.514	-0.648
	Stress	1.847**	0.701	0.747	0.407	-0.008	0.017*	0.011*	-0.022**	0.434	-1.164
RH 0116 x RH0952	Normal	-1.884**	-1.015**	-1.149**	-1.880**	0.024**	0.008	-0.025**	0.010	2.623**	1.53*
	Stress	-0.739	-0.626	0.220	-1.079*	-0.013**	0.019**	0.018**	0.018**	3.271**	2.15*
RH0116x RH0555A	Normal	-1.711**	1.239**	-0.355	2.190**	-0.014*	0.007	-0.020**	0.007	5.429**	1.16*
	Stress	-0.016	-0.592	-0.530	0.617	0.028**	-0.030**	0.007	0.024**	5.851**	-0.023

*,**significant at=0.05 and 0.01, respectively.

Components	Environment	Canopy temperature at 40 DAS (˚C)	Canopy temperature at 50 DAS (˚C)	Canopy temperature at 60 DAS (˚C)	Canopy temperature at 70 DAS) (˚C)	Chlorophyll fluorescence (Fv/Fm) at 40 DAS	Chlorophyll fluorescence (Fv/Fm) at 50 DAS	Chlorophyll fluorescence (Fv/Fm) at 60 DAS	Chlorophyll fluorescence (Fv/Fm) at 70 DAS	Seeding mortality (%)	Seed yield/ plant (g)
RH 0116 x RH0644	Normal	-1.394**	-2.041**	-0.289	1.910**	-0.008	-0.028**	-0.031**	0.019**	-3.254**	-1.42*
	Stress	-0.549	0.374	-0.676	1.171*	0.002	-0.017*	-0.053**	-0.021**	-5.426**	2.83**
RH 0116 x BPR543-3	Normal	4.992	0.089	-0.075	1.056**	-0.003	-0.027**	-0.002	0.025**	1.169*	-0.291
	Stress	-0.559	0.834*	-0.813	-0.513	0.015**	0.063**	-0.018**	0.006	-4.682**	3.50**
BPR 349-9 x RH0952	Normal	-1.594**	-1.268**	-0.249	0.962**	-0.011	0.005	0.007	0.012	-0.557	-2.39**
	Stress	0.967*	0.044	-2.843	-0.699	0.003	0.018**	-0.043**	0.028**	-1.466**	0.450
BPR 349-9 x RH 0555A	Normal	-2.521**	-2.015**	-1.589**	-1.570**	0.00	-0.002	-0.031**	-0.005	2.683**	1.47*
	Stress	-0.009	-0.422	1.140	-2.436**	-0.007	0.001	0.024**	-0.056**	-7.786**	-2.78**
BPR 349-9 x RH0644	Normal	-3.171**	-2.561**	-0.789	-3.017**	-0.005	-0.025**	-0.059**	0.007	-4.701**	5.192**
	Stress	-0.143	-0.922*	-0.240	-0.283	0.001	0.000	0.045**	0.030**	0.004	4.264**
BPR 349-9 x BPR543-3	Normal	-0.951	0.969*	0.691	-1.804**	0.011	-0.017**	0.051**	-0.016*	0.789	3.555**
	Stress	0.114	-0.196	1.990**	1.134	-0.019**	0.014*	0.001	0.008	2.848**	3.07**
RH0952 x RH0555A	Normal	-1.584**	0.312	0.395	0.286	-0.008	0.00	-0.035**	0.016*	-3.847**	3.052**
	Stress	-0.496	-0.149	0.580	2.577**	-0.017**	-0.006	0.041**	0.040**	1.784**	2.65**
RH0952 x RH0644	Normal	1.266*	2.099**	0.461	-1.827**	-0.027**	-0.034**	-0.002	-0.072**	-2.997**	1.44*
	Stress	-0.063	0.718	0.700	0.197	-0.026**	-0.009	0.053**	-0.005	-3.726**	-2.97**
RH0952 x BPR543-3	Normal	1.386**	-0.805	0.475	-2.347**	0.027**	0.019**	0.028**	0.011	-5.641**	-0.965
	Stress	0.327	0.011	0.197	-0.419	0.005	-0.040**	-0.049**	0.005	-1.582**	-0.166
RH0555A x RH0644	Normal	3.539**	0.985*	-0.249	-3.124**	0.000	-0.004	0.024**	-0.009	-1.691**	0.232
	Stress	0.161	-0.316	-1.183*	-0.573	0.029**	0.015*	-0.055**	-0.015**	1.321**	4.734**
RH0555A x BPR543-3	Normal	1.959**	1.282**	-0.165	-2.944**	-0.006	-0.031**	0.025**	-0.062**	1.533**	-1.105
	Stress	-1.183*	0.911*	-0.520	-1.023	-0.001	0.008	-0.060**	-0.019**	-5.069**	0.007
RH0644 x BPR543-3	Normal	2.876**	0.269	0.268	1.576**	0.003	-0.009*	0.035**	0.000	5.016**	5.215**
	Stress	-0.883	0.678	0.334	-0.303	0.013**	0.004	-0.065**	-0.014**	4.288**	-3.886**
S.E. (S_{ii})	Normal	0.448	0.324	0.348	0.290	0.005	0.004	0.004	0.006	0.448	0.596
	Stress	0.415	0.358	0.0499	0.459	0.004	0.005	0.004	0.004	0.412	0.726
S.E. (S_{ij})	Normal	0.516	0.372	0.400	0.333	0.006	0.005	0.005	0.007	0.515	0.685
	Stress	0.477	0.412	0.574	0.527	0.004	0.006	0.004	0.005	0.474	0.835
S.E. (S_{ii}-S_{ij})	Normal	0.623	0.449	0.484	0.403	0.007	0.006	0.006	0.008	0.623	0.828
	Stress	0.576	0.497	0.694	0.637	0.005	0.008	0.005	0.006	0.573	1.009
S.E. (S_{ij}-S_{ik})	Normal	0.763	0.551	0.593	0.494	0.009	0.008	0.007	0.009	0.763	1.014
	Stress	0.706	0.609	0.0849	0.781	0.006	0.009	0.006	0.007	0.702	1.236
S.E. (S_{ij}-S_{kl})	Normal	0.179	0.519	0.558	0.466	0.008	0.007	0.007	0.009	0.719	0.956
	Stress	0.666	0.575	0.801	0.736	0.006	0.009	0.006	0.007	0.662	1.165
C.D. at 5 %(S_{ij}-S_{ik})	Normal	1.522	1.098	1.18	0.985	0.018	0.014	0.014	0.019	1.52	2.022
	Stress	1.408	1.216	1.694	1.558	0.013	0.019	.0014	0.015	1.400	2.465
C.D. at 1 %	Normal	1.970	1.420	1.529	1.274	0.024	0.018	0.019	0.025	1.96	2.616
	Stress	1.823	1.573	2.192	2.015	0.017	0.025	0.016	0.019	1.812	3.189

*,**significant at=0.05 and 0.01, respectively.

Table 5: Top five heterotic hybrids for seed yield/plant and its physiological component traits in Indian mustard

Environment	Superior heterotic hybrids for seed yield/plant over mid and better parent	Heterosis for its component traits
Normal	RH8814 x BPR543-3	CT 40 DAS, CT 50 DAS, CT 60 DAS, seed yield per plant
Late	RH8814x BPR349-9	CT40 DAS, CT 50 DAS, CF 50 DAS, seed yield per plant
Normal	RH8814 x RH0555A	CF 40 DAS, CF 60 DAS, seed yield per plant
Late	BPR349-9 x RH0644	CT 50 DAS, CF 40 DAS, CF 60 DAS, seedling mortality, seed yield per plant
Normal	RH8814 x RH0116	CT 40 DAS, CT 50 DAS, CF 40 DAS, CF 50 DAS, CF 60 DAS, seed yield/plant
Late	RH0555A x RH0644	CF 40 DAS, CF 50 DAS, seedling mortality, seed yield/plant
Normal	BPR349-9 x BPR543-3	CT 70 DAS, CF 40 DAS, CF 60 DAS, seed yield per plant
Late	RH0116 x RH0644	seedling mortality, CF 40 DAS, Seed yield/plant
Normal	RH0644 x BPR543-3	Seed yield per plant
Late	RH0735 x RH0116	CT 40 DAS, CT 50 DAS, CF 40 DAS, CF 50 DAS, CF 70 DAS, Seed yield per plant

CT: Canopy temperature, CF: Chlorophyll fluorescence, DAS: Days after sowing

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