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Manifestation of Heterosis in Indian Mustard: Through Physiological characters for Seed Yield

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ABSTRACT

Half diallel F1 crosses and parents of Indian mustard [B. juncea (L.) Czern & Coss.] genotypes were evaluated for canopy temp. (0C) at 40 DAS, 50 DAS, 60 DAS, 70 DAS and chlorophyll fluorescence at 40 DAS, 50 DAS, 60 DAS, 70 DAS, seedling mortality (%) and seed yield per plant (g). Mean squares due to parent v/s crosses were significant for all the traits, except for canopy temperature at 50 DAS, chlorophyll fluorescence (Fv/Fm) at 40 DAS, chlorophyll fluorescence (Fv/Fm) at 50 DAS 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. For seed yield and physiological traits, crosses RH8814 x RH0555A, RH0644 x BPR543-3 and BPR349-9 x RH0644 in timely sown condition and crosses RH0555A x RH0644, RH0735 x RH0116 and BPR349-9 x RH0644 in late sown were identified as promising on the basis of their high per se performance with positive and negative heterotic effects. From the component character analysis, it was concluded that characters canopy temperature , chlorophyll fluorescence (Fv/Fm) and seedling mortality contributed significantly towards heterosis in seed yield. These crosses could be further used to select superior segregants.

Key words: Brassica juncea, half diallel, heterosis breeding, seed yield, yield components.

INTRODUCTION

Indian mustard (Brassica juncea) is a naturally autogamous species, yet in this crop frequent out-crossing occur which varies from 5 to 30% depending upon the environmental conditions and random variation of pollinating insects. In India, the area of rape and mustard is 61.90 lakh/ha, with production of 58.03 lakh tons and yield 0.94 tons/ ha in 2015-16.

The success stories of hybrid breeding are the reason for its expansion in all most all major fields of agricultural plants. For developing a hybrid, genetic analysis of important characters and their combination in a single hybrid is essential.. It has become a common practice of the plant breeders to obtain genetic information from diallel analysis of progenies and desirable parental combination which can reflect a high degree of heterotic response for its commercial exploitation in future breeding programs. Heterosis has been earlier explored and utilized for boosting various quality traits in Brassica and other crops (Hassan et al. 2006). According to Pal and Sikka, (1956) heterosis is a quick, cheap and easy method for increasing crop production. Therefore, present study was conducted to explore the role of some physiological traits in expression of heterosis (mid-parent and better-parent) on F1 generation of mustard genotypes using diallel analysis.

MATERIALS AND METHODS

Eight diverse mustard genotypes namely RH8814, RH0735, RH0116, BPR349-9 RH0952, RH0555A, RH0644, BPR543-3 were selected as parents on the basis of their origin, adaptability, diversity and yield potential. Crosses were attempted during Rabi, 2013-14 in a diallel fashion (excluding reciprocals). Eight parents along with 28 F1s were evaluated during Rabi, 2014-15 in randomized block design with three replications

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having plot size of two row of three meter length under timely and late sown conditions. The data were recorded on ten characters (Table 1), form five competitive plants excluding border plants in each F1s and parents which were randomly selected from each replication. All the recommended cultural practices were followed throughout the crop season to raise a good crop. Standard formulas were used for estimation of heterosis. Table value of 't' at error d.f. corresponding to 5% or 1% level of significance. Negative direction of heterosis was considered for canopy temp. at 40 DAS, 50 DAS, 60 DAS, 70 DAS and seedling mortality, whereas, positive direction was considered for rest of the traits.

RESULTS AND DISCUSSION

Analysis of variance showed that mean sum of squares were significantly different for most of the physiological traits in both the environments, indicating presence of adequate genetic variation among the genotypes (F1+ parents). except for Chlorophyll fluorescence (Fv/Fm) at 40 DAS in late sown condition among parents. Mean squares due to parent v/s crosses were also significant for all the traits which depicted presence of variations for different traits. , Superiority of F1s in mustard was also reported by Vaghela et al. (2011), Patel et al. (2012) and Arifullah (2013). The results on heterosis for different traits are detailed below:

Canopy temperature **(**0C**)** at 40,50,60,70 DAS- Minimum canopy temperature was treated as desirable attribute and accordingly negative estimates of heterosis were considered to be desirable. Five crosses exhibited significant negative significant heterosis over better parents and mid-parents for this trait. in both the environments Minimum magnitudes of heterobeltiosis was observed for the cross i.e. RH0555A x BPR543-3 (-14.80), followed by RH0644 x BPR543-3 (-14.42) and RH0735 x RH0952 (-13.92). Differential magnitude of of mid parent heterosis over mid-parent and better parent for canopy temperature (0C) at 50 DAS recorded by crosses viz., RH8814 x RH0116, RH8814 x BPR349-9, RH8814 x RH0644, RH8814 x BPR543-3, RH0735 x BPR543-3 and BPR349-9 x RH0644 in both the environments. Similarly, negative and significant heterosis over better parents in both the environments was exhibited by crosses ; RH8814 x RH0116, RH8814 x RH0952, RH8814 x RH0644, RH8814 x BPR543-3, RH0735 x RH0952, RH0116 x RH0952 and BPR349-9 x RH0952 for canopy temperature (0C) at 60 and 70 DAS. Similar results was also reported earlier by Kumar et al. (2007) and Nasrin et al. (2011) in Brassica juncea. Negative and significant heterosis over better parent expressed by the seven cross combinations viz., RH8814 x RH0116, RH8814 x BPR349-9, RH8814 x BPR543-3, RH0735 x RH0116, RH0116 x RH0952, BPR349-9 x RH0952 and BPR349-9 x RH0555A in both the environments. Therefore, it is suggested that these crosses may be used in the development of high temperature tolerant hybrids after converting CMS lines or restorer lines for low canopy temperature (0C). The same results were also reported earlier by Vaghela et al. (2011) and Verma et al. (2011) in mustard.

Chlorophyll fluorescence (Fv/Fm) at 40,50,60,70 DAS -For chlorophyll fluorescence (Fv/Fm) at 40 DAS five cross in both the environments manifested significant positive heterosis over mid-parent. Three crosses RH8814 x RH0555A, RH0735 x RH0952 and RH0952 x BPR543-3 manifested significant positive heterosis over better-parent in both environments. Significant heterobeltiosis for chlorophyll fluorescence (Fv/Fm) at 50 DAS was noticed in six crosses in both the environments namely; RH8814 x BPR349-9, RH0735 x RH0952, RH0735 x RH0555A, RH0735 x BPR543-3, RH0116 x BPR349-9, RH0116 x RH0952. Similar results were revealed by Singh et al. (2005), Sadanand et al. (2009), Patel et al. (2012), Yadava et al. (2012), Singh et al. (2013) and Gami and Chauhan (2013). Heterobeltiosis for chlorophyll fluorescence (Fv/Fm) at 70 DAS was significant and positive manifested by only one cross i.e. RH0116 x RH0952 in both the environments. **These traits can be improved by**

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 (0C)	Canopy temperature at 50 DAS (0C)	Canopy temperature at 60 DAS (0C)	Canopy temperature at 70 DAS (0C)	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 Mean (%) and range of heterosis (MP) and heterobeltiosis (BP) for yield and different physiological traits in Indian mustard

Traits	Environment	MP		BP	
		Mean	Range	Mean	Range
Canopy temperature at 40 DAS	Normal	-2.76	-25.4-28.5	-9.30	-28.26-25.08
	Late	-4.20	-19.06-10.33	-7.85	-20.83-7.92
Canopy temperature at 50 DAS	Normal	0.14	-21.22-36.80	-5.28	-24.15-35.83
	Late	-1.27	-12.56-12.61	-3.67	-13.15-11.67
Canopy temperature at 60 DAS	Normal	-3.28	-11.87-7.74	-6.29	-15.41-0.98
	Late	-3.11	-19.87-15.55	-6.40	-24.14-7.21
Canopy temperature at 70 DAS	Normal	-5.43	-32.33-19.52	-11.99	-36.21-8.59
	Late	-2.79	-19.27-19.19	-7.61	-22.35-12.74
Chlorophyll fluorescence (Fv/Fm)at 40 DAS	Normal	0.49	-4.73-4.86	-1.36	-2.87-2.61
	Late	-0.61	-8.85-6.65	-1.08	-9.54-6.12
Chlorophyll fluorescence (Fv/Fm)at 50 DAS	Normal	0.09	-5.79-9.15	-2.37	-11.69-6.28
	Late	2.13	-4.15-10.44	0.39	-4.63-9.76
Chlorophyll fluorescence (Fv/Fm)at 60 DAS	Normal	-0.37	-11.56-10.57	-4.05	-12.56-4.26
	Late	-2.89	-15.54-4.46	-4.93	-17.80-4.46
Chlorophyll fluorescence (Fv/Fm) at 70 DAS	Normal	**2.22**	-9.38-13.29	-1.57	-11.86-6.72
	Late	-2.16	-11.37-4.33	-3.59	-13.53-3.66
Seeding mortality (%)	Normal	-0.77	-38.28- 53.26	-10.05	-45.49-31.8
	Late	-11.13	-43.74- 32.85	-17.03	-46.64-24.53
Seed yield/plant (g)	Normal	21.555	-16.29-73.19	11.287	-25.61-62.31
	Late	17.476	-51.18-68.47	6.897	-53.73-66.02

Table: 3 Extent of hetrosis (%) for canopy temp. at 40 DAS, 50 DAS, 60 DAS, 70 DAS and chlorophyll fluorescence at 40 DAS in Indian mustard

Crosses	Environ-ment	Canopy temperature at 40 DAS Heterosis (%) over		Canopy temperature at 50 DAS Heterosis (%) over		Canopy temperature at 60 DAS Heterosis (%) over		Canopy temperature at 70 DAS Heterosis (%) over		Chlorophyll fluores-cence (Fv/Fm) at 40 DAS Heterosis (%) over	
		M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.
RH8814 x RH0735	Normal	4.24	-5.09	0.77	-6.43	0.44	-0.44	19.52**	5.05	0.46**	-1.78
	Late	4.20	2.41	-6.64	-10.39**	-1.94	-6.84	1.61	-2.00	-7.68	-8.48
RH8814 x RH0116	Normal	-23.89**	-28.26**	-14.25**	-15.83**	-4.69	-10.22**	0.22	-16.73**	3.50**	2.025**
	Late	-1.65	-2.65	-12.56**	-13.15**	-9.17*	-9.65*	-12.38**	-18.79**	-8.86	-9.54
RH8814 xBPR349-9	Normal	-8.20*	-16.62**	-8.88*	-10.55*	-5.87	-9.45*	8.68**	-7.75*	3.25**	2.07**
	Late	-19.06**	-20.83**	-8.84**	-9.02*	-6.82	-7.72	-8.46	-12.70*	-2.58	-3.43
RH8814 x RH0952	Normal	-1.96	-3.51	3.23	-4.76	-5.36	-10.18**	16.82**	8.59*	-3.38	-5.88
	Late	0.22	-5.83	-0.72	-5.49	-15.23**	-19.75**	-4.66	-6.89	-4.70	-4.94
RH8814 xRH0555A	Normal	-1.11	-9.59**	3.54	-2.62	7.68*	0.97	7.02*	-8.64**	2.43**	1.14**
	Late	5.19	4.75	5.09	1.18	4.97	2.68	1.85	-0.42	1.73**	1.59**
RH8814 x RH0644	Normal	-23.98**	-27.43**	-10.28**	-11.93**	-9.39**	-15.41**	10.03**	-5.92	-0.71	-3.97
	Late	-8.74*	-10.91*	-11.35**	-11.96**	-14.53**	-17.13**	2.50	0.43	-0.54	-1.41
RH8814 xBPR543-3	Normal	-25.39**	-27.01**	-14.55**	-16.40**	-7.60*	-13.11**	7.02*	-8.64**	1.09**	-1.75
	Late	-6.45	-10.63*	-8.18*	-9.80*	-16.31**	-17.66**	-9.03*	-14.62**	0.00	-0.13
RH0735 x RH0116	Normal	-7.65*	-19.41**	-7.29	-15.37**	-4.28	-9.82**	-32.23**	-36.21**	3.52**	-0.21
	Late	-11.20**	-12.94**	-7.92*	-11.22**	3.72	-1.24	-6.44	-15.94**	0.79**	0.66**
RH0735 xBPR349-9	Normal	-14.43**	-27.79**	23.62**	12.84**	-8.00*	-11.50**	-1.41	-4.84	0.50**	-0.62
	Late	-10.42*	-14.90**	-8.50*	-11.02**	-0.84	-5.19	-6.55	-13.71**	-2.4	-2.44
RH0735 x RH0952	Normal	10.85**	3.62	36.78**	35.83**	-8.73*	-13.37**	8.34**	1.46	1.15**	0.78**
	Late	-5.79	-13.92**	-0.74	-2.71	-12.37**	-21.16**	-3.42	-4.43	6.65**	6.12**
RH0735 xRH0555A	Normal	5.14	-10.76**	13.42**	11.89*	6.02	-0.58	-5.36	-8.06*	1.29**	0.41**
	Late	0.60	-1.96	12.61**	11.67**	15.55**	7.21	9.32	3.40	-2.72	-3.68
RH0735 x RH0644	Normal	-0.45	-12.12**	26.38**	15.37**	7.74*	0.58	-4.36	-6.90*	0.00	-1.09
	Late	-6.51	-7.06	8.24*	5.77	4.39	-3.95	3.49	-1.92	2.81**	2.81**
RH0735 xBPR543-3	Normal	7.25	-3.19	-16.65**	-24.15**	-4.47	-10.18**	-4.75	-7.47*	-3.74	-4.33
	Late	-11.48**	-12.90**	-8.44*	-9.55*	-0.64	-7.30	2.47	-6.82	-2.58	-3.18
RH0116 xBPR349-9	Normal	-7.08*	-11.60**	-2.26	-3.78	-1.71	-3.92	1.52	-0.74	4.8**	2.20**
	Late	10.33*	7.92	0.20	0.00	2.21	1.23	-4.83	-8.70	-2.56	-2.69

RH0116 x RH0952	Normal	-11.68**	-17.14**	-9.81*	-19.33**	-11.57**	-12.35**	-16.16**	-25.56**	3.97**	0.00
	Late	-5.32	-11.04*	-4.43	-9.02*	-5.46	-10.50*	-10.63*	-19.81**	-2.41	-2.78
RH0116 xRH0555A	Normal	-8.65**	-12.50**	6.59	-2.89	-4.30	-4.67	5.05	2.04	-0.48	-3.12
	Late	-0.21	-0.62	-1.63	-5.29	-1.03	-3.19	1.29	-5.19	3.93**	3.03**
RH0116 x RH0644	**Normal**	-9.31**	-9.52*	-19.64**	-20.89**	-4.96	-5.78	4.68	1.48	-0.76	-5.23
	Late	-6.91	-9.13*	1.88	1.18	-7.22	-10.05*	4.86	-2.04	0.91**	0.79 **
RH0116 xBPR543-3	**Normal**	28.55**	25.08**	-8.89*	-10.00*	-3.62	-3.72	-0.67	-3.52	1.15**	-3.06
	Late	-8.04*	-12.14**	4.19	2.35	-7.16	-8.66	-8.07	-10.37*	1.63**	1.12 **
BPR349-9 xRH0952	**Normal**	-15.46**	-23.91**	-9.57*	-19.11**	-6.42	-8.38*	-0.75	-9.61**	-1.08	-2.43
	Late	6.42	3.11	-2.16	-6.86	-19.87**	-24.14**	-10.54*	-17.65**	-0.87	-1.49
BPR349-9xRH0555A	**Normal**	-16.98**	-17.10**	-15.12**	-22.67**	-11.87**	-14.79**	-18.94**	-19.02**	0.72**	0.59 **
	Late	0.00	-3.51	-2.44	-6.08	8.40*	6.04	-19.27**	-22.35**	-1.04	-2.15
BPR349-9 xRH0644	**Normal**	-22.40**	-25.94**	-21.22**	-22.44**	-8.11*	-11.56**	-26.25**	-26.47**	-0.83	-2.88
	Late	-4.40	-9.52*	-7.60*	-8.24*	-4.16	-7.08	-5.82	-9.61	0.25**	0.12 **
BPR349-9xB-PR543-3	**Normal**	-6.07	-12.46**	-1.01	-2.22	0.91	-2.15	-19.53**	-19.61**	2.33**	0.57 **
	Late	-3.99	-11.01*	-3.79	-5.49	8.20*	6.45	-0.49	-0.78	-3.12	-3.84
RH0952 xRH0555A	**Normal**	-5.05	-15.26**	11.78**	10.27*	-0.39	-0.78	-7.64*	-15.72**	-1.54	-2.75
	Late	-2.88	-9.30*	4.34	1.91	1.96	-0.79	19.19**	12.74*	-1.59	-1.97
RH0952 x RH0644	**Normal**	7.46*	0.00	20.35**	9.86*	-1.07	-1.93	-19.96**	-26.82**	-4.73	-5.43
	Late	-3.68	-11.71*	7.24*	1.59	-2.67	-4.44	3.49	-1.92	-2.33	-2.81
RH0952 xBPR543-3	**Normal**	15.67**	10.23*	-5.63	-14.12**	-0.88	-0.98	-23.79**	-30.45**	2.99**	2.61 **
	Late	-2.43	-12.33**	2.34	-2.03	-4.35	-7.46	-4.18	-12.87**	0.71**	0.59 **
RH0555A xRH0644	**Normal**	16.93**	11.59**	13.57**	3.67	-1.46	-2.31	-29.40**	-29.61**	-1.07	-2.99
	Late	-1.63	-3.97	1.32	-0.99	-4.89	-5.44	-2.00	-3.13	5.72**	4.67 **
RH0555AxB-PR543-3	**Normal**	16.49**	8.55*	11.64**	1.59	-0.88	-0.98	-28.75**	-28.82**	-0.62	-2.20
	Late	-10.82**	-14.80**	8.44*	7.11	-0.76	-1.67	-7.96	-10.92*	0.88**	0.75 **
RH0644 xBPR543-3	**Normal**	19.90**	16.67**	-2.59	-3.78	1.08	0.98	-1.08	-1.18	-0.53	-0.89
	Late	-13.02**	-14.42**	4.59	2.75	-0.93	-1.83	-3.52	-6.63	2.95**	2.32 **
CD. at 5 %	**Normal**	**1.38**	**1.60**	1.01	1.15	**1.07**	**1.24**	**0.89**	**1.03**	**0.016**	**0.019**
	Late	**1.28**	**1.48**	**1.11**	**1.28**	**0.77**	**0.89**	**1.42**	**1.64**	**0.012**	**0.014**
CD at 1 %	**Normal**	**1.84**	**2.13**	**1.33**	**1.53**	**1.43**	**1.65**	**1.19**	**1.37**	**0.022**	**0.025**
	Late	**1.70**	**1.97**	**1.47**	**1.70**	**1.54**	**1.78**	**1.88**	**2.18**	**0.016**	**0.018**

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

Table: 4 Extent of hetrosis (%) for Chlorophyll fluorescence (Fv/Fm) at 50 DAS, 60 DAS, 70 DAS, seedling mortality and seed yield in mustard

Crosses	Environment	Chlorophyll fluores-cence (Fv/Fm)at 50 DAS Heterosis (%) over		Chlorophyll fluores-cence (Fv/Fm)at 60 DAS Heterosis (%) over		Chlorophyll fluores-cence (Fv/Fm)at 70 DAS Heterosis (%) over		Seeding mortality (%) Heterosis (%) over		Seed yield/ plant(g) Heterosis (%) over	
		M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.	M.P.	B.P.
RH8814 x RH0735	**Normal**	0.34**	-0.17	2.04**	1.53**	5.83 **	-4.77	-22.0**	-22.41**	6.29	-10.11
	Late	5.49**	3.35**	1.52**	0.88**	-0.12	-1.09	-9.75**	-20.48**	24.49*	5.57
RH8814 x RH0116	**Normal**	3.44**	3.05**	2.72**	0.92**	2.47**	-3.47	16.15 **	6.19	55.19**	54.99**
	Late	-0.58	-2.41	0.13**	-1.12	-2.23	-2.83	-39.15**	-44.71**	17.25	8.17
RH8814 xBPR349-9	**Normal**	1.43**	0.79**	-5.88	-6.11	10.32**	1.72**	8.97	5.33	-1.56	-7.45
	Late	4.762 **	2.63**	1.36**	-1.36	-9.06	-10.16	-1.54	-8.43*	58.15**	56.35**
RH8814 x RH0952	**Normal**	1.83**	1.06**	-2.86	-4.85	13.29**	6.72**	31.39**	11.00**	8.24	5.01
	Late	-2.44	-3.17	-4.58	-5.06	-6.51	-8.26	32.85**	24.53**	21.32**	14.5
RH8814 x RH0555A	**Normal**	0.95**	-1.25	4.26**	1.13**	8.61**	-1.54	36.52**	25.60**	70.49**	56.90**
	Late	1.89**	0.87**	2.54**	-0.21	-6.47	-7.64	-9.75**	-20.48**	34.20**	10.02
RH8814 x RH0644	**Normal**	-3.09	-8.74	-1.06	-3.08	9.36**	0.25**	-34.26**	-43.61**	5.15	-6.75
	Late	-2.92	-3.16	-4.06	-4.30	-1.86	-2.10	-13.69**	-26.78**	8.37	6.80
RH8814 x BPR543-3	**Normal**	2.95**	-0.12	10.58**	2.13**	9.90**	0.96**	-3.37	-8.51	73.19**	62.31**
	Late	-1.80	-3.14	-1.04	-3.44	-0.25	-1.99	-28.80**	-39.86**	-7.61	-21.04*
RH0735 x RH0116	**Normal**	0.08**	-0.67	-3.72	-5.87	3.96**	-0.99	-14.32*	-21.67**	-1.35	-16.84**
	Late	4.88**	0.89**	-1.00	-1.61	0.82**	0.45**	1.25	-1.52	46.06**	34.76**
RH0735 x BPR349-9	**Normal**	-0.96	-1.21	-11.57	-11.78	-0.94	-3.54	17.70**	13.78*	-16.29**	-25.61**
	Late	6.23**	6.23**	0.734**	-2.56	-8.44	-8.67	23.38**	17.12**	-32.05**	-41.19**
RH0735 x RH0952	**Normal**	5.59**	4.40**	-6.63	-8.09	-3.29	-7.91	2.82	-13.14**	-8.16	-17.02**
	Late	5.14**	2.25**	-10.35	-10.47	-1.72	-4.48	-27.27**	-31.52**	9.23	-1.43
RH0735 x RH0555A	**Normal**	2.97 **	1.09**	3.13**	-0.45	-2.76	-3.57	-6.52	-14.00**	-12.57*	-20.70**
	Late	3.26 **	0.17**	3.83**	0.29**	-3.83	-5.94	-15.58**	-16.14**	-51.18	-53.73**
RH0735 x RH0644	**Normal**	5.57 **	-0.11	-0.32	-1.88	1.05**	-0.99	1.69	-12.78**	-9.31	-14.56*
	Late	1.81**	-0.51	-4.37	-5.34	0.00	-0.73	-21.26**	-25.14**	45.68**	26.43**
RH0735 x BPR543-3	**Normal**	9.15**	6.28**	3.19**	-5.13	0.94**	-1.47	-30.34**	-34.04**	20.75**	-3.51
	Late	5.34**	1.82**	-0.95	-2.64	-3.09	-5.69	-17.86**	-22.30**	-4.39	-4.73
RH0116 x BPR349-9	**Normal**	1.64**	0.62**	0.38**	-1.75	4.76**	2.39**	3.70	-6.67	7.80	1.35
	Late	6.03**	2.00**	1.60**	-2.45	-4.93	-5.51	-3.68	-6.51	13.94	5.56

RH0116 x RH0952	**Normal**	1.49**	0.98**	-6.21	-9.82	3.43**	3.43	16.20**	-7.55	20.94**	11.74
	Late	3.38**	2.37**	-0.71	-1.58	3.75**	1.06	10.31**	6.19	41.26**	36.94**
RH0116 x RH0555A	**Normal**	0.08**	-2.47	-3.16	-4.42	1.77**	-2.31	53.26**	31.80**	30.21**	19.83**
	Late	-2.10	-2.94	0.09**	-3.90	1.71**	-0.16	15.47**	12.11**	-6.39	-17.21**
RH0116 x RH0644	**Normal**	-5.77	-11.47	-5.83	-9.44	4.01**	1.04	-29.67**	-43.27**	-7.91	-9.44
	Late	-1.45	-3.02	-10.72	-12.16	-2.55	-2.91	-36.42**	-40.85**	-5.96	-10.67 *
RH0116 x BPR543-3	**Normal**	-3.49	-6.72	4.11**	-2.25	5.10**	2.34	11.33*	-1.70	-3.13	-5.56
	Late	10.44**	9.76**	-7.43	-8.55	0.71**	-1.64	-35.18**	-40.00**	-1.75	-6.67
BPR349-9 x RH0952	**Normal**	0.42**	-0.96	-3.99	-5.73	2.75**	0.419	-5.95	-18.23**	-28.50 **	-35.00 **
	Late	4.55**	1.54**	-6.71	-9.66	1.84**	-1.38	-8.20*	-9.50*	5.26	2.36
BPR349-9 x RH0555A	**Normal**	-1.60	-3.03	-6.44	-9.47	-0.78	-2.47	27.79**	21.40**	-0.50	-9.17 *
	Late	2.78**	-0.29	4.46**	4.46**	-11.37	-13.53	-43.74**	-46.64**	28.74 **	19.15 **
BPR349-9 x RH0644	**Normal**	-5.79	-10.65	-10.96	-12.56	1.54**	0.91	-38.28**	-45.49**	-14.69 **	-16.11 **
	Late	1.86**	-0.59	3.86**	1.46**	0.69**	-0.28	-8.11**	-16.39**	2.75	-2.96
BPR349-9 x BPR543-3	**Normal**	-2.73	-4.93	9.20**	0.62**	-1.13	-1.38	4.57	2.34	-13.96 **	-16.11 **
	Late	5.47**	1.94**	-3.28	-8.11	-2.08	-4.94	2.39	-7.30*	0.39	-5.19
RH0952 x RH0555A	**Normal**	0.12**	-2.75	-6.11	-10.74	1.22**	-2.71	-16.36**	-23.33**	-14.95 **	-16.51 **
	Late	-0.83	-0.95	3.22**	-0.04	4.33**	3.66	3.15	-4.48	14.94 **	6.38
RH0952 x RH0644	**Normal**	-5.52	-11.69	-3.12	-3.24	-9.38	-11.86	-29.23**	-30.00**	-30.73 **	-36.67 **
	Late	-2.14	-2.75	1.45**	0.67**	0.00	-2.11	-23.96**	-32.38**	-21.57 **	-25.93 **
RH0952 x BPR543-3	**Normal**	3.18**	-0.59	6.68 **	-3.32	1.63**	-0.92	-37.01**	-43.83**	-26.51 **	-33.33 **
	Late	-4.15	-4.63	-12.57	-14.27	1.34**	1.075	-16.34**	-25.95**	-16.08 **	-20.74 **
RH0555A x RH0644	**Normal**	-2.87	-6.58	2.52**	-2.52	-2.33	-3.52	-14.13**	-19.76**	-5.21	-13.33 **
	Late	1.38**	0.62**	-10.36	-12.44	-3.94	-5.37	-6.61*	-11.20**	-3.86	-8.67
RH0555A x BPR543-3	**Normal**	-4.05	-4.85	9.67**	4.27**	-8.74	-10.07	15.10**	10.59*	-10.76 **	-19.05 **
	Late	2.32**	2.06**	-12.12	-16.50	-4.62	-5.11	-36.14**	-39.59**	-5.96	-10.67 *
RH0644 x BPR543-3	**Normal**	-2.89	-5.83	9.02**	-1.32	-0.29	-0.66	12.71**	0.50	-19.09 **	-21.11 **
	Late	1.09**	-0.04	-15.54	-17.80	-2.48	-4.42	2.60	1.22	-10.59	-15.56 **
CD. at 5 %	**Normal**	**0.012**	**0.014**	**0.013**	**0.015**	**0.017**	**0.020**	**1.38**	**1.60**	0.51	0.58
	Late	**0.017**	**0.020**	**0.012**	**0.014**	**0.013**	**0.016**	**1.27**	**1.47**	0.46	0.53
CD at 1 %	**Normal**	**0.017**	**0.019**	**0.017**	**0.020**	**0.023**	**0.027**	**1.84**	**2.12**	0.67	0.77
	Late	**0.023**	**0.027**	**0.016**	**0.019**	**0.018**	**0.021**	**1.69**	**1.96**	0.61	0.69

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

advancing these crosses through pedigree selection in successive segregating generation. These results for chlorophyll fluorescence were also reported earlier by Shanthi *et al* (2011) in rice.

Seedling mortality (%)- Significant and negative heterosis over mid-parent for seedling mortality was manifested by eight crosses namely; RH8814 x RH0735, RH8814 x RH0644, RH0735 x BPR543-3, RH0116 x RH0644, BPR349-9 x RH0644, RH0952 x RH0644, RH0952 x BPR543-3 and RH0555A x RH0644 in both the environments. Negative and significant heterosis over better parent was expressed by the seven cross combinations viz., RH8814 x RH0735, RH0116 x RH0644, BPR349-9 x RH0952, BPR349-9 x RH0644, RH0952 x RH0644, RH0952 x BPR543-3 and RH0555A x RH0644 in both the environments. Similar results for seedling mortality were also reported earlier by Sio-Se *et al* (2006), Sharma *et al* (2011, 2012), Sharma and Sardana (2013).

Seed yield/plant (g)- Maximum significant positive heterosis was exhibited by cross RH8814 x BPR543-3 (73.19%) followed by RH8814 x RH0555A (70.49%) and RH0644 x BPR543-3(67.80%) in timely sown condition where as six crosses exhibited significant and positive mid-parent heterosis r and maximum heterosis was exhibited by cross RH8814 x BPR349-9 (58.15%) followed by the cross RH0116 x RH0644 (57.85%) and RH0735 x RH0116 (46.06%) in late sown condition. Heterosis over mid-parent for seed yield/plant ranged from -16.29 (to 73.19 in timely sown condition and-51.18 to 68.47 in late sown condition. Significant and positive heterosis over better parent was manifested by three crosses namely; RH0116 x BPR543-3, BPR349-9 x RH0644 and RH0555A x RH0644 in both the environments and the cross RH8814 x BPR543-3(62.31%) recorded maximum positive heterosis over better parent followed by RH8814 x RH0555A (56.90%) and RH8814 x RH0116(54.99%) in timely sown condition. The significant and maximum positive heterosis over better parent in late sown condition manifested by the crosses namely; RH8814 x BPR349-9(56.35%) followed by RH0116 x RH0644 (46.67%) and RH0116 x RH0952 (36.94%). Heterobeltiosis for seed yield/plant ranged from -25.61 (RH0735 x BPR349-9) to 62.31 (RH8814 x BPR543-3) in timely sown condition and -53.73 (RH0735 x RH0555A) to 66.02 (BPR349-9 x RH0644) in late sown condition. These high yielding crosses may be exploited for developing superior genotypes and the parents involved may be converted to well adapted cytoplasmic male sterile or restorer lines to develop commercially viable hybrids. Positive significant heterosis for seed yield in late sown condition was also reported earlier by different workers; Kumar et al. (2007), Aher et al. (2009), Nasrin et al. (2011), Vaghela et al. (2011) and Verma et al.(2011).

CONCLUSION

From the present investigations it is concluded that crosses RH8814 x RH0555A, RH0644 x BPR543-3 and BPR349-9 x RH0644 in timely sown condition and crosses RH0555A x RH0644, RH0735 x RH0116 and BPR349-9 x RH0644 in late sown condition were identified as promising on the basis of their high per se performance, average heterosis, heterobeltiosis may used in future breeding programmes for improving the seed yield and related traits in Indian mustard.

REFERENCES

Aher C D, Shelke L T, Chinchane V N, Borgaonkar S B and Gaikwad A R (2009). Heterosis for Yield and Yield Components in Indian Mustard [*Brassica juncea* (L.) Czern and Coss.]. *Int J Plant Sci* **4**: 30–32.

Arifullah M, Munir M, Mahmood A, Ajmal K S and Hassan-ul- F (2013). Genetic analysis of some yield attributes in Indian Mustard (*Brassica juncea* L.) *African J Pl Sc* **7**(6): 219-226

Gami R A and Chauhan R M (2013). Heterosis and Combining Ability Anlaysis for Seed Yield and its attributes in Indian Mustard [*Brassica juncea* (L.) Czern and Coss.] *Indian J Agri Res* **47**(6): 535-539.

Hassan G F, Mohammad I H, Khalil and Raziuddin. (2006). Heterosis and heterobeltiosis studies for morphological traits in bread wheat. *Sarhad J Agri* **22**(1): 51-54.

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

Kumar R, Singh M and Singh V P (2007). *Heterosis and inbreeding depression in relation to seed yield in Indian mustard [Brassica juncea* (L.) Czern and coss]. National seminar on changing global vegetable oils scenario. Issues and challenges before India. pp: 92-93.

Nasrin S, F Nur M K Nasreen M S R Bhuiyan S Sarkar and Islam M M (2011). Heterosis and combining ability analysis in Indian mustard (*B. juncea* L.). *Bangladesh Res Pub J* **6**(1): 65-71.

Pal B P and Sikka S M (1956). Exploitation of hybrid vigour in the improvement of crop plants, fruits and vegetables. *Indian J Gen Plant Breed* **16**(2): 95-193.

Patel A. M, Prajapati D B and Patel, D G (2012). Heterosis and combining ability studies in Indian Mustard (Brassica juncea L.) *Indian. J Sc. Res Tech* **1**(1): 38-40.

Sadanand Prasad, S, Ojha S K, Sohan Ram R K (2009). Combining ability analysis for yield and its contributing characters in Indian mustard. *Environ and Eco* **27**: 4A, 1811-1817.

Shanthi P, Jebaraj S, Geetha S (2011). Study on gene action for sodic tolerance traits in rice (*Oryza sativa* L.). *Elect J Plant Breeding* **2**(1):24-30.

Sharma P and Sardana V (2013). Screening of Indian mustard (Brassica juncea) for thermo tolerance at seedling and terminal stages. *J. Oilseed Brassica* **4**: 61-67.

Sharma P, Sardana V and Banga S S (2011). *Differential tolerance of Indian mustard (Brassica juncea) genotypes to high temperature at seedling and terminal stage.* In: Rang, et al. (eds.) Proc. Int. Conf. Preparing Agriculture for Climate Change held at Ludiana, India: Crop Improv 38: 152-153.

Sharma P, Sardana V and Banga S S (2012). *Thermo tolerance responses of selected Brassica genotypes.* In Proc. 1st National Brassica Conference on Production Barriers & Technological Options in Oilseed Brassica held at CCSHAU, Hisar. pp 32-33.

Singh A, Avtar R, Singh D, Sangwan O, Thakral N K, Malik V S, Goyat B and Dalal U (2013). Combining Ability Analysis for Seed Yield and Component Traits in Indian Mustard [Brassica juncea(L.) Czern and Coss.]. *Res Plant Biol* **3**(2): 26–31.

Sio-Se M A, Ahmadi A, Poustini K and Mohammadi V (2006). Evaluation of drought resistance indices under various environmental conditions. *Field Crops Res* **98**: 222-229.

Vaghela P O, Thakkar D A, Bhadauria H S, Sutariya D A, Parmar S K and Prajapati D V (2011). Heterosis and combining ability for yield and its component traits in Indian mustard [*Brassica juncea* (L.) Czern and Coss]. *J Oilseeds Res* **2**(1): 39-43.

Verma O P, Yadav R, Kumar K, Singh R, Maurya K N and Ranjana (2011). Combining ability and Heterosis for seed yield and its components in Indian mustard (*Brassica juncea*). *Plant Archiv* **11**: 863– 865.

Yadava D K, Singh N, Vasudev S, Singh R, Singh S, Giri S C, Dwivedi V K and Prabhu K.V (2012). Combining ability and heterobeltiosis for yield and yield-contributing traits in Indian mustard (Brassica juncea). *Indian J Agri Sci* **82**: (7):563-567.

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