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

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A B S T R A C T

Half diallel analysis of eight parents was carried out to identify the high heterotic crosses and their relationship in terms of general and specific combining ability (gca & sca) in *Brassica juncea* L. Czern and Coss. 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 days to maturity, plant height, siliquae on main shoot, number of seeds/siliqua, siliqua length and oil content in timely sown condition and for plant height, number of primary branches per plant, siliqua on main shoot and 1000 seed weight in late sown condition. The heritability in narrow-sense showed the prevalence of additive variance for siliqua length, days to maturity, number of primary branches per plant in late sown condition, while for other traits an appreciable proportion of total variance was non-additive in both the environments. In the present study, an overall appraisal of GCA effects revealed that RH0735 and BPR349-9 in normal environment and RH0116 and RH0555A in late sown environment were good general combiner for majority of the characters. High GCA effects are related to additive gene effects or additive x additive interaction which represent the fixable genetic component of variation. Hence these parents could be efficiently used for exploiting seed yield. For seed yield the 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 were identified as promising on the basis of their high *per se* performance and with high significant SCA effects. These crosses could be extensively used in breeding programme to develop superior segregants and the parents involved may be converted to well adapted cytoplasmic male sterile or restorer lines in further breeding programmes.

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. Cytologically Indian mustard is an amphidiploid (2n=36), derived from interspecific cross of *Brassica campestris* (2n=20) and *Brassica* nigra (2n=16) followed by natural chromosome doubling. These relationships have been confirmed by the artificial synthesis of amphidiploids species by hybridizing basic diploid species and also by analysis of chloroplast and mitochondrial DNA restriction pattern of basic and amphidiploids species. The improved mustard seeds contain 39-44% oil. For International acceptance, erucic acid content should be <2%. 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 (FAO, 2013).

For developing a hybrid, as a first step information available on genetic analysis of important characters is collected. This information are then used to combine desirable traits in a single hybrid. For this purpose, genetic information on heterosis is useful for developing breeding strategies to meet the demands of increased population. 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 (Amiri-Oghan *et al.,* 2009).

Estimation of genetic constitution of parents for seed yield and it components can be important for indirect selection for high seed yield in rapeseed (Nassimi *et al.,* 2006; Singh *et al.,* 2010). 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 (Wos *et al.,* 1999). On the other hand, Teklewold *et al.,* (2005) reviewed evidences for the presence of significant sca effects for yield and yield components. Ramsay *et al.,* (1994) reported that variation for both gca and sca were responsible for dry matter yield and other quantitative traits in *B. napus*. Significant gca and sca effects were reported for siliquae per main shoot, siliquae per plant, siliqua length, number of seeds per siliqua, 1000-seed weight and seed yield in *B. napus* (Leon, 1991; Thakur and Sagwal, 1997).

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) at oilseed research area of Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar. The data was recorded on eleven characters, form five competitive plants excluding border plants in each F_{1s} and parents which were randomly selected from each replication. Oil content was estimated by Sokshlet method (AOAC, 1995). All the recommended cultural practices were followed throughout the crop season to raise a good crop. 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 (1956).

Results and Discussion

Estimation of Gene action

Mean squares due to genotypes and F_1s revealed significant differences for all the traits in both the environments (normal and late sown), indicating presence of adequate genetic variation among the experimental material and both gcs and sca were involved in the genetic expression of studied traits. Mean squares due to parent v/s crosses were also significant for all the traits which depicted presence of heterosis for these traits in the series of crosses, except for days to maturity, plant height, siliquae on main shoot, siliqua length, oil content in normal environment and plant height, number of primary branches per plant, siliqua on main shoot, 1000 seed weight in late sown environment. 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.,* (2009), Shanthi *et al.,* (2011) in rice and Vaghela *et al.,* (2011) and Arifullah (2013) in Mustard. The mean squares due to gca and sca were significant for most of the traits suggesting the operation of both additive and non-additive components of gene action in the materials study in both environments, except gca for days to maturity and sca for oil content in timely sown condition. These results exhibited the importance of additive type of variance in the inheritance of most of the traits studied, similar findings were reported by Labana *et al.,* (1978) and Tamber *et al.,* (1991) in Indian mustard. The variance due to sca is higher than the gca for the characters viz., days to maturity, plant height, number of secondary branches per plant, oil content and seed yield per plant indicated that role of non-additive gene action inheritance of these traits. The ratio of variance due to general and specific combining ability was low for all the traits studied in both the environments, which was less than unity for all the traits indicating the predominance of non additive gene action for these traits except siliqua length in timely sown condition. In such cases, a breeding strategy which would enable to utilize maximum proportion of fixable genetic variation (additive and additive×additive epistasis) as well as non additive genetic components (dominance, additive×dominance and dominance×dominance) would be effective. Similar findings were reported by Gupta *et al.,* (2010). Higher magnitude of gca component (g_i^2) than sca component (s_{ij}^2) was observed for siliqua length in timely sown condition, indicating that this trait was mainly under the control of additive genetic variance. The general predictability ratio was near unity for siliqua length and oil content in timely sown condition, indicative that the performance of F_1 crosses for these traits can be predicted on the basis of general combining ability effects alone.These findings were also corroborated by earlier findings by Patel *et al.,* (1993), Rao and Gulati (2001) with different set of material.

Estimation of general combining ability (gca)

In the present study, an overall appraisal of gca effects revealed that RH0735 and

BPR349-9 in normal environment and RH0116, RH8814 and RH0555A in late sown environment emerged as good general combiners for point to seed yield/plant and most of the yield component characters, thus, these genotypes probably possessed the desirable genes for high temperature tolerance during seed filling period. So these parents shall be included in the breeding program for accumulation of favorable alleles in a single genetic background.

High gca effects are related to additive gene effects or additive x additive interaction effects (Sprague, 1942) which represent the fixable genetic component of variation. Spragme (1966) reported that when general combining ability effects are significant, additive or additive×additive gene effects are responsible for the inheritance of that particular trait. Hence these parents could be efficiently used for exploiting seed yield. Similar results were revealed by Patel *et al.*, (2012), Yadava *et al.*, (2012), Singh *et al.*, (2013) and Gami and Chauhan (2013) in *Brassica juncea*. For Brassica, day to maturity and reduced pant height are desirable traits hence; higher the negative values of gca and sca, better are the genotypes for breeding. In our study, maximum negative gca value was exhibited by the genotype, RH0555A in normal environments and RH0644 in late sown environment exhibited negative significant gca effects and these were considered as good general combiners for early maturity.

The parent RH0952 in normal environments, BPR 349-9 in late sown environment had negative gca effects for plant height and thus, considered desirable for dwarfness. Similarly, parents RH8814 in normal and RH0116 in late sown environment for no. of primary branches per plant and RH0735 in normal and RH0116 had significant desirable gca effects in late sown environment for no. of secondary branches per plant. Kumar *et al.*, (1997) and Teklewold and Becker (2005) also reported similar results in Indian mustard with a different set of material. The genotype RH0644 in both the environments for main shoot length and RH0644 in normal environment for siliquae on main shoot with significant desirable gca effects were found to be the good general combiners. The good general combiners for number of seeds per siliqua and siliqua length were BPR349-9 and RH0116 in normal environment and RH0735 in late sown (stress) environment as they were associated with desirable gca effects. Parents, RH0555A desirably complemented for 1000 seed weight in both the environments and parent RH0116 also complemented for point to oil content in late sown environment showing significant desirable gca effects. Sheikh and Singh (1998) and Acharya and Swain (2004) obtained desirable gca effects for siliqua length in glossy mutant and Pusa Bahar in *Brassica juncea*. These results clearly indicated that there is a scope for improving combining ability of parents for attributing traits, as good combiners for seed yield traits, therefore, one should breed to improve the combining ability of yield contributing traits which would ultimately improve the gca of seed yield directly.

Estimation of specific combining ability (sca)

The estimates of SCA are presented in table 4. Crosses, namely, BPR 349-9 x RH0952 in both the environments for early maturity, crosses RH0952 x RH0555A, RH 0735 x BPR 349-9 and RH 8814 x RH 0116 in late sown environment and RH 8814 x RH0555A, RH 0735 x BPR543-3 and RH 0116 x BPR 349-9 in normal environment for dwarfness showed significant negative sca effects. This indicates that the reduction in plant height and days to maturity may be due to negative heterosis in these crosses for these traits, which is desirable.

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

Source	d.f.	Days to maturity	Plant height (cm)	No. of 1^0 branches/ plant	No. of 2^0 branches/ plant	Main shoot length (cm)	Siliquae on main shoot	No. of seeds/ Siliqua	Siliqua length (cm)	Seed yield/ plant (g)	1000 seed weight (g)	Oil content (%)
						Normal environment						
Replications	2	1.512	48.176	0.34778	0.71361	17.428	11.815	1.180	0.076	3.538	0.188	0.154
Genotypes	35	7.564**	258.640**	1.62807**	13.531**	114.421**	31.046**	3.434**	0.494**	28.864**	1.311**	0.202
Parents	7	2.334	255.428**	0.4619	0.74357	58.148**	52.756**	8.860**	0.847**	16.508**	2.096**	0.053
Crosses	27	8.974**	268.906**	1.2845**	16.346**	98.647**	26.293*	2.063	0.421**	27.100**	0.990**	0.247*
Parents v/s crosses	1	5.979	3.8211	19.068**	27.043**	934.214**	7.403	2.493	0.004	162.971**	4.468**	0.054
Error	70	1.557	82.899	0.39073	0.636	19.025	15.761	1.323	0.075	1.714	0.129	0.157
						Late sown environment						
Replications	2	0.398	58.694	0.321	0.472	75.966**	115.629**	1.654	0.067	1.718	0.074	0.0123
Genotypes	35	6.174**	291.51**	0.822**	8.266**	92.300**	60.062**	3.428**	0.750**	29.562**	0.568**	0.534**
Parents	7	4.232*	330.07*	0.582	5.101**	14.015	171.429**	2.685**	1.513**	14.995**	0.136	0.617**
Crosses	27	6.392**	286.53*	0.883**	8.662**	113.391**	31.978*	3.080**	0.491**	31.759**	0.697**	0.514**
Parents v/s crosses	1	13.905**	156.214	0.838	19.702**	70.850**	38.764	18.049**	2.420**	72.198**	0.089	0.489
Error	70	1.579	147.923	0.340	0.371	8.556	11.548	0.824	0.124	2.546	0.104	0.125

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

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

Source	d.f.	Environment	Mean squares										
			Days to maturity	Plant height (cm)	No. of 1^0 branches/ plant	No. of 2^0 branches/ plant	Main shoot length (cm)	Siliquae on main shoot	No. of seeds/ Siliqua	Siliqua length (cm)	Seed yield/ plant (g)	1000 seed weight (g)	Oil content (%)
Gca	7	Normal	1.02	77.11*	0.63**	5.56**	18.49**	14.89*	1.89**	0.53**	7.15**	1.03**	0.10*
		Late	2.10**	109.57*	0.37**	2.24**	24.44**	11.97**	1.35**	0.70**	4.79**	0.43**	0.16*
Sca	28	Normal	2.88**	88.49**	0.52**	4.25**	43.05**	9.21*	0.95**	0.07**	10.23**	0.29**	0.06
		Late	2.04**	94.06*	0.24**	2.88**	32.34**	22.03**	0.96**	0.13**	11.11**	0.12**	0.18**
Error	70	Normal	0.52	27.63	0.13	0.21	6.34	5.25	0.44	0.03	0.57	0.04	0.05
		Late	0.52	49.30	0.11	0.12	2.85	3.84	0.27	0.904	0.84	0.03	0.04

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

Table.3 Components of combining ability, gca/sca ratio, heritability and general predictability ratio in diallel using Method 2, Model I (Griffing, 1956)

Components	**Environment**	**Days to maturity**	**Plant height (cm)**	**No. of 1^0 branches/ plant**	**No. of 2^0 branches/ plant**	**Main shoot length (cm)**	**Siliquae on main shoot**	**No. of seeds/ Siliqua**	**Siliqua length (cm)**	**Seed yield/ plant (g)**	**1000 seed weight (g)**	**Oil content (%)**
$1/7\sum_i g_i^2$	Normal	0.055	4.947	0.050	0.535	1.215	0..964	0.145	0.050	0.657	0.099	0.005
	Late	0.157	6.027	0.025	0.211	2.15	0.812	0.108	0.066	0.394	0.040	0.012
$1/28\sum_i\sum_j s_{ij}^2$	Normal	2.365	60.85	0.390	4.035	36.710	3.957	0.515	0.048	9.667	0.244	0.005
	Late	1.521	44.762	0.136	2.76	29.49	18.18	8.14	0.094	10.26	0.092	0.139
h^2_{ns}	Normal	0.037	0.100	0.161	0.201	0.053	0.173	0.233	0.579	0.113	0.407	0.152
	Late	0.133	0.113	0.170	0.128	0.117	0.068	0.165	0.496	0.066	0.387	0.119
h^2_{bs}	Normal	0.827	0.719	0.790	0.960	0.860	0.528	0.646	0.856	0.950	0.910	0.238
	Late	0.777	0.535	0.623	0.962	0.922	0.837	0.789	0.846	0.928	0.832	0.797
gca/sca	Normal	0.023	0.081	0.128	0.132	0.033	0.243	0.282	1.047	0.068	0.405	0.888
	Late	0.103	0.134	0.188	0.076	0.073	0.044	0.132	0.708	0.038	0.435	0.087
General predictability ratio	Normal	0.042	0.0139	0.204	0.209	0.062	0.327	0.352	0.677	0.119	0.447	0.639
	Late	0.172	0.212	0.0.274	0.133	0.128	0.082	0.209	0.586	0.072	0.465	0.149

Table.4 Estimates of gca effects for differents characters under normal and late sown condition in Indian mustard (Griffing, 1956)

Components	Environment	Days to maturity	Plant height (cm)	No. of 1^0 branches/ plant	No. of 2^0 branches/ plant	Main shoot length (cm)	Siliquae on main shoot	No. of seeds/ Siliqua	Siliqua length (cm)	Seed yield/plant (g)	1000 seed weight (g)	Oil content (%)
RH8814	Normal	0.375	1.100	-0.489**	-0.612**	-1.339	-0.834	-0.131	-0.290**	-0.085	-0.185**	-0.202**
	Late	0.342	0.750	-0.182	-0.346**	0.347	1.666**	-0.393*	-0.286**	0.781**	-0.138*	-0.126**
RH0735	Normal	0.108	-1.730	-0.019	0.402**	-0.204	1.836**	-0.044	0.143**	1.358**	0.065	0.127
	Late	0.208	-0.517	-0.088	0.158	1.533**	-0.094	0.507**	0.144*	-0.018	0.086	0.011
RH0116	Normal	-0.292	1.730	0.038	-0.468**	0.574	0.786	-0.767**	0.163**	0.935**	0.052	0.031
	Late	0.575**	3.517	0.368**	0.811**	-2.167**	0.299	-0.226	0.121*	1.019**	0.066	0.237**
BPR349-9	Normal	0.175	-0.133	0.078	-0.195	-1.129	0.262	0.543**	-0.307**	1.178**	-0.098	0.011
	Late	0.008	-5.883**	-0.178	0.699**	-0.970	-2.19**	0.461**	0.054*	-0.911**	0.146*	-0.069
RH0952	Normal	0.008	-5.767**	0.187	-0.305*	-1.893*	0.034	0.463*	-0.067	-0.595**	-0.005	0.074
	Stress	0.308	-3.583	0.102	-0.142	-0.457	0.319	0.181	-0.096	-0.444	-0.231**	-0.069*
RH0555A	Normal	-0.592**	0.567	-0.243*	0.695**	0.147	-2.26**	-0.291	0.373**	0.582*	0.718**	-0.076
	Late	-0.125	0.083	-0.112	-0.119	-1.603**	0.396	-0.369**	0.514**	0.752**	0.386**	-0.142*
RH0644	Normal	0.342	3.567*	0.241*	1.475**	1.761*	-0.394	0.339	0.027	-0.435	-0.212**	0.057
	Late	-0.692**	2.517	0.155	-0.136	2.260**	0.222	0.134	-0.206**	0.043	-0.124*	0.067
BPR543-3	Normal	-0.125	0.667	0.207	0.592**	1.674*	0.639	-0.111	-0.043	0.095	-0.335**	-0.023
	Late	-0.625**	3.117	-0.065	0.474**	1.057*	-0.611	-0.296	-0.246**	0.339	-0.191**	0.091
S.E. (gi)	Normal	0.212	0.155	0.106	0.136	0.744	0.678	0.196	0.046	0.223	0.061	0.067
	Late	0.215	2.077	0.099	0.104	0.499	0.580	0.155	0.060	0.272	0.055	0.060
S.E. (gi-gj)	Normal	0.321	2.350	0.161	0.206	1.126	1.025	0.297	0.070	0.338	0.093	0.102
	Late	0.324	3.140	0.150	0.157	0.755	0.877	0.234	0.090	0.412	0.083	0.091
C.D. at 5% (gi-gj)	Normal	0.640	4.688	0.321	0.410	2.246	2.044	0.592	0.141	0.674	0.185	0.204
	Late	0.647	6.263	0.300	0.313	1.506	1.749	0.467	0.181	0.821	0.166	0.182
C.D. at 1% (gi-gj)	Normal	0.828	6.065	0.416	0.531	2.209	2.644	0.766	0.182	0.872	0.240	0.264
	Late	0.837	8.101	0.388	0.405	1.948	2.263	0.604	0.234	1.063	0.215	0.235

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

Table.5 Estimates of sca effects for different characters under normal and late sown condition in Indian mustard (Griffing, 1956)

Components	Environment	Days to maturity	Plant height (cm)	No. of 1^0 branches/ plant	No. of 2^0 branches/ plant	Main shoot length (cm)	Siliquae on main shoot	No. of seeds/ Siliqua	Siliqua length (cm)	Seed yield/ plant (g)	1000 seed weight (g)	Oil content (%)
RH 8814 x RH 0735	Normal	-1.881**	-1.181	0.128	0.341	4.66*	2.139	0.097	-0.050	0.289	0.126	-0.154
	Late	2.163**	8.600	0.172	-0.111	6.97**	-2.433	0.212	0.257	2.26**	0.014	0.016
RH 8814 x RH 0116	Normal	-1.148*	0.685	-0.262	1.908**	-1.708	0.725	0.797	0.164	4.089**	-0.261	-0.024
	Late	-0.870	-18.4**	0.95**	1.969**	-2.091	-2.593	1.44**	0.58**	-1.143	-0.47*	-0.277
RH8814xBPR 349-9	Normal	3.358**	-2.115	-0.102	-0.766	0.995	-2.085	1.254*	0.100	-2.798**	0.189	0.296
	Late	-1.304	3.967	-0.271	0.113	5.51*	5.04**	0.925	-0.153	3.987**	-0.146	-0.437
RH 8814 x RH0952	Normal	-1.448*	5.185	-0.179	-1.832**	1.325	-0.121	0.001	0.227	-1.118	0.229	0.100
	Late	0.396	10.667	0.182	-2.077**	2.632	-3.73*	-1.26**	-0.236	0.420	0.364	0.129
RH8814 xRH0555A	Normal	-1.181	-12.15*	-0.082	-0.066	9.38**	6.44**	0.821	-0.113	6.042**	-0.161	-0.017
	Late	-0.504	-0.333	0.429	2.699**	6.88**	2.043	0.455	0.121	3.524**	-3.086	-0.331
RH 8814 x RH0644	Normal	3.885**	21.52**	-1.03**	-1.27**	-4.56*	-3.191	-0.409	-0.233	-2.738**	0.44*	-0.117
	Late	2.396**	5.900	-0.371	-0.82*	-9.22**	-0.317	-0.248	0.51**	-1.96*	0.324	-.47*
RH8814x BPR543-3	Normal	0.685	12.75**	-0.332	-0.686	3.292	0.072	1.241	-0.26*	3.959**	0.226	-0.704*
	Late	-3.004**	0.967	-0.285	-0.627	-7.214**	0.883	-0.085	-0.119	-2.130	0.056	0.40*
RH 0735 x RH 0116	Normal	-1.548*	9.85*	0.368	1.00*	2.615	0.152	-0.523	0.130	0.039	0.189	-0.087
	Late	0.596	3.167	0.75*	2.23**	-5.24**	-3.75*	1.18*	0.351	4.160**	-0.46*	0.419
RH0735xBPR 349-9	Normal	-0.681	-1.948	-0.206	0.99*	8.12**	2.009	-0.766	0.034	-1.98**	0.306	-0.167
	Late	0.163	18.77**	-0.165	-0.257	-0.741	-0.883	0.759	0.117	-4.543**	-0.236	-0.041
RH 0735 x RH0952	Normal	3.152**	-1.315	-0.549	-2.142**	-4.55*	0.872	-0.753	-0.140	-0.335	-0.288	0.136
	Late	1.530*	3.600	-0.311	-0.75*	-1.021	0.653	0.072	-0.199	0.557	0.007	-0.71**
RH0735x RH0555A	Normal	0.752	-2.315	-0.69*	-3.276**	-2.625	-0.435	0.234	0.087	-2.808**	-0.011	-0.047
	Late	-1.704*	3.933	-0.231	-1.104**	-6.41**	-6.28**	-1.48**	-0.48*	-7.206**	0.39*	0.033
RH 0735 x RH0644	Normal	0.152	10.35*	-0.269	0.188	11.56**	4.70*	0.137	0.100	-1.82**	0.312*	0.186
	Late	-0.137	1.167	-0.298	-1.421**	5.49**	-1.870	-0.048	0.48*	3.970**	0.267	-0.48*
RH 0735xBPR543-3	Normal	-0.048	-10.75*	-0.569	-0.029	5.315*	1.232	0.587	0.004	1.542*	-0.32*	0.100
	Late	-0.537	-3.433	0.055	-1.031	1.632	-1.670	-0.118	0.22	-0.593	-0.233	-0.201
RH0116xBPR 349-9	Normal	1.719*	-12.42*	-0.496	-2.409**	-4.151*	-2.138	0.124	0.417	-0.648	-0.181	0.063
	Late	0.463	-3.800	0.045	-0.011	-5.47**	-3.74*	-0.075	-0.093	-1.164	0.45*	0.67**
RH 0116 x RH0952	Normal	0.219	-7.448	-0.572	-1.00*	-0.688	-3.308	-0.829	0.70**	1.53*	-0.54**	-0.100
	Late	-0.170	-5.433	-0.235	0.266	1.579	-5.84*	1.21*	-0.043	2.15*	-0.073	-0.067
RH0116x RH0555A	Normal	0.152	-9.781	0.191	-0.542	3.239	-0.715	1.16*	-0.166	1.16*	0.302	0.050
	Late	0.930	0.900	-0.488	-1.691**	0.492	-3.67*	0.522	0.081	-2.54**	-0.023	0.106

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

Components	Environment	Days to maturity	Plant height (cm)	No. of 1^0 branches/ plant	No. of 2^0 branches/ plant	Main shoot length (cm)	Siliquae on main shoot	No. of seeds/ Siliqua	Siliqua length (cm)	Seed yield/ plant (g)	1000 seed Weight (g)	Oil content (%)
RH 0116 x RH0644	Normal	0.552	0.219	-0.092	-1.979**	-4.47*	0.489	0.16	0.080	-1.42*	-0.068	0.116
	Late	-1.504*	-6.200	-0.055	1.093**	1.629	0.937	-1.12*	-0.233	2.83**	-0.087	0.129
RH 0116 x BPR543-3	Normal	-0.315	10.12*	-1.09**	-1.896**	9.75**	1.719	0.31	-0.28*	-0.291	0.289	-0.237
	Late	-0.570	3.533	-0.035	-0.417	0.599	0.203	0.08	0.207	3.50**	0.354	0.57**
BPR 349-9 x RH0952	Normal	-1.581*	5.085	-1.08**	-2.416**	6.32**	-0.218	-0.41	0.044	-2.39**	-0.791**	-0.047
	Late	-2.604**	7.967	-0.255	0.78*	-5.05**	-2.677	1.72**	0.82**	0.450	-0.020	0.073
BPR 349-9 x RH 0555A	Normal	0.019	-3.915	-1.25**	-1.33**	-9.591**	-6.76**	-1.95**	0.104	1.47*	0.32*	-0.097
	Late	-1.504*	0.700	-0.77*	-1.247**	-3.44*	-0.640	-0.96*	0.114	-2.78**	0.63**	0179
BPR 349-9 x RH0644	Normal	0.248	-3.915	0.534	1.714**	2.895	0.679	-0.22	-0.116	5.192**	-0.32*	-0.164
	Late	1.063	15.53*	0.592	-1.297**	5.99**	3.067	-0.47	-0.43*	4.264**	-0.093	0.103
BPR 349-9 x BPR543-3	Normal	0.885	8.319	1.00**	1.03*	-1.018	3.342	1.53*	0.187	3.555**	-0.149	0.150
	Late	0.996	7.933	0.51*	2.659**	5.40**	8.60**	-0.71	-0.126	3.07**	-0.126	0.221
RH0952 x RH0555A	Normal	1.519*	-2.281	-0.092	0.584	-2.261	1.872	0.26	0.130	3.052**	0.308	-0.327
	Late	0.863	-20.67**	-0.188	0.429	1.249	-0.037	0.25	0.164	2.65**	-0.41*	0.346
RH0952 x RH0644	Normal	-0.415	-8.615	0.091	1.948**	-4.44*	-5.03*	0.33	-0.123	1.44*	-1.0**	0.206
	Late	-0.904	-4.100	-0.021	-0.521	11.15**	3.237	-0.25	0.051	-2.97**	-0.75**	0.069
RH0952 x BPR543-3	Normal	1.385*	2.619	0.558	3.898**	5.945*	1.505	-0.75	-0.52**	-0.965	-0.65**	0.59**
	Late	-1.304	3.300	0.099	-0.83*	-6.211**	-3.93*	0.142	0.157	-0.166	-0.45*	-0.187
RH0555A x RH0644	Normal	-0.148	-4.615	0.154	2.748**	6.12**	1.102	-0.949	-0.030	0.232	-0.010	-0.110
	Late	-0.137	3.233	1.06**	3.756**	-6.23**	4.41*	2.462**	-0.126	4.734**	-0.133	-0.157
RH0555A x BPR543-3	Normal	-0.681	7.619	-0.446	-3.436**	3.27	-0.57	0.134	0.074	-1.105	-0.38*	0.103
	Late	0.130	13.97*	-0.255	1.013**	9.60**	3.98*	0.159	-0.253	0.007	-0.166	0.053
RH0644 x BPR543-3	Normal	-3.615**	-12.38*	0.071	1.294**	-0.71	-0.56	-0.163	-0.31*	5.215**	-0.38*	-0.030
	Late	-0.304	-3.467	0.71*	2.596**	3.64*	2.04	1.35**	0.50**	-3.886**	-0.32*	-0.72**
S.E. (S_{ii})	Normal	0.566	4.146	0.284	0.363	1.986	1.81	0.523	0.124	0.596	0.164	0.180
	Late	0.572	5.438	0.265	0.277	1.332	1.547	0.413	0.160	0.726	0.147	0.161
S.E. (S_{ij})	Normal	0.651	4.766	0.327	0.417	2.283	2.078	0.602	0.143	0.685	0.188	0.207
	Late	0.657	6.367	0.305	0.318	1.531	1.779	0.476	0.184	0.835	0.169	0.185
S.E. (S_{ii}-S_{ij})	Normal	0.786	5.758	0.395	0.504	2.758	2.510	0.727	0.173	0.828	0.227	0.250
	Late	0.794	7.692	0.369	0.385	1.849	2.149	0.574	0.222	1.009	0.204	0.223
S.E. (S_{ij}-S_{ik})	Normal	0.963	7.052	0.484	0.618	3.378	3.075	0.891	0.212	1.014	0.279	0.307
	Late	0.973	9.420	0.451	0.471	2.265	2.632	0.703	0.272	1.236	0.250	0.273
S.E. (S_{ij}-S_{kl})	Normal	0.908	6.649	0.457	0.582	3.185	2.899	0.840	0.200	0.956	0.263	0.289
	Late	0.917	8.882	0.426	0.444	2.136	2.481	0.663	0.257	1.165	0.236	0.258
C.D. at 5 %(S_{ij}-S_{ik})	Normal	1.921	14.065	0.965	1.232	6.738	6.133	1.777	0.423	2.022	0.556	0.612
	Late	1.941	18.789	0.901	0.941	4.518	5.249	1.402	0.543	2.465	0.499	0.546
C.D. at 1 %	Normal	2.485	18.195	1.249	1.594	8.710	7.934	2.298	0.547	2.616	0.720	0.792
	Late	2.511	24.305	1.166	1.217	5.845	6.791	1.814	0.701	3.189	0.646	0.707

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

The results are in accordance with, Nasrin *et al.,* (2011), Gupta *et al.,* (2011), Vaghela *et al.,* (2011) identified superior cross combinations on the basis of gca and sca effects for days to maturity and plant height in mustard.

Cross combination, *i.e.,* BPR 349-9 x BPR543-3, RH 8814 x RH 0116, RH 0735 x RH 0116, BPR 349-9 x BPR543-3, RH0555A x RH0644 and RH0644 x BPR543-3 for no. of secondary branches per plant, RH 8814 x RH 0735, RH 8814 x RH0555A and RH 0735 x RH0644 for main shoot length showed significant positive sca effects in both the environments. Crosses, RH 0735 x RH0644 in normal environment and BPR 349-9 x BPR543-3, RH 8814 x BPR 349-9 in late sown environment for siliquae on main shoot, BPR349-9xBPR543-3, RH 0116 x RH0952 in normal environment and RH 8814 x RH 0116, BPR 349-9 x RH0952 in late sown environment for number of seeds per siliqua and siliqua length were expressed significant highest positive sca effects. Our findings are in agreement with the earlier results in mustard reported by Singh and Murty (1980), Sheikh and Singh (1998) and Chowdhury *et al.,* (2004a).The magnitude of sca effects for seed yield/plant revealed in crosses viz., RH 8814 x RH0555A, RH 0116 x RH0952, BPR 349-9 x RH0644, BPR 349-9 x BPR543-3 and RH0952 x RH0555A in both the environments, seven crosses in normal and late sown environment showed significant positive sca effects. Teklewold *et al.,* (2005), Nassimi *et al.,* (2006) and Wang *et al.,* (1997) observed significant positive sca effect for seed yield. Significant positive sca effects in both the environments were expressed by only one cross combinations, namely, BPR 349-9 x RH0555A for 1000 seed weight, RH0952 x BPR543-3 in normal and RH 8814 x BPR543-3, RH 0116 x BPR 349-9 and RH 0116 x BPR543-3 in late sown environments oil content. The outcomes clearly indicate that the parents involved in these crosses were good specific combiners; however, the relative contribution of the parents to specific combining ability effect for seed yield was through various yield attributing traits in different hybrids (Tables 1–5). Singh *et al.,* (2000) in YSC-68 x SS-2 in *Brassica campestris*, Chowdhury *et al.,* (2004a) in Dhali x Sampad in *Brassica rapa*, Acharya and Swain (2004) in Pusa Bold x Pusa Bahar in *Brassica juncea* observed significant positive sca effects for 1000 seed weight. Sheikh and Singh (1998) obtained significant positive sca effects for oil content in Glossy mutant x BJ-1257 and poorbijaya x BJ-38 respectively in *Brassica juncea*. These crosses and parent could be extensively used in breeding programme to develop superior segregants could be derived in further breeding programmes.

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