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Rashmi
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Neha Dahiya
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Mahak Tufchi
Government College for Women, Parade, Jammu, Jammu & Kashmir, India

Preeti Lohani
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Ram Bhajan
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Usha Pant
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Correspondence
Rashmi
Department of Genetics and Plant Breeding, College of Agriculture, G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India

Studies on heterosis and combining ability for yield and its contributing traits in CMS based hybrids of *Brassica juncea* L.

Rashmi, Neha Dahiya, Mahak Tufchi, Preeti Lohani, Ram Bhajan and Usha Pant

Abstract
Heterosis and combining ability for yield and its contributing traits from trail with 10 CMS lines, 3 testers and 30 alloplasmic hybrids were evaluated for 13 characters. Results indicated that ANOVA for line × tester revealed that treatment variances were highly significant for all the characters. Partitioning of total variance into variance due to parents, crosses and parent *vs* crosses revealed that there were significant parental differences for all characters except number of primary branches. All characters showed significant differences for parent *vs* crosses variance except days to 50% flowering, days to maturity, number of primary branches and siliqua length which exhibited that there is manifestation of heterosis due to interaction of lines and testers. However, all characters showed significant differences for crosses. Based on desirable GCA effects for seed yield per plant PYR-2009-13 along with PBR-357 and Maya were found to be promising lines while only IC-414317 showed promising among testers. PBR-357, PR-20 and Rohini were identified as promising donor for oil content among lines and IC-414322 in testers. Of these PBR-357, was found to have high GCA for seed yield per plant as well as oil content in converged with key component traits. 20% crosses had significant SCA effects for seed yield per plant while 36% crosses for oil content. Maya × IC-414317, Rohini × IC-414317 and EJ-22 × IC-414322 had manifested significant SCA effects for both of these end products in desirable direction. Frequency of superior crosses for mid-parent as well as better parent heterosis was very few in number for developmental traits except for plant height. Maya × IC-414317 manifested the highest heterosis followed by Maya × IC-414322 and PBR-357 × PR-2006-14 for seed yield per plant however, number of crosses displaying desirable heterosis for oil content was very limited.

Keywords: Heterosis, *Brassica juncea* L.

Introduction

Brassicas are the important source of vegetable oil in Indian subcontinent by contributing 28% to the total oilseeds production as well as 15% to the world's contribution. In India, these crops were grown on approximately 5.79 mha area and produced 6.31 mtonnes of oilseeds with 1.08 t/ha productivity which hovers below the world's average. Enhancement in seed yield to provide oil security needs steps in direction of hybrids by utilizing heterosis breeding which is regarded as most popular phenomenon of crop breeding in 20th century to increase the productivity of the crops like sorghum, maize, pearl millet as well as in self-fertilized crops. The basic material required for development of hybrids is production of large number and perfectized experimental hybrids to be evaluated in multi-location trials but since, Indian mustard (*Brassica juncea* L.) is self-fertilized crop, there is economical constraint in the form of hand emasculation and pollination. CMS based hybrids can be used to overcome this barrier and hence, therefore, number of CMS systems have been developed for exploitation of heterosis out of *Ogu*, *Mori* and 126-1 has been utilized to developed hybrids in India so far. Assessment of hybrid vigour on the basis of magnitude and direction provides basis of genetic diversity and a guide for choice of desirable parents for developing superior F_1 hybrids in addition to combining ability which offers an opportunity to identify superior parents.

Material and Method

The experimental material for the present study includes 10 diverse CMS *Ogu* conversion lines viz. PRL-2008-5 A, PBR-357 A, Maya A, PR-20 A, Rohini A, Sej-2 A, Vaibhav A, EJ-22 A, PYR-2009-5 A and PYR-2009-13 A used as females and 3 restorers as testers viz.

IC-414317 R, IC-414322 R and PR-2006-14 R to generate 30 alloplasmic hybrids All crosses were made carefully by hand emasculation and pollination to avoid any mixing. The crosses and their parents evaluated in compact family block design with three replication in rabi 2016-17 for 13 traits including days to 50% flowering, days to maturity, plant height, length of main raceme, siliqua on main raceme, siliqua density, number of primary branches, number of secondary branches, siliqua length, number of seeds per siliqua, seed yield per plant, 1000 seed weight and oil content. Each plot comprised of 1 row of 3 meter long. The row to row distance was 30 cm and plant to plant distance of 10 cm was maintained by thinning after 20-25 days of sowing. Single row of Indian mustard strain Divya was grown on either side of block as guard rows. The recommended agronomic practices were followed from sowing to final harvest of the produce. Observation on oil content was determined by NIR. The Line X Tester analysis in which several testers are used [1] which was later modified by Arunachalam [2] and provides information about general and specific combining ability of parents and at the same time it is helpful in estimating various types of gene effects used here.

Results and Discussion

Analysis of variance for line × tester revealed that treatment variances were highly significant for all the characters. Partitioning of total variance into variance due to parents, crosses and parent *vs* crosses revealed that there were significant parental differences for all characters except number of primary branches. All characters showed significant differences for parent *vs* crosses variance except days to 50% flowering, days to maturity, number of primary branches and siliqua length which exhibited that there is manifestation of heterosis due to interaction of lines and testers. However, all characters showed significant differences for crosses (Table 1.1).

On the basis of estimate of GCA effect, each parent was ranked good (=G), average (=A) and poor (=P) general combiner. Results showed that none of the line/tester was good general combiner for all traits; instead the parents differed considerably in building up their GCA effect for different characters. PRL-2008-5 and PBR-357 was found good general combiner for 5 traits each; Rohini, Sej-2 and PYR-2009-5 for four each; Maya, PR-20, Vaibhav and EJ-22 for three and PYR-2009-13 for two traits while IC-414317 among testers was good general combiner for seven traits and PYR-2006-14 for two traits.

The high GCA for PBR-357 was associated with high GCA for Days to 505 flowering, days to maturity and 1000 seed weight. High GCA in case of Maya was associated with length of main raceme and 1000 seed weight. Among testers, IC-414317 showed high GCA for seed yield per plant was found to be associated with length of main raceme, siliqua on main raceme, number of primary branches, siliqua length and 1000 seed weight. These findings showed similarity with results reported earlier [3, 4, 5, 6] on accounts that high GCA status for seed yield in different lines differed considerably in constellation of component traits with high GCA. For oil content, PBR-357, PR-20 and Rohini emerged as promising lines as donor, IC-414322 among testers fulfilled the criteria. Results also led to identify PBR-357 as most outstanding good general combiner as this exhibited good GCA for 5 traits along with seed yield per plant and oil content. Similarly, among testers IC-414317 was found to be as good general combiner for 7 traits (Table 1.2).

The improvement programme involves genetic recombination needs selection of superior cross combinations and their subsequent advancement using appropriate breeding methodology, thus SCA analysis becomes an important step. A cursory view on character-wise presentation of SCA effects (Table 1.3) revealed considerable differences for manifestation of significant SCA effects for different characters in 30 crosses studied for instance number of crosses showing significant SCA effect in desired direction for days to 50% flowering was 11. Similarly, 9 out of 30 crosses showed significant SCA for days to maturity; 12 for plant height; 9 for length of main raceme; 7 for siliqua on main raceme; 1 each for siliqua density, siliqua length and number of seeds per siliqua i.e. siliqua traits; 4 for number of secondary branches; 6 for seed yield per plant; 14 for 1000 seed weight and 11 for oil content. None of the crosses showed significant SCA effects for number of primary branches. Further, it was revealed from the present study that there is no consistency in GCA status of parent involved in the crosses having significant SCA effects. The superior crosses identified for seed yield per plant as well as for oil content are having H×L, L×H and L×L GCA parents involved. Thus, it could be inferred at this stage that high estimates of GCA effects did not necessarily results in manifesting high estimates of SCA effects in such crosses. These results also indicated the operation of additive × dominance and/or dominance × dominance gene interaction for expressing of yield and oil content in these crosses. The superior crosses which involved both parents with poor GCA status is not amenable to exploitation using conventional breeding procedures like pedigree method. In such situation, heterosis breeding appears to be the most appropriate choice. Similar results have been reported earlier by Singh *et al.* (2009) [8], Srivastav *et al*. (2009) [8] and Singh *et al*. (2017) [9].

In pursuance of heterosis exploitation knowledge of SCA effects assumes greater significance. The desirable SCA effects may not be of practical utility until and unless per se performance of the combinations are compared to that of respective mid parent (MP) and better parent (BP). With the objective to compare the heterosis expressed in crosses, estimates of MP and heterobeltiosis (BP) were analyzed for seed yield and its contributing traits in different cross combinations generated by using 10 lines and 3 testers in alloplasmic background (Table 1.4). The estimates of heterosis were high for development traits like plant height and days to maturity but not for days to 50% flowering. Generally, heterosis is low in such cases (Singh 1973) [10]. Such variations may be effect of CMS cytoplasm (Rashmi *et al*. 2017) [11]. The magnitude for BP heterosis seems to be limited for length of main raceme, siliqua on main raceme, siliqua density and siliqua length while higher in case of MP heterosis. Similar trends were observed for seed yield per plant, 1000 seed weight and oil content.

Table 1.1: ANOVA for Line × Tester Analysis for different characters in alloplasmic set of crosses in Indian mustard

Mean Squares Source of Variations	Replication	Treatment	Parents	Parents vs. Crosses	Crosses	Line	Tester	L×T	Error
Df	2	42	12	1	29	9	2	18	84
Days to 50% flowering	37.266	56.993**	51.855	1.891**	61.020	59.607	23.036	65.947**	2.660
Days to maturity	43.890	45.115**	37.696**	3.9375	49.605**	40.628	12.871	58.175**	2.987
Plant height (cm)	6.105	451.825**	257.396**	529.625**	529.602**	652.408	422.529	480.096**	3.900
Length of main raceme (cm)	3.888	177.482**	113.936**	409.586**	195.773**	122.562	174.974	234.689**	4.011
Siliquae on main raceme	1.756	21.889**	11.783**	16.539**	26.255**	22.808	15.892	29.129**	1.963
Siliqua density	0.000	0.002**	0.002**	0.003*	0.002**	0.004	0.000	0.002**	0.001
Number of primary branches	1.330	0.608*	0.234	0.283	0.774**	0.849	2.042*	0.596*	0.333
Number of secondary branches	4.487	19.613**	18.421**	127.279**	16.394**	9.927	56.458*	15.176**	2.202
Siliqua length (cm)	0.551	0.449**	0.795**	0.339	0.309*	0.339	0.366	0.288*	0.163
Number of seeds per siliqua	7.981	4.959**	4.798**	22.278**	4.428**	4.048	1.165	4.981**	1.471
Seed yield per plant (g)	2.923	16.680**	2.828**	246.937**	14.472**	26.337**	41.805**	5.502**	0.777
1000 seed weight (g)	0.020	1.360**	3.209**	1.617**	0.586**	0.331	2.118*	0.543**	0.001
Oil content (%)	0.107	1.282**	2.663**	0.191**	0.748**	1.477**	0.786	0.379**	0.910

Table 1.2: Promising parents identified on basis of their GCA effects for different characters in Indian mustard

S. No.	Characters	BEST COMBINERS	
		Lines/Testers	Numbers
1	Days to 50% Flowering	PRL-2008-5, PBR-357, Sej-2	3
2	Days to Maturity	PRL-2008-5, PBR-357	2
3	Height (cm)	PR-20, Sej-2, Vaibhav	3
4	Length of Main Raceme (cm)	PRL-2008-5, Maya, Rohini	3
5	Siliquae on main raceme	PRL-2008-5, Rohini, Vaibhav, PYR-2009-5	4
6	Siliqua density	PRL-2008-5, Vaibhav, PYR-2009-5	3
7	Number of primary branches	PYR-2009-5, IC-414317	2
8	Number of secondary branches	IC-414317	1
9	Siliqua Length (cm)	PYR-2009-5, IC-414317	2
10	No. of seeds/siliqua	Sej-2, EJ-22	2
11	Seed yield per plant (g)	PBR-357, Maya, IC-414317	3
12	1000 seed weight (g)	PBR-357, Maya, PR-20, IC-414317	4
13	Oil Content (%)	PBR-357, PR-20, Rohini, IC-414322	4

Table 1.3: Promosing specific crosses for 13 characters in Indian mustard

S. No.	Characters	Crosses	No.
1	Days to 50% Flowering	PRL-2008-5×IC-414317, PRL-2008-5×PR-2006-14, PBR-357×IC-414322, Maya×PR-2006-14, PR-20×IC-414322, RohiniI×PR-2006-14, Sej-2×IC-414322, Sej-2×PR-2006-14, Vaibhav×IC-414317, PYR-2009-5×PR-2006-14, PYR-2009-13×IC-414322	11
2	Days to Maturity	PRL-2008-5×IC-414317, PRL-2008-5×PR-2006-14, PBR-357×IC-414322, PR-20×IC-414322, RohiniI×PR-2006-14, Sej-2×PR-2006-14, Vaibhav×IC-414317, PYR-2009-5×PR-2006-14, PYR-2009-13×IC-414322	9
3	Height (cm)	PRL-2008-5×IC-414322, PBR-357×IC-414317, PBR-357×PR-2006-14, Maya×IC-414322, PR-20×IC-414322, Rohini×IC-414322, Sej-2×IC-414317, Sej-2×PR-2006-14, Vaibhav×IC-414322, EJ-22×IC-414317, PYR-2009-5×IC-414322, PYR-2009-13×PR-2006-14	12
4	Length of Main Raceme (cm)	PBR-357×IC-414322, PBR-357×PR-2006-14, Maya×IC-414317, Maya×PR-2006-14, RohiniI×IC-414317, Sej-2×IC-414322, Vaibhav×IC-414317, EJ-22×IC-414322, PYR-2009-13×IC-414322	9
5	Siliquae on main raceme	Maya×PR-2006-14, RohiniI×IC-414317, Sej-2×IC-414322, Vaibhav×IC-414317, EJ-22×IC-414322, PYR-2009-5×PR-2006-14, PYR-2009-13×IC-414322	7
6	Siliqua density	PBR-357×IC-414317	1
7	Number of primary branches	-------	0
8	Number of secondary branches	PBR-357×PR-2006-14, Maya×IC-414322, Rohini×IC-414317, PYR-2009-5×IC-414317,	4
9	Siliqua Length (cm)	Vaibhav×PR-2006-14	1
10	No. of seeds/siliqua	EJ-22×PR-2006-14	1
11	Seed yield per plant (g)	PBR-357×IC-414322, Maya×IC-414317, PR-20×PR-2006-14, Rohini×IC-414317, EJ-22×IC-414322, PYR-2009-5×IC-414317	6
12	1000 seed weight (g)	PRL-2008-5×IC-414317, PRL-2008-5×PR-2006-14, PBR-357×IC-414322, Maya×IC-414322, PR-20×IC-414317, PR-20×PR-2006-14, RohiniI×IC-414322, Sej-2×IC-414322, Sej-2×PR-2006-14, Vaibhav×IC-414317, Vaibhav×IC-414322, EJ-22×PR-2006-14, PYR-2009-5×IC-414317, PYR-2009-13×PR-2006-14	14
13	Oil Content (%)	PRL-2008-5×IC-414322, Maya×IC-414317, PR-20×IC-414317, Rohini×IC-414317, Sej-2×IC-414322, Sej-2×PR-2006-14, Vaibhav×IC-414322, EJ-22×IC-414322, EJ-22×PR-2006-14, PYR-2009-5×IC-414322, PYR-2009-13×IC-414317,	11

Table 1.4: Percentage of estimates of MP and BP heterosis for F_1 CMS crosses of Indian mustard

S. No.	Characters	Percentage of crosses with significant heterosis over MP	Percentage of crosses with desirable heterosis over BP
1	Days to 50 % flowering	10	0
2	Days to Maturity	73.33	0
3	Plant height (cm)	70	33.33
4	Length of main raceme (cm)	76.67	26.67
5	Siliquae on main raceme	90	3.33
6	Siliqua density	100	6.67
7	Number of primary branches	100	26.67
8	Number of secondary branches	86.67	60
9	Siliqua length (cm)	100	16.67
10	Number of seeds per siliqua	83.33	56.67
11	Seed yield per plant (g)	90	50
12	1000-seed weight (g)	100	40
13	Oil Content (%)	96.67	16.67

Conclusion

Overall results on heterosis for seed yield and oil content vis-à-vis *per se* performance and SCA effects of crosses have been identified in (Table 1.5). Besides, this table also presents significant SCA effects of the related traits and suggested breeding methodology for genetic improvement. Based on arguments two potential crosses each for both sets for seed yield per plant as well as oil content were identified. It was found that Maya × IC-414317 for seed per plant and PBR-357 × PR-2006-14 for oil content were two promising combinations among 30 crosses studied. The GCA status of parents involved in this cross for seed yield per plant in both sets was high but other promising crosses for this attribute combined parents with differing in their GCA status. Thus, it was obvious that high GCA status of both the parents involved in highly heterotic cross combinations will not be necessary instead it can also be results from H × L GCA status. The high expression of the traits due to H × L GCA status combination is possible due to complementation of additive genetic effects of good general combiner and epistatic effect of poor combiner. For oil content, though both the crosses displayed significant heterosis over mid parent as well as better parent albeit of low magnitude, the SCA effect of the crosses was non-significant indicating thereby the poor specific combining ability of these combinations.

Table 1.5: Promising cross combinations based on heterosis, vis-à-vis *per se* performance and combining ability for seed yield and oil content in Indian mustard

Cross Combinations	Mean	SCA effect	Heterosis (%)		GCA status of parents	Suggested breeding methods
			MP	BP		
Seed yield (g/plant)						
Maya × IC-414317	12.25	1.36**	169.23**	112.43**	H × H	Heterosis breeding, conventional breeding methods with selection pressure on OC & LMR
PBR-357 × IC-414322	11.08	1.25**	92.98**	41.73**	H × A	Heterosis breeding/mass selection with concurrent mating
Oil content (%)						
PBR-357 × PR-2006-14	40.40	0.04	2.21**	2.17**	H × H	Heterosis breeding, conventional breeding methods with selection pressure on DF, DM, LMR & NSB
PBR-357 × IC-414322	40.42	0.04	1.30**	0.32**	H × H	Heterosis breeding, conventional breeding methods with selection pressure on PH, LMR, SY & TW

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