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Heterosis and combining ability for different traits in local germplasm and varietal crosses in *Brassica juncea* L

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Abstract
Ten parents comprising six selected local germplasm lines (PWR 15-8, PRHC 17-1, FS-14-24, PWR 15-8-1, PRHC 12-14, PRHC 13-14) and four released varieties (RGN-73, Maya, Kranti, PM 25) were crossed in diallel fashion (excluding reciprocals). Ten parents and thier 45 F_1's were evaluated in randomized block design during *rabi* 2014-15 for 15 traits including seed yield per plant (g) and oil content (%) alongwith two quality traits viz. protein content (%), glucosinolate content (µmole/g). Results indicated that predominance of additive gene action for expression for all traits barring oil and glucosinolate content. Combining ability studies revealed that PRHC 17-1, RGN73, Maya, Kranti, PRHC 13-14 were good combiners for seed yield per plant but none hadgood GCA for oil content. Out of 45 crosses, 13 crosses viz. PWR 15-8×PRHC 12-14, PWR 15-8×Kranti, PRHC 17-1×FS-14-24, PRHC 17-1×PWR 15-8-1, PRHC 17-1×RGN73, PRHC 17-1×PRHC 13-14, FS-14-24×Maya, PWR 15-8-1×RGN73, PWR 15-8-1×PM 25, RGN73×Maya, RGN73×Kranti, Maya×PRHC 12-14, PRHC 12-14×PRHC 13-14 were good specific combinations for high yield/plant. In all 20 crosses over better parent (BP) and 12 over standard variety (SV) manifested significant desirable heterosis. Of these nine crosses displayed heterosis over both BP as well as SV. The magnitude of desired heterosis over BP was quite high in different crosses (8.37 to 131.55%).

Keywords: Heterosis, *Brassica juncea* L

Introduction
The oleiferous *Brassica* species, generally referred to as rapeseed-mustard, are one of the economically important agricultural commodities. India's combined volume of exports of rapeseed-mustard seed oil is almost 10.07% of the total vegetable oilseeds. World output of rapeseed-mustard crops rose from about 36 million tonnes in 2001-02 to 67.9 million tons in 2015-16 (www.fas.usda.gov.in). However, the demand for rapeseed-mustard oils continues to escalate steeply due to increasing consumption and diversion of bioenergy use. Although, mustard (*Brassica juncea* L.) is mainly self-pollinating, although an average of 7.5 to 30 per cent out-crossing does occur under natural field conditions [1, 2] but reports on the availability of heterosis in this crop dates back to 1943[3] which had generated interest of plant breeders to harness hybrid vigour. In this crop high level of heterosis (>100% on plant basis) was reported by researchers [4, 5] but yield advantage of hybrid populations over standard checks under commercial practices was significantly lower (<40%). Various Indian mustard cross combinations showing hybrid yield advantage over better parent or standard cultivar have been reported. This study presents the results of heterosis and combining ability in local germplasm lines and varietal crosses under *tarai* conditions (Pantnagar) of Uttarakhand.

Material and Method
The experimental material for the present study comprised of 10 diverse genotypes of mustard (*Brassica juncea* L.), of which six were selected local germplasm lines viz. PWR 15-8, PRHC 17-1, FS-14-24, PWR 15-8-1, PRHC 12-14, PRHC 13-14 and four were released popular varieties viz. RGN-73, Maya, Kranti, PM 25. The parents were crossed in *diallel* mating design excluding reciprocals (half *diallel*). Ten parents and 45 F_1's were evaluated in a randomized block design with three replications during *rabi* 2014-15 for 15 traits including seed yield per plant (g) and oil content (%) along with two quality traits (protein content (%), glucosinolate content (µmole/g). Observations on oil content and two quality traits were recorded using FT-NIR. The data collected were analyzed following method-2, model-1 of

Griffings [6] for combining ability and heterosis over better parent and standard variety (Kranti) as per standard procedure.

Results and Discussion

Analysis of variance for general combining ability and specific combining ability showed significant mean squares due to GCA and SCA for all the characters except for oil content (Table 1). Relative magnitude of mean squares due to GCA was higher than the mean squares due to SCA for all the characters, barring oil content and glucosinolate content. This indicated predominance of additive gene action for the expression of these characters. Higher magnitude of mean squares due to SCA indicated the predominance of non-additive gene action for oil content and glucosinolate content as also reported earlier [7-12].

On the basis of estimates of GCA effect, each parent was ranked (G= good general combiner, A= average general combiner and P= poor general combiner) for various characters. Each of the parent emerged as good general combiner for variable number of traits but not for all the traits. For example, Maya was a good general combiner for ten traits, PRHC 13-14 for nine, RGN-73 for eight, Kranti for seven, PM 25 for six, PRHC 17-1 and PWR 15-8-1 for five, PRHC 12-14 for four, and PWR 15-8 (3) and FS-14-24 for two traits each (Table 2). The high GCA of PRHC 17-1 for seed yield was associated with high GCA for siliqua density, number of primary branches and number of secondary branches. High GCA for seed yield in case of RGN-73 was associated with high GCA for days to initial flowering, days to maturity, length of main raceme, seeds per siliqua, siliqua on main raceme, siliqua length and 1000-seed weight, high GCA effect of Maya for seed yield was contemplation of positive GCA effect for days to initial flowering, days to maturity, plant height, length of main raceme, number of primary branches, number of secondary branches, siliqua length and 1000-seed weight. Kranti showed high GCA for seed yield which was found to be associated with days to initial flowering, days to maturity, plant height, length of main raceme, siliqua length and 1000-seed weight. In case of PRHC 13-14 days to initial flowering, days to maturity, plant height, length of main raceme, siliqua on main raceme, siliqua length, seeds per siliqua and 1000-seed weight [12-15]

The success of any crop improvement programme through genetic recombination is essentially determined by selection of superior cross combinations and their subsequent handling by application of appropriate breeding procedures, thus SCA analysis becomes intrinsic. Studies on specific combining ability effects (SCA) showed that out of 45 crosses, 7, 12 and 9 crosses each manifested significant SCA effects in desirable direction for days to initial flowering, days to maturity and plant height respectively. Similarly, ten crosses for length of main raceme, 11 for siliquae on main raceme, 8 for siliqua density, two crosses each for primary branches per plant, siliqua length, 1000-seed weight, six crosses for secondary branches per plant, four for seeds per siliqua, 13 for seed yield, four for protein content and 12 for glucosinolate content manifested significant SCA effects in desirable direction. Further, it was revealed from the present study that there was no consistency in GCA status of the parents involved in the superior crosses having significant SCA effects. The superior crosses identified for seed yield per plant are having G×G or G×P GCA parents. Thus, it could be inferred that high estimates of GCA effects did not necessarily results in manifestating high estimates of SCA effects in such crosses.

Results of heterosis over better parent (BP) as well as standard variety (SV) revealed that the frequency of crosses manifesting desired heterosis was, in general, low for days to initial flowering, days to maturity, plant height, siliqua length, seed/siliqua and 1000-seed weight. For plant height no cross manifested desired (negative) heterosis. For oil content only one cross manifested desired heterosis over better parent. The low magnitude of heterosis that too in less number of crosses especially for days to flowering and days to maturity may be due to quantitatively photosensitive nature of these traits in oilseed *Brassicas* as has been argued earlier [16].

For seed yield, 20 crosses over BP and 12 over SV manifested significant desirable heterosis. Of these nine crosses displayed heterosis over both BP as well as SV. The magnitude of desired heterosis over BP was quite high in different crosses (8.37 to 131.55%). High magnitude of heterosis for seed yield was also reported [17-21]

Table 1: Analysis of variance for combining ability for different characters in mustard genotypes

S.V.	d.f.	Mean of squares														
		DF	DM	PH	LMR	SMR	SD	PB	SB	SL	S/S	TW	Y/P	OC	PC	GC
GCA	9	361.61**	307.70**	1515.22**	528.88**	53.74**	0.13**	1.07**	36.04**	0.67**	4.46**	1.40**	25.05**	2.18	1.73**	13.86**
SCA	45	24.15**	27.81**	191.58**	46.94**	49.73**	0.01**	0.63**	12.08**	0.11**	1.00**	0.13**	4.50**	2.41	1.38**	17.72**
Error	108	1.93	2.09	11.41	3.71	2.30	0.001	0.23	1.20	0.04	0.23	0.03	0.30	1.76	0.30	0.25

*Note DF= Days to initial flowering, DM= Days to maturity, PH= Plant Height, LMR= Length of main raceme, SMR= Siliqua on main raceme,, SD= Siliqua density, PB= primary branches/plant, SB= secondary branches/plant, SL= Siliqua length, S/S= Number of seeds/siliqua, TW= 1000-seed weight, Y/P= Seed yield/plant, OC= Oil content, PC= Protein Content, GC= Glucosinolate Content.

Table 2: Promising general combiners and specific crosses for 15 characters in mustard

S. No.	Character	Good general combiners		Promising specific cross combinations	
		Parents	No.	Crosses	No.
1	Days to initial flowering	RGN73, Maya, PRHC 12-14, Kranti, PM 25, PRHC 13-14	6	PRHC 17-1×FS-14-24, PRHC 17-1×PM 25, PWR 15-8-1×Kranti, RGN73×Maya, RGN73×PM 25, Kranti×PM 25, PM 25×PRHC 13-14.	7
2	Days to maturity	RGN73, Maya, PRHC 12-14, Kranti, PM 25, PRHC 13-14	6	PWR 15-8×FS-14-24, PRHC 17-1×FS-14-24, PRHC 17-1×Kranti, PRHC 17-1×PM 25, PWR 15-8-1×RGN73, PWR 15-8-1×Kranti, RGN73×Maya, RGN73×PRHC 13-14, Maya×Kranti, PRHC 12-14×PRHC 13-14, Kranti×PM 25, Kranti×PRHC 13-14.	12
3	Plant height	FS-14-24, PWR 15-8-1, Maya, Kranti, PM 25, PRHC 13-14	6	PWR 15-8×RGN73, PRHC 17-1×PRHC 13-14, FS-14-24×PRHC 12-14, PWR 15-8-1×RGN73, PWR 15-8-1×PM 25, RGN73×PM 25, PRHC 12-14×Kranti, PRHC 12-14×PRHC 13-14, Kranti×PM 25.	9
4	Length of main	RGN73, Maya, PRHC	6	PWR 15-8×PRHC 12-14, PWR 15-8×PM 25, PWR 15-8×PRHC 13-14, PRHC 17-1×RGN73,	10

	raceme	12-14, Kranti, PM 25, PRHC 13-14		PRHC 17-1×Kranti, FS-14-24×PWR 15-8-1, FS-14-24×Kranti, PWR 15-8-1×Maya, RGN73×PRHC 13-14, PRHC 12-14×PRHC 13-14.	
5	No. of siliquae on main raceme	PWR 15-8, RGN73, PRHC 13-14	3	PWR 15-8×PRHC 12-14, PWR 15-8×PM 25, PWR 15-8×PRHC 13-14, PRHC 17-1×FS-14-24, PRHC 17-1×PWR 15-8-1, FS-14-24×PM 25, FS-14-24×PRHC 13-14, PWR 15-8-1×Kranti, RGN73×PRHC 12-14, Maya×PRHC 12-14, Maya×Kranti.	11
6	Siliqua density	PWR 15-8, PRHC 17-1, PWR 15-8-1	3	PWR 15-8×FS-14-24, FS-14-24×PM 25, FS-14-24×PRHC 13-14, PWR 15-8-1×RGN73, PWR 15-8-1×PRHC 13-14, RGN73×PRHC 12-14, Maya×PRHC 12-14.	7
7	No. of primary branches/plant	PRHC 17-1, FS-14-24, Maya	3	FS-14-24×PRHC 12-14, PWR 15-8-1×PM 25.	2
8	No. of secondary branches/ plant	PRHC 17-1, FS-14-24, Maya	3	PRHC 17-1×PRHC 13-14, FS-14-24×PRHC 12-14, PWR 15-8-1× PM 25, RGN73×Maya, PRHC 12-14×Kranti, PRHC 12-14×PRHC 13-14.	6
9	Siliqua length	RGN73, Maya, PRHC 12-14, Kranti, PM 25, PRHC 13-14	6	PWR 15-8×PRHC 12-14, PWR 15-8-1×PRHC 12-14.	2
10	No. of seeds / siliqua	PWR 15-8-1, Maya, PRHC 13-14	3	PWR 15-8×PWR 15-8-1, PRHC 17-1×PWR 15-8-1, FS-14-24×Maya, Maya×PRHC 12-14.	4
11	Seed yield/ plant (g)	PRHC 17-1, RGN73, Maya,Kranti, PRHC 13-14	5	PWR 15-8×PRHC 12-14, PWR 15-8×Kranti, PRHC 17-1×FS-14-24, PRHC 17-1×PWR 15-8-1, PRHC 17-1×RGN73, PRHC 17-1×PRHC 13-14, FS-14-24×Maya, PWR 15-8-1×RGN73, PWR 15-8-1×PM 25, RGN73×Maya, RGN73×Kranti, Maya×PRHC 12-14, PRHC 12-14×PRHC 13-14.	13
12	1000 seed weight (g)	RGN73, Maya, Kranti, PM 25, PRHC 13-14	5	PWR 15-8-1×PM 25, Maya×PM 25.	2
13	Protein content (%)	PWR 15-8, PWR 15-8-1	2	PWR 15-8×PWR 15-8-1, PWR 15-8×PRHC 12-14, FS-14-24×RGN73, RGN73×Maya.	4
14	Oil content (%)		0	-	0
15	Glucosinolate content	PRHC 17-1, PWR 15-8-1, Maya	3	PWR 15-8×PRHC 17-1, PWR 15-8×RGN73, PRHC 17-1×RGN73, PRHC 17-1×PRHC 12-14, FS-14-24×Maya, PWR 15-8-1×Maya, PWR 15-8-1×PRHC 12-14, PWR 15-8-1×Kranti, PWR 15-8-1×PM 25, RGN73×Kranti, RGN73×PM 25, Maya×PRHC 13-14.	12

Table 3: Superior cross combinations based on *per se* performance and desirable SCA effects for seed yield per plant and suggested breeding strategy

Cross combinations	*Per se* performance (g/plant)	SCA effects	Heterosis (%)		GCA effect of combining parent	Other characters with significant SCA effects	Suggested breeding method
			BP	SV			
PWR 15-8×Kranti	12.68	4.388**	35.09**	35.09**	P × G	-----	Heterosis breeding / mass selection with concurrent random mating
PRHC 17-1×RGN73	11.89	2.132**	24.55**	26.60**	G × G	LMR, GC	Heterosis breeding / conventional breeding methods with selection pressure on DF, DM, PH, SL, NSS, PB, SB, S/P, and OC
PRHC 17-1×PRHC 13-14	11.36	1.965**	51.01**	21.03**	G × G	PH, SB	Heterosis breeding / conventional breeding methods with selection pressure on DF, DM, SL, PB, NSS, S/P, and OC
RGN73×Maya	12.62	1.571*	8.82**	34.36**	G × G	DF, DM, SB, PC	Heterosis breeding / conventional breeding methods with selection pressure on PH, SL, NSS, PB, S/P, and OC
RGN73×Kranti	11.72	2.003**	22.80**	24.83**	G × G	GC	Heterosis breeding / conventional breeding methods with selection pressure on DF, DM, PH, PB, SB NSS, SL, S/P, and OC
PRHC 12-14×PRHC 13-14	11.26	3.676**	49.60**	19.90**	P × G	DM, PH, LMR, SB	Heterosis breeding / mass selection with concurrent random mating

Conclusion

The commercial worth of the genotype will, nevertheless, depends on magnitude of improvement in yield *per se* over BP and SV. Hence, combinations that registered high yield *per se* along with significant positive SCA, heterobeltiosis and economic heterotic responses for yield may be considered ideal for use in yield improvement programme (Table 3). Besides, this table also presents significant SCA effects of the related traits and suggested breeding methodology for genetic improvement. Based on this argument six potential crosses could be identified for seed yield per plant. GCA status of both the parents of superior heterotic crosses (PRHC 17-1×RGN73, PRHC 17-1×PRHC 13-14, RGN73×Maya, RGN73×Kranti) was Good. Thus, these crosses are amenable for improvement through conventional breeding procedures with selection pressure on days to initial flowering, days to maturity, siliqua length, primary branches per plant, number of seeds per siliqua and oil content. The other two promising crosses namely PWR 15-8×Kranti and PRHC 12-14×PRHC 13-14 for seed yield combined parents with differing GCA status. Thus, it is obvious that a good cross combination is not always the result of Good ×Good GCA parents, instead it can also result from Good×Average or Good×Poor GCA parents. High GCA status of one of the parent and average/poor of the other in heterotic crosses indicates that additive gene effects of good general combiner and epistatic effects of average/poor combiner acted in a complementary manner leading to high expression of the traits. Such crosses are amenable to improvement through biparental mating and/or heterosis breeding.

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