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Line×Tester Analysis for Heterosis and Combining Ability for Seed Yield and its Component Traits in Indian Mustard

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ABSTRACT

Twelve advanced lines/varieties of Indian mustard (*Brassica juncea* L.) were selected for building the experimental material. It consisted of 8 lines and 4 testers, mated in Line × Tester design during *rabi* season 2018-19. These parents alongside with their 32 F_{1s} were evaluated in RBD in *rabi* season 2019-20 for 13 traits including seed yield per plant (g), glucosinolate content (µmole/g) and oil content (%). Analysis of variance for combining ability showed that significant differences were present amid treatments for all the characters, except for siliqua length and seeds per siliqua. Line PAB 17-1 was identified as a good combiner on the basis of their GCA effect for seed yield, test weight; PAB 17-15 for number of primary branches, number of secondary branches, PAB 17-21 for plant height, length of main raceme, siliquae on main raceme, glucosinolate content and PAB 17-23 for oil content. Highest significant SCA effect was shown by cross-combination PAB 17-2×PHR-2 for seed yield per plant, PAB 17-23×NRCHB-101 for glucosinolate content and PAB 17-1×PAB-9511 for oil content. Cross combination PAB 17-2×PHR-2 showed highest heterobeltiosis (BP) for seed yield per plant followed by PAB 17-1 × PHR-2. The magnitude of heterosis over BP in the desired direction was quite high ranging from -36.18 to 160.14. Cross PAB 17-23×PHR-1 for oil content showed highest heterosis over BP. Cross combination PAB 17-15×PAB-9511 showed highest relative heterosis for seed yield per plant and PAB 17-20×PAB-9511 for oil content. Similarly PAB 17-2×PHR-2 showed highest economic heterosis for seed yield per plant.

Keywords Combining ability, Heterosis, Indian mustard, Line×Tester, Seed yield.

INTRODUCTION

Oilseed brassica, also known as Rapeseed-Mustard, supports as a backbone of the agricultural economy of India for a long time and is considered as the second largest and chiefly traded agricultural commodity in India, after cereals. India is the fourth-largest producer of oilseeds, with an average annual production of roughly 29 million tonnes, next to the United States, China, and Brazil and has made a significant paradigm shift in the production of all oilseeds, going from an inadequate 5.26 million metric tonnes (MMT) in marketing year (MY) 1949–50 to a massive increase

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of about 35.92 MMT in MY 2019–20, of which 8.703 MMT has been exclusively contributed by rapeseed and mustard (USDA 2021). In the MY 2020/21 rapeseed and mustard production itself is revised to 7.65 MMT produced from 7.2 million hectares and has secured its position as an important oilseed crop (USDA 2021).

Rapeseed-Mustard includes *Brassica rapa* var. toria, *B. rapa* var. yellow sarson, *B. rapa* var. brown sarson, *B. juncea*, *Eruca sativa* species and *B. nigra* along with some exotic species like gobhi sarson (*B. napus*), Ethiopian mustard (*B. carinata*) and white mustard (*Sinapis alba*). *Brassica juncea* (L.) Czern and Coss (Indian mustard), a natural amphidiploid (2n=4x=36) that is primarily grown during the *rabi* season resulted from a natural cross between *Brassica campestris* (2n=20) and *Brassica nigra* (2n=16) proposed by Nagaharu (1935).

Combining ability analysis is used for assessment of the elite lines in on the basis of their genetic value and suitability to be used as parental materials in different hybridization programs along with the identification of superior cross combinations to be further utilized for commercial exploitation (Singh *et al.* 2013). GCA is primarily contributes to the additive gene action, whereas, SCA is majorly effected by the non-additive gene action. The knowledge of the magnitude and nature of both fixable and non-fixable gene action is of chief importance for formulating a competent breeding program. Indian mustard is self-pollinating in nature, therefore, Line×Tester mating system for GCA and SCA analysis is very useful for screening of lines with speed. This method was proposed by Kempthorne (1957). Further for making genetic improvement in seed yield and its component traits along with the exploitation of non-fixable gene actions in a crop improvement program, knowledge of heterosis is important. The degree of heterosis serves as a foundation and a guide for selecting ideal parents for creating superior F_1 hybrids and for generating gene pools that may be used in a breeding program for the evaluation of genetic diversity.

Rapeseed mustard production and productivity is seriously affected by the different biotic and abiotic stresses. In Northern part of the country *Alternaria* blight has been a devastating disease since long and not much understanding and solution has been achieved. Scientists are continuously putting their efforts in the direction to develop the varieties with good agronomic performance with resistance to *Alternaria blight*. The lines used in the study were developed using *Alternaria blight* tolerant donor with agronomically superior parent. These advanced lines showed *Alternaria blight* tolerance and have never been evaluated for their agronomic worth. Therefore, the investigation was design with an objective to find out the worth of these developed lines through study of combining ability and heterosis so that identified lines could be used as potential donor in hybridization program targeted for multi-dimensional improvement of crop.

MATERIALS AND METHODS

The experimental material for the present research comprised of 12 advanced lines/varieties of Indian mustard (*Brassica juncea* L.), i.e., 8 lines (PAB 17-1, PAB-17-2, PAB 17-4, PAB 17-5, PAB 17-15, PAB 17-20, PAB 17-21, PAB 17-23) and 4 testers (NRCHB-101, PAB-9511, PHR-1, PHR-2) obtained from Department of Genetics and Plant Breeding, GBPUA and T, Pantnagar. 12 parents and their 32 single crosses (F_1s) were developed via hand emasculation, hand pollination and selfing, using Line × Tester mating design in *rabi* season of 2018-19. They were tested for 13 features including seed yield per plant (g), oil content (%) and glucosinolate content (μmole/g) after being sowed in Randomized Block Design (RBD) with three replications in each setting. FT-NIR was used for recording observations like oil content and glucosinolate content. The data recorded was further analyzed for GCA and SCA effects following Kempthorne (1957) method, relative heterosis using Shull (1908) method, standard heterosis using Briggle (1963) method and heterobeltiosis using Fonesca and Patterson (1968) procedure. Experimental material was scored for *Alternaria blight* disease. It was done on a scale of 0-6 on the basis of disease assessment key on leaves and pods of the plants (Conn *et al.* 1990) (Table 1).

RESULTS AND DISCUSSION

Analysis of variance (ANOVA) unveiled the existence

Table 1. *Alternaria blight* scoring on leaves.

Sl. No.	Line	AB rating (leaves)	AB rating (pods)	Sl. No.	Tester	AB rating (leaves)	AB rating (pods)
1	PAB 17-1	3	3	1	PHR-1	3	5
2	PAB 17-2	2	2	2	PHR-2	5	3
3	PAB 17-4	5	3	3	PAB-9511	5	3
4	PAB 17-5	5	3	4	NRCHB-101	5	3
5	PAB 17-15	6	5				
6	PAB 17-20	5	3				
7	PAB 17-21	2	3				
8	PAB 17-23	5	5				

of strong genetic variance amid the parents and hybrids for almost all the traits under. Out of thirteen characters, ten characters showed considerable differences except for siliquae on main raceme, siliqua length and number of seeds per siliqua for parents. However, variance due to parents vs crosses was highly significant for plant height, number of secondary branches per plant, seed yield per plant, test weight, oil content and glucosinolate content, whereas, significant variation was observed for days to 50% flowering and seeds per silique (Table 2). The combining ability ANOVA revealed that practically all of the traits under evaluation had considerable GCA and SCA variation, demonstrating the significance of both additive and non-additive gene actions in the expression of seed yield and its component traits.

Each parent was rated as a good (G), average (A), or poor (P) general combiner based on the GCA effect estimate. No parent was found to be a compe-

Table 2. Analysis of variance for combining ability for 13 characters under study in *Brassica juncea* (Indian mustard).

		Mean sum of squares					
Sources of variation	Df	DFI	DF (50%)	PH (cm)	LMR (cm)	SMR (No)	NPB (No)
Replications	2	163.93	60.83	59.58	170.14	17.73	1.49
Treatments	43	246.25**	304.98 **	1058.98**	207.40**	34.25**	5.11 **
Parents	11	358.21**	426.51**	1847.92**	175.06**	13.62	7.49**
Crosses	31	214.24 **	268.05**	731.73**	224.02**	42.21**	4.41**
Parent v/s crosses	1	6.98	112.91*	2525.56**	47.82	14.45	0.76
Lines	7	110.58	124.02	523.06	190.78	88.43**	8.14*
Testers	3	428.38	648.45	740.24	607.85*	78.28*	4.02
Line × Tester	21	218.19**	261.72**	800.06**	180.27**	21.65*	3.22**
Error	86	29.91	25.15	70.49	33.96	12.25	0.73

Table 2. Continued.

		Mean sum of squares						
Sources of variation	Df	NSB (No)	SL (cm)	S/S (No)	SY (g)	TW (g)	GC	OC (%)
Replications	2	5.99	0.10	1.25	2.53	0.14	34.90	3.78
Treatments	43	19.60**	0.18	2.19	15.88**	0.29**	69.99**	6.16**
Parents	11	21.91**	0.25	1.63	5.99**	0.39**	70.79**	8.42**
Crosses`	31	18.23**	0.17	2.23	15.35**	0.24**	64.19**	5.17**
Parent v/s crosses	1	36.62**	0.01	7.16*	141.25**	0.42**	241.05**	12.11**
Lines	7	15.69	0.28*	2.31	14.48	0.32	84.66	1.12
Testers	3	1.78	0.19	1.79	39.64*	0.49*	61.56	2.38*
Line × Tester	21	21.43**	0.13	2.27	12.17**	0.18**	57.75**	5.67**
Error	86	1.65	0.15	1.51	1.12	0.04	3.55	0.79

Table 3. Promising general combiner and specific combiners for various traits under study in *Brassica juncea* (Indian mustard).

Sl. No.	Traits/characters under study	Good general combiners/parents: Parents	Total number	Good specific combiners/crosses: Crosses	Total number
1	DFI	PAB 17-5, NRCHB-101	2	PAB 17-1 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-4 × PAB-9511, PAB 17-15 × PHR-2, PAB 17-20 × NRCHB-101, PAB 17-20 × PHR-2, PAB 17-23 × PAB-9511	7
2	DF	PAB 17-5, NRCHB-101	2	PAB 17-1 × NRCHB-101, PAB 17-1 × PHR-2, PAB 17-2× PAB-9511, PAB 17-20 × NRCHB-101, PAB 17-23 × PAB-9511	5
3	PH	PAB 17-21, PAB 17-23, NRCHB-101, PAB-9511	4	PAB 17-1 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-4 × PHR-1, PAB 17-4 × PHR-2, PAB 17-5 × NRCHB-101, PAB 17-5 × PHR-2, PAB 17-15 × NRCHB-101, PAB 17-15 × PHR-1, PAB 17-20 × NRCHB-101, PAB 17-20 × PHR-1, PAB 17-21 × PHR-1, PAB 17-23 × PAB-9511	12
4	LMR	PAB 17-4, PAB 17-20, NRCHB-101	3	PAB 17-4 × NRCHB-101, PAB 17-20 × NRCHB-101, PAB 17-23 × PAB-9511	3
5	SMR	PAB 17-5, PAB 17-21, PAB-9511	3	PAB 17-4 × PAB-9511	1
6	NPB	PAB 17-1, PAB 17-15, PHR-1	3	PAB 17-1 × PAB-9511, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-15 × PHR-2, PAB 17-23 × NRCHB-101	5
7	NSB	PAB 17-1, PAB 17-2, PAB 17-15, PAB 17-23	4	PAB 17-1 × PHR-1, PAB 17-1 × PHR-2, PAB 17-2 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-2 × PHR-2, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-20 × NRCHB-101	8
8	SL	--	0	--	0
9	SS	--	0	--	0
10	SY	PAB 17-1, PAB 17-15, PAB-9511, PHR-2	4	PAB 17-1 × PHR-2, PAB 17-2 × PHR-2, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-15 × PAB-9511, PAB 17-23 × NRCHB-101	6
11	TW	PAB 17-1, PAB-9511	2	PAB 17-1 × NRCHB-101, PAB 17-4 × PAB-9511, PAB 17-23 × PHR-1	3
12	GC	PAB 17-4, PAB 17-15, PAB 17-20, PHR-1	4	PAB 17-1 × PHR-1, PAB 17-1 × PHR-2, PAB 17-2 × PAB-9511, PAB 17-4 × PHR-1, PAB 17-15 × PAB-9511, PAB 17-20 × NRCHB-101, PAB 17-21 × PHR-1, PAB 17-21 × PHR-2, PAB 17-23 × NRCHB-101	9
13	OC	PAB 17-23, PAB-9511, PHR-1	3	PAB 17-1 × PAB-9511, PAB 17-20 × PAB-9511, PAB 17-23 × PHR-1	3

tent general combiner for all characters, in its place each parent differed considerably and established their own GCA effect for various traits (Table 3). Parent PAB-9511 was found to be a good combiner for five traits. PAB 17-1, PAB 17-15 and NRCHB-101 for four traits, PAB 17-5, PAB 17-23 and PHR-1 for 3 traits, PAB 17-20, PAB 17-21 and PAB 17-4 for 2 traits; PAB 17-2 and PHR-2 for 1 trait. For days to flower initiation and days to 50% flowering parents PAB 17-5 and NRCHB-101 were identified as best parent that contributed in desirable negative direction. For plant height, NRCHB-101 and PAB 17-21 were found to be the good general combiner. PAB 17-20 and NRCHB-101 emerged as good combiners for length of main raceme. PAB 17-21 and PAB-9511 were found as good combiners for siliquae on main raceme. It was found that PAB 17-15 and PAB 17-1 make an excellent general combiner for number of primary branches and secondary branches per plant. Parents PAB 17-1 and PAB-9511 were good combin-

Table 4. Best two cross combination based on better parent heterosis, relative heterosis and economic heterosis.

Sl. No.	Characters	Better parent heterosis	Relative heterosis	Economic heterosis
1	DFI	PAB 17-20 × NRCHB-101	PAB 17-2 × PAB-9511	PAB 17-2 × PAB-9511
		PAB 17-23 × PAB-9511	PAB 17-15 × PHR-2	PAB 17-1 × NRCHB-101
2	DF	PAB 17-20 × NRCHB-101	PAB 17-23 × PAB-9511	PAB 17-2 × PAB-9511
		PAB 17-23 × PAB-9511	PAB 17-2 × PAB-9511	PAB 17-23 × PAB-9511
3	PH	PAB 17-23 × PAB-9511	PAB 17-23 × PAB-9511	PAB 17-23 × PAB-9511
		PAB 17-4 × PHR-2	PAB 17-4 × PHR-2	PAB 17-21 × PHR-1
4	LMR	PAB 17-23 × PAB-9511	PAB 17-23 × PAB-9511	PAB 17-20 × NRCHB-101
		PAB 17-20 × NRCHB-101	PAB 17-20 × NRCHB-101	PAB 17-4 × NRCHB-101
5	NPB	PAB 17-15 × PHR-2	PAB 17-1 × PAB-9511	PAB 17-15 × PHR-2
		PAB 17-1 × PAB-9511	PAB 17-15 × PHR-2	PAB 17-5 × PHR-1
6	NSB	PAB 17-4 × PAB-9511	PAB 17-4 × PAB-9511	PAB 17-4 × PAB-9511
		PAB 17-1 × PHR-2	PAB 17-1 × PHR-2	PAB 17-1 × PHR-2
7	SL	PAB 17-23 × PHR-2	PAB 17-4 × PHR-2	PAB 17-5 × NRCHB-101
		PAB 17-4 × PHR-2	PAB 17-23 × PHR-2	PAB 17-1 × NRCHB-101
8	SMR	PAB 17-4 × PAB-9511	PAB 17-2 × PHR-1	PAB 17-4 × PAB-9511
		PAB 17-4 × PHR-1	PAB 17-4 × PAB-9511	PAB 17-23 × PAB-9511
9	S/S	PAB 17-2 × PAB-9511	PAB 17-2 × PAB-9511	PAB 17-5 × NRCHB-101
		PAB 17-23 × PAB-9511	PAB 17-1 × PHR-1	PAB 17-1 × PHR-1
10	SY	PAB 17-2 × PHR-2	PAB 17-15 × PAB-9511	PAB 17-2 × PHR-2
		PAB 17-1 × PHR-2	PAB 17-2 × PHR-2	PAB 17-1 × PHR-2
11	TW	PAB 17-2 × PAB-9511	PAB 17-2 × PAB-9511	PAB 17-1 × NRCHB-101
		PAB 17-20 × PAB-9511	PAB 17-20 × PAB-9511	PAB 17-4 × PAB-9511
12	GC	PAB 17-15 × PHR-2	PAB 17-4 × PHR-1	PAB 17-4 × PHR-1
		PAB 17-20 × PHR-2	PAB 17-15 × PHR-2	PAB 17-15 × PAB-9511
13	OC	PAB 17-23 × PHR-1	PAB 17-20 × PAB-9511	PAB 17-23 × PHR-1
		PAB 17-20 × PAB-9511	PAB 17-23 × PHR-1	PAB 17-20 × PAB-9511

ers for seed yield/plant and 1000 seed weight. Good combiners for glucosinolate content were found to be PAB 17-4 and PHR-1. Whereas, in case of oil content good combiners were found to be PAB 17-23 and PAB-9511. It was quite apparent in this present research that some parents and crosses showed potential based on the relevant multiple parameters. The parents which showed good GCA can be utilized as donor for specific trait and cross-combinations which were identified with good SCA, can be used through heterosis breeding using the most suited breeding. Every time the heterotic crosses have not come from crossing of high GCA parents but still this preliminary practices helps to group parents in different diverse pool for development in unique recombinants.

Lines, PAB 17-1, PAB 17-15 and testers PAB-9511 and PHR-2 showed good GCA for seed yield/plant. PAB 17-1 showed high GCA estimates for other traits namely, number of secondary branches, number of primary branches, seed yield/plant and 1000 seed weight; PAB 17-15 for number of primary branches, number of secondary branches, seed yield/plant and glucosinolate content; PAB-9511 was found for plant height, siliquae on main raceme, seed yield, test weight and oil content. These conclusions displayed resemblance with results published earlier by other researchers on basis that assemblage of component traits with higher GCA values, high GCA status for seed yield in different lines differed significantly (Dahiya *et al.* 2018, Kaur *et al.* 2019).

Superior cross combination selection and their subsequent advancement in subsequent generations with the help of appropriate plant breeding methods is essential in any crop improvement program. For this SCA analysis is done for all selected superior crosses and study showed that out of 32 crosses taken under study, maximum of 25 crosses showed SCA in the desired direction for plant height. Similarly SCA in desired direction for seed yield per plant, flowering initiation, days to 50% flowering, plant height, the length of main raceme, siliquae on main raceme, number of primary branches, number of secondary branches, 1000 seed weight, oil content and glucosinolate content were shown by 06 (PAB 17-1 ×

Table 5. Superior crosses on the basis of SCA effects for seed yield per plant, glucosinolate content and oil content with suitable breeding strategy for crop improvement.

Sl. No.	Character	Crosses with highest SCA effect	*Per se* performance	SCA effect	Other traits showing highest SCA effect	Heterosis Mid parent	Heterosis Better parent	Heterosis Standard	Parent combination	Suitable breeding method
1	Seed yield	PAB 17-2×PHR-2	11.6202	3.80**	——	185.68**	160.14**	129.25**	A×P	Heterosis breeding/ diallel selective mating with selection pressure on GC, NPB, NSB, SMR, TW
		PAB 17-23×NRCHB-101	8.352	3.44**	GC, NPB	110.69**	46.24**	64.77**	A×P	
		PAB 17-4×PAB-9511	10.3722	3.00**	DFI, SMR, NPB, NSB, TW	143.76**	104.63**	104.63**	P×G	
2	Oil content	PAB 17-20×PAB-9511	41.787	1.85**	-----	11.5**	4.37*	4.37*	P×G	Heterosis breeding / diallel selective mating with selection pressure on NPB and TW
		PAB 17-1×PAB-9511	41.227	1.81**	NPB	3.69*	2.97	2.97	P×G	
		PAB 17-23×PHR-1	42.887	1.74**	TW	8.82**	8.47**	7.95**	G×G	
3	Glucosinolate content	PAB 17-23×NRCHB-101	19.910	-7.55 **	NPB, SY	-19.96**	-26.51**	-19.17**	A×P	Heterosis breeding / diallel selective mating with selection pressure on PH, NPB, NSB and PH
		PAB 17-1×PHR-1	23.000	-5.14 **	NSB	-20.62**	-27.01**	-5.04	P×G	
		PAB 17-21×PHR-1	21.367	-4.39 **	PH	-29.18**	-36.98**	-11.78	P×G	

PHR-2, PAB 17-2 × PHR-2, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-15 × PAB-9511, PAB 17-23 × NRCHB-101), 07 (PAB 17-1 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-4 × PAB-9511, PAB 17-15 × PHR-2, PAB 17-20 × NRCHB-101, PAB 17-20 × PHR-2, PAB 17-23 × PAB-9511), 05 (PAB 17-1 × NRCHB-101, PAB 17-1 × PHR-2, PAB 17-2 × PAB-9511, PAB 17-20 × NRCHB-101, PAB 17-23 × PAB-9511), 12 (PAB 17-1 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-4 × PHR-1, PAB 17-4 × PHR-2, PAB 17-5 × NRCHB-101, PAB 17-5 × PHR-2, PAB 17-15 × NRCHB-101, PAB 17-15 × PHR-1, PAB 17-20 × NRCHB-101, PAB 17-20 × PHR-1, PAB 17-21 × PHR-1, PAB 17-23 × PAB-9511), 03 (PAB 17-4 × NRCHB-101, PAB 17-20 × NRCHB-101, PAB 17-23 × PAB-9511), 01 (PAB 17-4 × PAB-9511), 05 (PAB 17-1 × PAB-9511, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-15 × PHR-2, PAB 17-23 × NRCHB-101), 08 (PAB 17-1 × PHR-1, PAB 17-1 × PHR-2, PAB 17-2 × NRCHB-101, PAB 17-2 × PAB-9511, PAB 17-2 × PHR-2, PAB 17-4 × PAB-9511, PAB 17-5 × PHR-1, PAB 17-20 × NRCHB-101), 03 (PAB 17-1 × NRCHB-101, PAB 17-4 × PAB-9511, PAB 17-23 × PHR-1), 03 (PAB 17-1 × PAB-9511, PAB 17-20 × PAB-9511, PAB 17-23 × PHR-1) and 09 (PAB 17-1 × PHR-1, PAB 17-1 × PHR-2, PAB 17-2 × PAB-9511, PAB 17-4 × PHR-1, PAB 17-15 × PAB-9511, PAB 17-20 × NRCHB-101, PAB 17-21 × PHR-1, PAB 17-21 × PHR-2, PAB 17-23 × NRCHB-101) crosses respectively (Tables 3–5). Further it was observed that crosses which showed superiority for seed yield were G×G or G×P GCA parents. Similar results were witnessed in case of other traits under study and was concluded there is direct relation between high estimates of GCA in parents and high estimates of SCA in crosses involving those parents. Study of heterosis over mid parent (MP), heterobeltiosis (BP) and standard heterosis (SH) for seed yield and its contributing traits for 32 cross combinations revealed that crosses showing desired heterosis were less in number in case of days to flowering initiation, days to 50% flowering, days to maturity, siliquae on main raceme, number of primary branches, number of secondary branches, number of seeds per siliquae, siliquae length and test weight. These low estimates can be explained via quantitatively photosensitive nature of some of these traits. 19 crosses over MP [PAB 17-15 × PAB-9511 (188.910**), PAB 17-2 × PHR-2 (185.679**), PAB 17-1 × PHR-2 (180.741**), PAB 17-4 × PAB-9511 (143.761**), PAB 17-15 × PHR-2 (129.775**), PAB 17-15 × NRCHB-101 (114.080**), PAB 17-23 × NRCHB-101 (110.686**), PAB 17-5

× NRCHB-101 (98.743**), PAB 17-1 × PAB-9511 (84.654**), PAB 17-5 × PHR-2 (77.436**), PAB 17-5 × PHR-1 (76.563**), PAB 17-4 × PHR-2 (69.018**), PAB 17-1 × NRCHB-101 (66.896**), PAB 17-5 × PAB-9511 (63.899**), PAB 17-23 × PHR-2 (60.811**), PAB 17-2 × PAB-9511 (58.364**), PAB 17-21 × PHR-2 (42.562*), PAB 17-21 × PAB-9511 (34.800*) and PAB 17-1 × PHR-1 (33.593 *)], 13 over BP [PAB 17-2 × PHR-2 (160.14**), PAB 17-1 × PHR-2 (154.28**), PAB 17-15 × PAB-9511 (112.52**), PAB 17-15 × NRCHB-101 (106.41**), PAB 17-4 × PAB-9511 (104.63**), PAB 17-15 × PHR-2 (89.68**), PAB 17-5 × NRCHB-101 (80.78*), PAB 17-1 × PAB-9511 (74.66**), PAB 17-4 × PHR-2 (63.79**), PAB 17-5 × PHR-2 (54.17*), PAB 17-2 × PAB-9511 (48.96**), PAB 17-23 × NRCHB-101 (46.24**) and PAB 17-23 × PHR-2 (32.05*)] and 11 over SH [PAB 17-2 × PHR-2 (129.250**), PAB 17-1 × PHR-2 (126.769**), 17-15 × PAB-9511 (112.516**), PAB 17-4 × PAB-9511 (104.628**), PAB 17-1 × PAB-9511 (74.665**), PAB 17-5 × PHR-1 (70.344**), PAB 17-23 × NRCHB-101 (64.773**), PAB 17-1 × PHR-1 (52.792**), PAB 17-2 × PAB-9511 (48.961**), PAB 17-23 × PHR-2 (48.787**) and PAB 17-15 × PHR-2 (37.274*)] displayed heterosis in desired direction for seed yield. Magnitude of heterosis was quiet high and similar results were also reported earlier by other researchers (Devi and Dutta 2020, Meena *et al.* 2014). For glucosinolate content 17 crosses [PAB 17-4 × PHR-1 (-37.509**), PAB 17-15 × PHR-2 (-36.331**), PAB 17-21 × PHR-2 (-30.914**), PAB 17-15 × PAB-9511 (-30.708**), PAB 17-21 × PHR-1 (-29.183**), PAB 17-1 × PHR-2 (-28.235**), PAB 17-20 × PHR-2 (-27.546**), PAB 17-4 × PHR-2 (-26.341**), PAB 17-5 × PHR-2 (-26.251**), PAB 17-1 × PHR-1 (-20.617**), PAB 17-23 × NRCHB-101 (-19.963**), PAB 17-20 × NRCHB-101 (-18.430**), PAB 17-4 × NRCHB-101 (-15.497**), PAB 17-2 × PHR-2 (-14.612**), PAB 17-15 × PHR-1 (-14.261**), PAB 17-5 × PHR-1 (-14.257**) and PAB 17-5×PAB-9511 (-12.278*)], 21 crosses [PAB 17-15 × PHR-2 (-44.01**), PAB 17-20 × PHR-2 (-42.60**), PAB 17-4 × PHR-1 (-40.76**), PAB 17-15 × PAB-9511 (-37.01**), PAB 17-21 × PHR-1 (-36.98**), PAB 17-21 × PHR-2 (-35.44**), PAB 17-4 × PHR-2 (-35.32**), PAB 17-1 × PHR-2 (-35.14**), PAB 17-5 × PHR-2 (-34.40**), PAB 17-2 × PHR-2 (-29.15**), PAB 17-1 × PHR-1 (-27.01**), PAB 17-23 × NRCHB-101 (-26.51**), PAB 17-20 × NRCHB-101 (-24.30**), PAB 17-23 × PHR-2 (-23.66**). PAB 17-21 × PAB-9511 (-22.09**), PAB 17-5 × PAB-9511 (-21.20**), PAB 17-5 × PHR-1 (-19.85**), PAB 17-4 × NRCHB-101 (-19.60**), PAB 17-15 × PHR-1 (-18.86**), PAB 17-4 × PAB-9511 (-12.93*) and PAB 17-20 × PHR-1 (-12.23*)] and 4 crosses [PAB 17-4 × PHR-1 (-27.828**), PAB 17-15 × PAB-9511 (-22.998**), PAB 17-23 × NRCHB-101 (-19.170**) and PAB 17-20 × NRCHB-101 (-16.734**)] displayed heterosis in the desired negative direction over MP, BP and SP, respectively. The majority of cross-combinations showed high levels of mid parent heterosis, better parent heterosis, and standard heterosis for most of the traits under study, demonstrating the noticeable benefit of heterozygosity in raising the seed yield per plant. As a result, heterosis breeding was chosen as the primary technique along with other methods, for utilizing the genetic diversity present in the sample of experimental material analyzed in Indian mustard (*Brassica juncea*).

CONCLUSION

Superior crosses on the basis of SCA effects for the traits under study can be further utilized in breeding using suitable breeding strategy for crop genetic improvement. Best two crosses based on BP, MP and standard heterosis results obtained for 13 traits under study were summarized PAB 17-2 × PHR-2 and PAB 17-23 × NRCHB-101 were two promising combinations found for seed yield per plant among all 32 cross combinations studied. Both the cross combinations have A×P GCA parents and showed that good combinations are not always result of G×G GCA parents. PAB 17-20 × PAB-9511 and PAB 17-1 × PAB-9511 were two combinations found superior for oil content. These promising cross combinations have G×P GCA status, and the high expression of traits in this state may be caused by the complementarity of the genetic effects of good general combiners and epistatic effect of poor combiners. Similarly cross combinations which were found superior for glucosinolate content were PAB 17-23 × NRCHB-101 and PAB 17-1 × PHR-1. Promising crosses for various traits showed contribution of parents carrying different GCA status and thus it was apparent that for getting a promising cross combination it is not necessary to have parent with good GCA. Instead they can have average or poor GCA status.

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