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Combining Ability and Heterosis for Seed Yield and Yield Components in Indian Mustard [*Brassica juncea* (L.) Czern and Coss]

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ABSTRACT

Background: Indian mustard is an important oilseed crop which occupies premier position in Indian agriculture. Developing high yielding genotypes is a major breeding objective in Indian mustard. Present study was conducted at Experimental Farm of Ranaghat, Nadia, West Bengal, during 2017 to 2019.

Methods: Line × tester analysis of seven lines and five testers was carried out to identify the high heterotic crosses and their relationship in terms of GCA and SCA in Indian mustard. The parents and F_1 hybrids were evaluated in RBD with three replications.

Result: The analysis of variances revealed significant differences of genotypes for all characters studied, indicating sufficient genetic variability for the characters. The estimates of SCA variances were higher than GCA variance the characters indicating that dominance variance was more than the additive variance. The ratio of variance due to general and specific combining ability was less than unity for all the traits that indicated the non-additive gene action was predominant over additive gene action. Five lines, *viz*. PM 24, PM 25, PM 30, Pusa Agrani, JD-6 and one tester, Pusa Bold were deemed to be the good general combiner for seed yield and yield attributing traits. On the basis of high heterosis over mid parent as well as better parent and significant SCA effects for seed yield per plant and its component traits, hybrids namely, JD-6 × Pusa Bold, PM 30 × Seeta, PM 25 × Pusa Bold, PM 24 × Kranti and PM 22 × Sarama were found to be very promising for further exploitation in breeding program.

Key words: Combining ability, GCA, Heterosis, Indian mustard, Line × tester, SCA.

INTRODUCTION

Indian mustard (*Brassica juncea* L.), which is cultivated through-out the world belongs to family Brassicaceae. Since oilseeds account for nearly 14% of gross national product and 7% of the value of all agriculture products and Indian mustard contributes more than 80% of the total rapeseed-mustard production contributing nearly 27% of edible oil pool of the country so, mustard considered as most important oilseed crop in India after groundnut (Singh *et al*., 2013).

The acreage, production and productivity of rapeseed-mustard in world during 2019-20 was 35.95 mha, 71.49 mt and 1990 kg/ha respectively (FAO stat 2019). In India rapeseed-mustard area, production and productivity were 6.86 mha, 9.12 mt and 1331 kg/ha respectively during 2019-20. Globally, India continues to be ranks 2nd after Canada in acreage (19.81%) and rank 4th after Canada, European Union and China in production (10.37%) (AICRP PC Report-2021, ICAR-DRMR).

Exploitation of heterosis may play a very significant role in boosting up the production and productivity of Indian mustard. Heterosis breeding can be one of the most useful options for breaking the present yield barrier. The combining ability analysis is one of the powerful tools to test the value of parental lines to produce superior hybrids and valuable recombinants to develop promising high yielding varieties. To develop better genotypes through hybridization, the choice of suitable parents plays a key role.

Combining ability studies emphasized the predominant effect of GCA on yield and most of the yield components indicating the importance of additive gene action (McGee and Brown, 1995; Gupta *et al.* 2006). Pandey *et al.* (1999) reviewed the evidences for the presence of significant SCA effects for seed yield and its components indicating importance of non-additive gene action. A wide range of positive heterosis for number of primary branches and secondary branches per plant, plant height and number of seeds per siliqua was reported by Rawat (1975). Similarly, significant positive heterosis for seed yield and component traits in Indian mustard were reported by many workers (Gami and Chauhan 2013, Meena *et al.* 2015 and Chauhan *et al.*2017) in different studies.

Keeping these points in view, the present investigation was undertaken to determine general combining ability and specific combining ability of parental lines and mid parent

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and better parent heterosis of different cross combinations in *Brassica juncea*.

MATERIALS AND METHODS

The study was conducted at Experimental Farm of Ranaghat, Nadia, West Bengal located at 23.17° North Latitude and 88.56° East Longitude during 2017-18 and 2018-19.The experimental materials for the present investigation comprised of 35 F_1's developed by crossing 7 lines *viz.,* PM 21, PM 22, PM 24, PM 25, PM 30, Pusa Agrani and Pusa Mahak (JD-6) with 5 testers viz., Sanjukta Asech, Seeta, Sarama, Pusa Bold and Kranti following Line × Tester mating design. A total of 47 treatments (35F1's+7 Lines+5 Testers) were used for this investigation. The crosses was carried out during *rabi* 2017-18. The crosses along with their parents were planted in randomized block design with three replications during *rabi* season 2018-2019. The treatments were raised in rows of 3 m length with a distance of 30 cm between rows and 15 cm between plants, where each treatment was represented by a single row.

Recommended agronomic practices were followed to raise a good crop. Observations were recorded on randomly selected five competitive plants excluding border plants for thirteen quantitative characters, *viz.,* days to flowering, days to 50% flowering, days to maturity, plant height (cm), primary branches/ plant, secondary branches/ plant, siliquae/plant, siliqua length (cm), seeds/siliqua, 1000 seed weight (g), length of main axis (cm), siliquae on main axis and seed yield/ plant (g). The data for days to flowering, days to 50% flowering and days to maturity were taken on a plot basis. The Combining ability analysis was carried for Line × Tester mating design as out lined by Kempthorne (1957).

RESULTS AND DISCUSSION

The analysis of variance (Table 1 a) for combining ability revealed that the mean sum of squares due to lines were significant for days to flowering, days to 50% flowering, days to maturity, plant height, secondary branches per plant and length of main shoot. The mean sum of squares due to testers was significant for plant height, total number of siliquae per plant and length of siliqua. Interaction effect for lines and testers was significant for all the traits. The variation due to parents vs. crosses was highly significant for all the characters except days to flowering and days to 50% flowering, suggesting the presence of heterosis for these characters in the crosses. Highly significant differences were recorded among the treatments for all the traits Similar finding were earlier reported by Arifullah *et al.*(2013), Synrem *et al.* (2015), Meena *et al.*(2015) and Chauhan *et al.* (2017). Similarly, highly significant variance due to crosses for all the traits was also observed by Synrem *et al.* 2014 and Meena *et al.* 2015 disclosing sufficient amount of genetic variability in the hybrids.

The estimates of SCA variances were higher than GCA variance (Table 1 b) for all the characters studied indicating that dominance variance was more than the additive

Table 1a: Analysis of variance for different characters in Line x Tester mating design in Indian mustard.

Source of variation	df	Days to flowering	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches /plant	Secondary branches/ plant	Total siliquae/ plant	Siliqua length (cm)	Seeds/ siliqua	1000-seed wt.(g)	Length of main axis(cm)	Siliquae on main axis	Seed yield/ plant(g)
Replication	2	0.76	0.26	2.65	0.30	0.02	1.32	28.67	0.0001	0.001	0.002	3.26	4.64	3.16
Treatments	46	133.09**	169.90**	92.56**	1491.50**	6.34**	71.78**	190250.09**	0.83**	7.99**	1.23**	299.00**	172.03**	777.67**
Parents	11	89.20**	110.72**	51.60**	960.85**	9.49**	113.79**	315090.27**	0.81**	6.06**	1.22**	274.90**	171.72**	1548.09**
Parents vs Crosses	1	1.60	0.06	115.21**	2791.63**	30.64**	433.34**	1048295.47**	0.89**	32.18**	1.31**	233.19**	36.76**	7971.50**
Crosses	34	151.15**	194.05**	105.15**	1624.94**	4.61**	47.56**	124623.99**	0.83**	7.90**	1.23**	308.74**	176.12**	316.83**
Parents (Lines)	6	350.67**	492.01**	224.20**	2066.89*	4.36	90.62*	142257.29	0.58	4.36	1.65	595.48*	301.32	480.56
Parents (Testers)	4	106.09	83.68	150.75	5559.07**	6.48	67.60	289249.01*	2.54**	5.68	1.86	271.02	48.90	285.73
Lines × Testers	24	108.79**	137.95**	67.79**	858.76**	4.36**	33.45**	92778.15**	0.61**	9.16**	1.14**	243.35**	166.02**	281.08**
Error	92	0.43	0.48	1.34	1.79	0.04	0.82	56.05	0.001	0.003	0.001	2.18	3.24	1.56

Table 1b: Estimates of components of genetic variance for various morphological traits in Indian mustard.

σ^2gca	0.83	1.10	0.73	14.97	0.01	0.28	622.28	0.004	0.03	0.002	1.28	0.20	0.70
σ^2sca	61.45	77.49	47.65	919.69	1.67	20.61	57301.73	0.41	2.17	0.44	120.67	55.98	114.81
σ^2A	1.66	2.19	1.46	29.94	0.01	0.55	1244.55	0.01	0.05	0.004	2.56	0.39	1.40
σ^2D	61.45	77.49	47.65	919.69	1.67	20.61	57301.73	0.41	2.17	0.44	120.67	55.98	114.81
σ^2gca/σ^2sca	0.01	0.01	0.02	0.02	0.003	0.01	0.01	0.01	0.01	0.01	0.01	0.004	0.01
2 σ^2gca/(2σ^2gca+σ^2sca)	0.03	0.03	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.02	0.01	0.01

variance. The ratio of variance due to general and specific combining ability was less than unity for all the traits highlighting preponderance effect of non-additive gene action. So, for the improvement of these traits, bi-parental mating followed by recurrent selection would be rewarding to get desirable recombinants. The present finding confirmed the study reported by Thakral *et al.* (2000), Singh *et al.* (2005), Gami and Chauhan (2013) and Chauhan *et al.* (2017).

The estimates of GCA effects of lines and testers are presented in Table 2 and it revealed that the parents namely, PM 24, PM 25, PM 30, Pusa Agrani and JD-6 among lines and Pusa Bold among the testers exhibited significantly positive GCA effects for seed yield per plant. So, additive gene action or additive × additive type of interaction effects mainly controlled these parents. Similarly, such additive type gene effect was also found in parents PM 25, PM 30, Pusa Agrani, JD-6, Pusa Bold and Kranti which exhibited significant GCA effects for siliquae/plant; PM 21, PM 24, Pusa Agrani, Sanjukta Asech and Sarama for siliqua length; PM 24, PM 25, Pusa Agrani, JD-6, Sanjukta Asech and Pusa Bold for seeds/siliqua; PM 21, PM 22, JD-6, Sanjukta Asech, Seeta and Sarama for 1000- seed weight; PM 22, PM 24, Pusa Agrani and Pusa Bold for days to maturity; PM 22, PM 24, PM 30, Pusa Agrani, JD-6, Sarama, Pusa Bold and Kranti for plant height; PM 25, PM 30, Pusa Agrani, JD-6 and Pusa Bold for primary and secondary branches/plant. The parent PM 25 had highest GCA effects among the lines for seed yield/plant followed by JD-6. Similarly, among the testers, only Pusa Bold had significant positive GCA effects for seed yield/plant. These parents can be utilized in further breeding program. Combining all traits the parents PM 24, PM 25, PM 30, Pusa Agrani, JD-6 and Pusa Bold appeared to be consistently superior for seed yield and important yield components consistently showing significantly positive SCA effects and thus the parents were mainly controlled by additive gene effect. All these parents can be considered as good general combiner for seed yield and important yield attributing traits like number of siliquae/plant, number of seeds/siliqua, number of primary branches/plant, plant height, days to maturity and so plants with higher yield coupled with more number of siliquae and early maturing lines would hopefully can be developed from segregating generations with fixable effect in nature.

Specific combining ability effect is a very important estimate for determining the potentiality of cross combination. In this study, out of 35 hybrids none of the crosses showed significant SCA effect for all the traits (Table 3). Similar results were observed by Patel *et al.,* (2015) and Synrem *et al.* (2015) also in their study. For days to flowering and maturity, earliness is a desirable criteria and so negative SCA effect was desirable. Similarly, for dwarf plant height is desirable in mustard and thus the hybrids which exhibits significantly negative SCA effects for these traits are of paramount importance in breeding program. For days to flowering 16 crosses showed highly significant but negative SCA effects. Similar effects were observed 18 crosses for days to 50% flowering, 11 for days to maturity and 16 crosses

Table 2: Estimates for GCA effects of line and testers for different characters in Indian mustard.

Parents	Days to flowering	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches/ plant	Secondary branches/ plant	Total siliquae/ plant	Siliqua length (cm)	Seeds/ siliqua	1000-seed wt.(g)	Length of main axis(cm)	Siliquae on main axis	Seed yield/ plant(g)
PM 21	1.50**	0.06	2.24**	14.83**	-0.74**	-2.79**	-118.29**	0.20**	-0.99**	0.51**	-3.34**	0.92	-6.34**
PM 22	-9.93**	-10.88**	-7.09**	-7.73**	-0.74**	-3.87**	-145.07**	-0.25**	-0.22**	0.13**	-6.09**	4.54**	-9.03**
PM 24	1.20**	1.66**	-1.03**	-5.83**	-0.11*	-0.36	-13.49**	0.25**	0.60**	-0.06**	4.31**	1.85**	2.34**
PM 25	0.59**	0.06	2.57**	18.55**	0.30**	2.49**	112.53**	0.01	0.35**	-0.60**	9.73**	3.94**	6.98**
PM 30	5.32**	6.92**	3.57**	-1.81**	0.46**	1.90**	57.71**	-0.09**	-0.25**	-0.004	-0.49	-6.16**	1.85**
Pusa Agrani	-1.41**	-2.48**	-2.76**	-7.69**	0.47**	1.52**	55.23**	0.11**	0.09**	-0.08**	3.77**	1.28**	0.87*
JD-6	2.72**	4.66**	2.51**	-10.32**	0.35**	1.11**	51.37**	-0.22**	0.41**	0.10**	-7.89**	-6.36**	3.37**
SE (Female)	0.17	0.18	0.30	0.35	0.05	0.23	1.93	0.01	0.01	0.01	0.38	0.47	0.32
Sanjukta Asech	2.16**	1.28**	1.94**	12.74**	-0.65**	-1.26**	-102.76**	0.56**	0.59**	0.24**	0.37	-0.56**	-1.31**
Seeta	0.57**	-0.15	1.04**	17.16**	-0.03	-0.75**	-55.89**	-0.03**	-0.26**	0.10**	-4.37**	1.83**	-1.95**
Sarama	-1.18**	0.80**	0.75**	-1.53**	-0.11**	-0.84**	-67.21**	0.04**	-0.47**	0.16**	3.24**	-0.81**	-1.03**
Pusa Bold	-3.29**	-3.39**	-4.72**	-24.12**	0.89**	3.15**	188.39**	-0.35**	0.53**	-0.32**	-2.91**	-1.80**	6.54**
Kranti	1.75**	1.47**	0.99**	-4.26**	-0.10**	-0.30**	37.48**	-0.22**	-0.40**	-0.18**	3.67**	1.33**	-2.25**
SE (Male)	0.14	0.15	0.25	0.29	0.04	0.20	1.63	0.01	0.01	0.01	0.32	0.39	0.27

for plant height. This indicates that the earliness in days to flowering, days to 50% flowering and days to maturity and reduction in plant height are possible to achieve and these negative trend are to be incorporated in high yielding background. Similar results of negative SCA effect for days to maturity and plant height were earlier reported by Yadava *et al.*(2012) and Meena *et al.*(2015). Significant and positive SCA effects were recorded for seed yield in 11 hybrids, 1000-seed weight in 19 hybrids, siliquae/plant in 13 hybrids, length of siliqua and seed/siliqua in 15 hybrids each, primary branches/plant in 10 hybrids and secondary branches/plant in 15 hybrids. All these crosses can be considered as good specific combiners.

The five best cross combinations having significantly positive SCA effects (Table 3 and Table 4) namely, JD-6 × Pusa Bold, PM 30 × Seeta, PM 25 × Pusa Bold, PM 24 × Kranti and PM 22 × Sarama showed that good specific combinations involve parents of high × high, high × low, low × low general combining ability effects. The crosses also showed significantly positive SCA effect for most of the traits (Table 3). Parents with high GCA effect are always favorable in a self-pollinated crop like mustard as characters with additive gene effect can be fixed at an early segregating generation (Singh *et al.* 1993). From these results it is clear that best cross combination are not always obtained from parents having high × high or high × low general combiners. In majority of the crosses expressing high SCA effects were found to have both or one of the parents as good general combiner for the trait under study. Hence, the ideal cross combination to be exploited is one which shows high magnitude of SCA in addition to GCA in both or at least in one of the parents. However the cross combinations where both parents are involved with non-additive gene effect can be useful for heterosis breeding or in such cross combination delayed selection can be practiced to get desirable recombinant type with homozygous effect (Singh *et al.* 1991).

The five best performing parents as good general combiners, best performing hybrids along with their heterosis (%) over mid parent as well as better parent and SCA effects for seed yield per plant is presented in Table 5. The estimates of SCA effects showed that five hybrids *viz*. JD-6 × Pusa Bold, PM 30 × Seeta, PM 25 × Pusa Bold, PM 24 × Kranti and PM 22 × Sarama exhibited significant and positive SCA effects for seed yield/plant. The performance of hybrids with compare to heterosis over mid parent (MP) and better parent (BP) for seed yield/plant revealed that out of total 35 crosses, five crosses also exhibited highly positive significant heterosis (Table 5). High amount of heterobeltiosis observed under the present study agreed with earlier reported by Vagela *et al.* (2011) and Patel *et al.* (2015). Yadava *et al.*(2012) who reported 54.38% heterobeltiosis in hybrid PM 25 × RGN 145 with highly significant SCA effects. Yadava *et al.*(1974) reported up to 239% heterosis over better parent and Verma *et al.*(2011) reported 24.36 to 80.97% heterosis in 15 crosses for seed yield per plant in mustard. Combining estimates of GCA, SCA and heterosis, five cross combinations namely

Table 3: Estimates for SCA effects of hybrids for different characters in Indian mustard.

Crosses	Days to flowering	Days to 50% flowering	Days to maturity	Plant height (cm)	Primary branches/ plant	Secondary branches/ plant	Total siliquae/ plant	Siliqua length (cm)	Seeds/ siliqua	1000-seed wt.(g)	Length of main axis(cm)	Siliquae on main axis	Seed yield/ plant(g)
PM 21 × Sanjukta Asech	2.87**	4.66**	4.52**	2.50**	-0.04	2.82**	171.67**	0.73**	1.30**	-1.02**	7.45**	6.45**	6.09**
PM 21 × Seeta	8.89**	10.42**	5.76**	14.28**	-1.26**	-1.69**	-91.33**	-0.24**	-0.72**	-0.98**	7.79**	-7.14**	-4.07**
PM 21 × Sarama	-2.78**	-4.20**	-3.95**	9.77**	1.43**	2.80**	236.98**	-0.22**	-0.52**	0.26**	-2.54**	11.70**	-0.33
PM 21 × Pusa Bold	-4.25**	-5.68**	-8.14**	-17.25**	0.03	-1.19*	-181.81**	0.68**	-1.60**	1.14**	-5.46**	-5.31**	-2.57**
PM 21 × Kranti	-4.72**	-5.20**	1.81**	-9.30**	-0.16	-2.74**	-135.50**	0.51**	1.54**	0.60**	-7.24**	-5.70**	0.89
PM 22 × Sanjukta Asech	-0.28	-0.41	-4.48**	-14.74**	0.57**	0.09	40.32**	-0.06**	-1.03**	0.46**	6.81**	2.82**	-1.69*
PM 22 × Seeta	2.32**	3.69**	2.09**	-21.86**	0.15	1.79**	78.85**	0.16**	0.07*	0.51**	-17.05**	-2.97**	0.16
PM 22 × Sarama	1.06**	-0.27	0.05	20.13**	0.23*	2.08**	113.17**	0.28**	-0.21**	-0.06**	11.94**	5.74**	8.03**
PM 22 × Pusa Bold	1.30**	1.59**	0.86	20.22**	-0.97**	-3.71**	-134.83**	-0.18**	-0.09**	-0.19**	1.29	-1.54	-6.94**
PM 22 × Kranti	-4.40**	-4.60**	1.48*	-3.74**	0.02	-0.26	-97.52**	-0.19**	1.25**	-0.72**	-2.99**	-4.06**	0.45
PM 24 × Sanjukta Asech	-5.84**	-2.61**	0.79	0.76	-0.27*	-3.41**	-159.87**	0.24**	-1.49**	0.94**	-12.50**	-7.88**	-9.26**
PM 24 × Seeta	-3.82**	-4.51**	-1.97**	14.64**	-0.27*	-1.31*	9.60*	0.01	0.77**	0.41**	1.52	-0.67	-3.21**
PM 24 × Sarama	0.49	-2.47**	2.65**	-18.97**	-0.80**	0.37	-98.62**	-0.22**	0.56**	-0.17**	-0.63	-1.56	7.26**
PM 24 × Pusa Bold	-6.40**	-6.94**	-4.54**	1.02	1.36**	1.72**	158.59**	-0.05**	0.21**	-0.68**	5.49**	0.16	-4.07**
PM 24 × Kranti	15.57**	16.53**	3.08**	2.56**	-0.02	2.63**	90.30**	0.02	-0.05	-0.51**	6.11**	9.97**	9.28**
PM 25 × Sanjukta Asech	-5.56**	-4.01**	-1.81**	-20.32**	0.13	3.14**	81.92**	-0.22**	-2.40**	-0.68**	-0.61	-0.27	4.31**
PM 25 × Seeta	0.04	-0.25	-0.24	-21.84**	-1.29**	-3.77**	-232.55**	-0.13**	0.06*	0.65**	-5.47**	-4.96**	-8.65**
PM 25 × Sarama	4.11**	2.47**	-2.62**	18.85**	-0.41**	-5.48**	-184.63**	0.10**	0.87**	-0.51**	2.22*	7.48**	-7.78**
PM 25 × Pusa Bold	3.55**	4.32**	4.52**	0.74	-0.01	2.33**	120.57**	0.78**	0.47**	0.05**	0.77	-4.13**	9.59**
PM 25 × Kranti	-2.15**	-2.53	0.14	22.58**	1.58**	3.78**	214.68**	-0.54**	1.00**	0.48**	3.09**	1.88	2.54**
PM 30 × Sanjukta Asech	-0.62	-2.21**	-4.14**	18.14**	-0.63**	-5.08**	-79.93**	0.08**	-0.20**	0.22**	12.50**	4.53**	-4.37**
PM 30 × Seeta	-8.03**	-10.11**	-6.57**	3.52**	3.35**	3.69**	267.07**	0.07**	1.86**	-0.75**	2.97**	-0.93	18.27**
PM 30 × Sarama	-1.29**	-1.40**	2.05**	-10.19**	-0.17	4.71**	150.58**	0.71**	1.27**	0.45**	-5.86**	-7.02**	7.15**
PM 30 × Pusa Bold	7.49**	8.79**	5.86**	-6.21**	-2.17**	-4.29**	-338.81**	-0.62**	-0.54**	0.05**	-12.12**	0.17	-19.02**
PM 30 × Kranti	2.45**	4.93**	2.81**	-5.26**	-0.38**	0.97	1.10	-0.24**	-2.40**	0.03	2.50**	3.25**	-2.04**
PusaAgrani × Sanjukta Asech	-1.56**	-2.81**	0.52	17.22**	0.55**	1.71**	-63.99**	0.58**	-0.54**	0.07**	2.75**	0.82	6.11**
Pusa Agrani × Seeta	3.70**	4.29**	3.10**	22.90**	-1.26**	-0.39	-12.85**	-0.14**	-0.88**	0.12**	10.29**	15.09**	0.25
Pusa Agrani × Sarama	-0.89*	-2.00**	-5.29**	-13.11**	0.58**	-1.77**	-123.01**	0.02	1.02**	-0.16**	-10.52**	-16.3**	-3.07**
Pusa Agrani × Pusa Bold	0.22	0.86*	2.19**	-12.93**	1.22**	2.10**	246.07**	-0.43**	-0.47**	0.07**	3.03**	5.52**	-0.24
Pusa Agrani × Kranti	-1.48**	-0.33	-0.52	-14.08**	-1.09**	-1.65**	-46.22**	-0.03*	0.86**	-0.10**	-5.55**	-5.10**	-3.06**
JD-6 × Sanjukta Asech	10.98**	7.39**	4.59**	-3.55**	-0.32**	0.72	9.87*	0.11**	4.34**	0.01	-16.39**	-6.47**	-1.19
JD-6 × Seeta	-3.10**	-3.51**	-2.17**	-11.63**	0.57**	1.68**	-18.79**	0.27**	-1.16**	0.04**	-0.05	1.57	-2.75**
JD-6 × Sarama	-0.69	7.87**	7.11**	-6.48**	-0.86**	-2.70**	-94.48**	-0.67**	-2.99**	0.19**	5.38**	-0.02	-11.27**
JD-6 × Pusa bold	-1.91**	-2.94**	-0.74	14.41**	0.54**	3.04**	130.23**	-0.18**	2.01**	-0.46**	6.99**	5.14**	23.26**
JD-6 × Kranti	-5.28**	-8.80**	-8.79**	7.25**	0.07	-2.74**	-26.83**	0.47**	-2.21**	0.21**	4.08**	-0.22	-8.06**
SE (SCA effect)	0.38	0.40	0.67	0.77	0.11	0.52	4.32	0.01	0.03	0.02	0.85	1.04	0.72

*and ** = Significant (0.05) and highly significant (0.01) respectively.

Table 4: Estimates of SCA effects of top five cross combinations for different characters in Indian mustard.

Characters	Crosses	SCA effects	GCA effect of parents		
			P1	P2	
Seed yield/plant(g)	JD-6 × Pusa Bold	23.26**	0.51**	-0.32**	H × L
	PM 30 × Seeta	18.27**	-0.06**	0.24**	L × H
	PM 25 × Pusa Bold	9.59**	-0.60**	0.09**	L × H
	PM 24 × Kranti	9.28**	0.51**	-0.18**	H × L
	PM 22 × Sarama	8.031**	0.132**	0.096**	H × H
1000-seed weight(g)	PM 21 × Pusa Bold	1.14**	0.51**	-0.32**	H × L
	PM 24 × Sanjukta Asech	0.94**	-0.06**	0.24**	L × H
	PM 25 × Seeta	0.65**	-0.60**	0.09**	L × H
	PM 21 × Kranti	0.60**	0.51**	-0.18**	H × L
	PM 22 × Seeta	0.506**	0.132**	0.096**	H × H
Siliquae/plant	PM 30 × Seeta	267.07**	57.71**	-55.89**	H × L
	Pusa agrani × Pusa Bold	246.07**	55.23**	188.39**	H × H
	PM 21 × Sarama	236.98**	-118.29**	-67.21**	L × L
	PM 25 × Kranti	214.68**	112.53**	37.48**	H × H
	PM 24 × Pusa Bold	158.587**	-13.487**	55.23**	L × H

H= High (significant and positive), L= Low (significant and negative), A= Average (non-significant). P1= Parent 1 and P2 = Parent 2.

Table 5: Top ranking crosses for seed yield in Indian mustard.

Cross combination	Heterosis		SCA effect	GCA effect for parents		Other characters with significant SCA effect
	MP	BP		P1	P2	
JD-6 × Pusa Bold	435.95**	316.85**	23.26**	0.51**	-0.32**	Seeds/siliqua, Secondary branches/plant
PM 30 × Seeta	341.42**	313.27**	18.27**	-0.06**	0.24**	Seeds/siliqua, Siliquae/plant, Days to maturity, Secondary branches/plant, Primary branches/plant
PM 25 × Pusa Bold	40.00**	17.93**	9.59**	-0.60**	0.09**	Siliqua length (cm)
PM 24 × Kranti	28.76**	11.11	9.28**	0.51**	-0.18**	Siliquae on main axis
PM 22 × Sarama	205.43**	181.00**	8.03**	0.13**	0.09**	Length of main axis (cm)

JD-6 × Pusa Bold, PM 30 × Seeta, PM 25 × Pusa Bold, PM 24 × Kranti and PM 22 × Sarama appeared superior for developing desirable lines as all these crosses were controlled by additive gene effect and also showed high heterosis for seed yield and several traits.

CONCLUSION

From the present investigation, it may be concluded that non-additive gene action was more important in the genetic control of seed yield and related traits. The parents namely, PM 24, PM 25, PM 30, Pusa Agrani, JD-6 and Pusa Bold were identified as general combiner for seed yield and yield attributing traits.These six parents can be utilized in heterosis breeding and also in the development of desirable recombinants. Based on high heterosis over mid parent as well as better parent and significant SCA effects, three cross combinations *viz.,*JD-6 × Pusa Bold, PM 30 × Seeta, PM 25 × Pusa Bold and PM 24 × Kranti were considered as superior for seed yield and its component traits where additive × additive or additive × non-additive gene effect operates. The high yielding desirable segregants with desirable traits would like to develop from superior cross combinations.

Conflict of interest: None.

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