Line × tester analysis for combining ability and heterosis in Indian mustard (*Brassica juncea*)

HS Meena[*], Arun Kumar, Swarnim Kulshrestha, PD Meena, Bhagirath Ram, Anubhuti Sharma, VV Singh and Dhiraj Singh

ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur-321303 (Raj) India
*Corresponding author: singh_hari2006@yahoo.co.in
(Received: 21 Nov 2016; Revised: 5 Dec 2016; Accepted: 16 Dec 2016)

Abstract

Line × tester analysis was carried out to estimate combining ability and heterosis of 18 hybrids developed by crossing 9 lines with 2 testers of Indian mustard. The F_1 hybrids along with parental genotypes planted at the experimental farm of ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur, India during 2015-16 were evaluated for twelve characters, including days to flowering, days to maturity, plant height (cm), number of primary & secondary branches / plant, main shoot length (cm), number of siliquae on main shoot, siliqua length (cm), number of seeds per siliqua, 1000-seed weight (g), oil content (%) and seed yield (kg/ha). Analysis of variance revealed sufficient genetic variability among parents, hybrids and parent vs. hybrids for most of the traits. The operation of both additive and non-additive gene actions with predominance of non-additive gene action was observed in controlling seed yield and contributing traits. Estimates of GCA effects indicated that RH 749, RH 406, Rohini, NRCHB 101 and NPJ 112 were good general combiner. Significant SCA effects for seed yield, 1000-seed weight, number of seeds/ siliqua and other attributing traits in desirable direction were recorded in a series of hybrids and a close association between SCA effects and heterosis was observed amongst the best hybrids identified on the basis of SCA effects. The three hybrids; NRCHB 101/ NPJ 112, RH-749/ NPJ 112 and RH-406/ RRN-727 exhibited high magnitude of better parent, standard parent and mid parent heterosis with highly significant SCA effects and higher per se performance for seed yield and important traits. The high yielding cross combinations can be further exploited for improving the seed yield by development superior genotypes and the parents involved in producing heterotic hybrids shall be converted to well adapted cytoplasmic male sterile or restorer lines.

Key words: Gene action, GCA, heterosis, Indian mustard, SCA

Introduction

Brassica juncea is an important oilseed crop plays a crucial role in edible oil economy of India and occupies premier position in Indian agriculture. It is major *rabi* oilseed crop of the Indian subcontinent occupies more than 80% of the total rapeseed-mustard cultivated area. Contributes nearly 27% of edible oil pool in India and accounts for more than 13% of the global edible oil production (Meena *et al*., 2014; Pratap *et al*., 2014). The average productivity of Indian mustard in India during last one and half decade, oscillating between 1.0 to 1.2 tonnes/ha, which is much below the world average of 1.98 tonnes/ha. Moreover, there is wider yield gaps when productivity of India is compared with countries like Germany (4.3 tonnes/ha), France (3.8 tonnes/ha) and UK (3.4 tonnes/ha) (Yadava *et al*., 2012). The enhancement in production and productivity of the crop assumes significance, not only for farmer's viewpoint but also for all closely linked enterprises. Thus, there is compelling need to increase and stabilize the productivity of Indian mustard to meet the growing demands for edible oil.

Comprehensive analysis of the combining ability involved in the inheritance of quantitative characters and in the phenomenon of heterosis is necessary for the evaluation of various possible breeding procedures (Allard, 1960).The knowledge of

combining ability is useful to get information on selection of parents and nature of gene actions involved. Combining ability analysis is one of the powerful tools to test the value of parental lines to produce superior hybrids and for recombinants (Singh *et al*., 2013). Exploitation of heterosis may play a very significant role to boost up the production and productivity of Indian mustard. Heterosis breeding can be one of the most viable options for breaking the present yield barrier. Further, for developing better genotypes through hybridization, the choice of suitable parents is of great concern. In rapeseed breeding program for hybrid and open pollinated varieties, general and specific combining ability effects (GCA and SCA) are important indicators of the potential of inbred lines in hybrid combinations. The various mating designs have been used for assessing the breeding value of the parents through the estimation of variance and combining ability effects. Indian mustard being a self pollinated crop, the technique of line x tester of Kempthorne (1957) for combing ability analysis is one of the efficient methods of evaluating large number of inbreds as well as providing information on the relative importance of GCA and SCA effects for interpreting the genetic basis of important plant traits (Singh and Chaudhury, 1977). Keeping these points in view, the present investigation was undertaken to determine type of gene action, general combining ability and specific combining ability of parental lines and heterosis of different cross combinations in *B. juncea*.

Materials and Methods

The study was conducted at ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur during 2014-15 and 2015-16. The experimental material consisted of 18 F_1s of Indian mustard (*Brassica juncea*) involving 9 lines namely RH-749 (RH-781/RH-9617), RH-406 (RH-6908/RH-8812), Rohini (Pure line selection from Varuna), NRCDR-2 (MDOC-43/NBPGR-36), NRCHB 101(BL-4/Pusa Bold), SEJ-2 (Synthetic amphiloid from *B. campestris*/*B.nigra*), DRMRIJ-31 (HB-9908/HB-9916), DRMR 2019 (EC-399288/BEC-107), DRMR 2035 (PHR-1/BEC-107) and two testers *viz.,* NPJ-112 (SEJ-8/Pusa Jagannath), RRN 727 (RW-01-02/Patan 67) were crossed in line × tester design during 2014–15. The aim of the present study was

to evaluate GCA and SCA of high yielding varieties and breeding lines with early maturing and dwarf donors. Therefore, in present study the two testers were selected on the basis of their maturity period and growth habit.

The crosses along with their parents were planted in randomized complete block design with three replications during *Rabi* 2015–16. The treatments were raised in rows of 5m length with a distance of 30cm between rows and 15cm between plants, where each treatment was represented by two rows. Standard agronomic practices were followed to raise the good crop. Recommended doses of fertilizers *viz.,* 80:40:40:40 kg/ha of N:P:K:S, respectively, were applied and irrigated thrice including pre-sowing irrigation. Observations were recorded on twelve quantitative traits, *viz.,* days to flowering, days to maturity, plant height (cm), number of primary branches / plant, number of secondary branches / plant, main shoot length (cm), number of siliquae on main shoot, siliqua length (cm), number of seeds per siliqua, 1,000-seed weight (g), oil content (%) and seed yield / hectare (kg). Observations on days to flowering and maturity were recorded on per plot basis, seed yield was converted & expressed in kg per hectare and the observations on remaining traits were recorded on randomly selected ten competitive plants in each replication.

The combining ability analysis was carried out as per the method of Kempthorne (1957). Standard heterosis (economic heterosis), better parent heterosis (heterobeltiosis) and mid-parent heterosis was calculated as deviation of F_1 value from the values for selected standard parent (commercial variety), better parent and mid-parent, respectively. The variety RH 749 was selected as standard parent for estimating standard heterosis. The calculations were performed through com-puter generated programme WINDOW STAT version 8.6 from INDOSTAT Services, Hyderabad, India.

Results and Discussion

The analysis of variance (Table 1) for combining ability revealed that the mean squares due to lines, testers and line × testers were highly significant for all the traits except for days to flowering, days to

Table 1: Analysis of variance for morphological traits in line × tester analysis in Indian mustard

Characters Source of variation	D.F.	Days to flowering	Days to maturity	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of siliqua on main shoot	Main shoot length (cm)	Siliqua length (cm)	Number of seeds /siliqua	1000 seed weight (g)	Oil content (%)	Seed yield (kg/ha)
Replication	2	11.18	119.46	232.19	0.49	16.01	28.86	65.32	0.02	0.25	0.01	1.34	20320.85
Treatments	28	177.66**	256.82**	3577.86**	5.37**	43.78**	177.14**	248.55**	1.96**	8.58**	4.08**	2.43**	1086544.0**
Parents	10	281.67**	427.33**	4046.22**	4.74**	65.93**	202.98**	371.49**	3.01**	6.62**	3.48**	3.72**	914366.20**
Parents (lines)	8	172.54**	299.89**	1294.15**	5.31**	81.51**	179.44**	180.84**	2.53**	7.56**	0.69**	2.41*	422007.00**
Parents (testers)	1	66.67	150.00	7392.06**	3.53*	4.86	15.36	802.73**	4.07**	5.23	13.05**	3.04	3488895.0**
Parents (L vs. T)	1	1369.70**	1724.15**	22716.95**	1.42	2.40	578.89**	1465.47**	5.83**	0.43	16.18**	14.87**	2278711.0**
Parents vs. crosses	1	463.95**	306.83*	1256.30**	0.09	14.14	22.01	2.54	1.72**	15.98**	11.43**	5.09*	476032.60**
Crosses	17	99.64**	153.57**	3438.92**	6.04**	32.49**	171.07**	190.69**	1.36**	9.29**	3.99**	1.51	1223738.0**
Line effects	8	118.71*	201.28	2845.37	7.05*	56.21*	155.30	127.11	0.46	6.30	2.46	1.54	1064929.0*
Tester effects	1	567.13**	253.50	26048.07**	32.67**	25.63	161.55	1107.96*	12.33**	20.17	29.05**	3.47	9840515.0**
L × T effects	8	22.13	93.37	1206.32**	1.71*	9.64	188.03**	139.63**	0.89**	10.93**	2.41**	1.23	305449.90**
Error	56	22.95	51.31	106.93	0.76	10.23	40.94	39.16	0.05	1.65	0.16	1.06	14204.49
Total	86	73.04	119.80	1239.91	2.25	21.29	85.02	107.94	0.67	3.88	1.432	1.51	36348070.70

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

Table 2: Estimates of components of variance for morphological traits in Indian mustard

Characters Component of variation	Days to flowering	Days to maturity	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of siliqua on main shoot	Main shoot length (cm)	Siliqua length (cm)	Number of seeds /siliqua	1000 seed weight (g)	Oil content (%)	Seed yield (kg/ha)
σ^2 lines	19.76	29.77	460.65	1.05	7.19	18.61	12.43	0.07	0.74	0.41	0.16	176287.03
σ^2 testers	21.00	8.55	961.73	1.18	0.47	4.37	39.09	0.46	0.68	1.08	0.11	364196.58
σ^2 GCA	20.77	12.41	870.62	1.16	1.69	6.96	34.24	0.39	0.69	0.95	0.12	330031.21
σ^2 SCA	7.32	23.56	374.95	0.32	-1.14	48.12	29.04	0.28	3.03	0.80	0.22	99414.27
σ^2 GCA / σ^2SCA	2.84	0.53	4.64	7.22	-2.95	0.29	2.36	2.72	0.46	2.39	1.06	6.64

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

maturity, number of secondary branches, number of siliqua on main shoot, number of seeds / siliqua & oil content (%) in testers and number of primary branches, number of secondary branches and number of seeds / siliqua in line vs. testers. This shows that sufficient genetic variability was present in the experimental material and both GCA and SCA were involved in the genetic expression of traits studied. The variation due to parents vs. crosses was significant for seed yield/ hectare (kg), days to flowering, days to maturity, plant height (cm), siliqua length (cm), number of seeds per siliqua, 1000-seed weight (g) and oil content (%), suggesting the presence of heterosis for these traits in the series of crosses. Similarly, highly significant variance due to crosses revealed that the sufficient amount of genetic variability was generated in the hybrids. The estimates of GCA and SCA variances for most of the traits indicating the operation of both additive and non-additive components of gene action in the materials under study (Table 2). Predominant role of non-additive gene effects in manifestation of heterosis for days to maturity, number of siliqua on main shoot, seeds/siliqua and oil content (%) was demonstrated by higher value of specific combining ability variance ($ó^2$ SCA) than general combining ability variance ($ó^2$ GCA). The ratio of GCA/SCA variances was less than unity for days to maturity, number of siliqua on main shoot, number of seeds / siliqua again indicating the predominance of non-additive gene action for these traits while it was higher than unity for traits like days to flowering, plant height (cm), number of primary branches, main shoot length siliqua length (cm), 1000-seed weight, oil content (%) and seed yield/hectare (kg) indicating the preponderance of additive gene effects for these traits. Further, both additive and non-additive types of gene actions were important for rest of the traits. Since both additive and non-additive gene actions are controlling the yield contributing traits, therefore, hybridization methods such as multiple or reciprocal recurrent selection would be helpful in genetic improvement of these traits. Similar results were earlier reported by many workers (Priti *et al*., 2011; Meena *et al*., 2015) in Indian mustard. 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. In order to make an effective breeding programme, biparental mating among randomly selected plants in F_2 and subsequent generation would help in pooling the desired genes together to develop pure lines. Further crossing of these lines would help in exploiting non-additive genetic components of variation to develop hybrids. Moreover, biparental mating, recurrent selection and selective diallel mating might be effective to exploit additive × additive type of epistasis. Furthermore, the combining ability variances for lines, testers and line × tester are significant for almost all the traits indicating the sufficient variation for combining ability in parents as well as in hybrids.

The estimates of GCA effects (Table 3) revealed that the parents RH-749, RH-406, Rohini, NRCHB-101 and NPJ-112 possessed highly significant positive GCA effects for seed yield / hectare indicating the presence of additive gene action or additive × additive interaction effects. Spragme (1966) reported that when general combining ability effects are significant additive or additive x additive gene effects are responsible for the inheritance of that particular trait. Parent RH 406 and tester NPJ 112 exhibited significant desirable GCA effects for 1000-seed weight; SEJ 2 for days to maturity; NRCHB-101, DRMR IJ-31, DRMR-2019 and RRN 727 for plant height; NRCHB-101, SEJ 2, DRMR-2019, DRMRIJ-31 and RRN-727 for days to flowering; NPJ 112 for main shoot length; RH 406 and NPJ-112 for number of primary branches; RH 406, DRMR IJ-31and NPJ-112 for siliqua length; SEJ-2 & NRCDR-2 for number of siliqua on main shoot and NRCDR 2 for number of secondary branches. Similarly for number of seeds per siliqua significant and positive GCA effects were possessed by DRMR-2019 and NPJ-112. Among lines NRCHB-101 had highest GCA effects and also complemented for days to flowering and plant height followed by RH 406 desirably complemented for number of primary branches, siliqua length and 1000-seed weight (g). Similarly among tester NPJ-112 had significant positive GCA effects for seed yield and complemented for other attributing traits like number of primary branches, main shoot length,

Table 3: Estimates for GCA effects of line and testers for twelve characters in Indian mustard

Parents Lines	Days to flowering	Days to maturity	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of siliqua on main shoot	Main shoot length (cm)	Siliqua length (cm)	Number of seeds /siliqua	1000 seed weight (g)	Oil content (%)	Seed yield (kg/ha)
RH-749	3.43**	2.70	11.94**	0.79	2.43	-2.71	-8.86**	-0.20	-1.27*	0.08	-0.47	110.24**
RH-406	4.59**	7.37**	36.77**	2.36**	1.76	1.55	-2.29	0.51**	-1.94**	1.55**	-0.25	574.44**
Rohini	-0.07	-3.13	6.64	-0.74*	-0.87	-0.58	-1.78	-0.12	-0.04	0.05	0.14	201.60**
NRCDR-2	3.09**	2.87	23.44**	0.63	3.63*	6.75*	3.61	-0.09	0.23	-0.13**	0.12	83.90
NRCHB-101	-7.24**	2.04	-18.73**	-0.87*	-0.97	-5.81*	0.81	0.08	0.36	0.01	0.53	597.49**
SEJ-2	-2.91**	-13.13**	-9.06*	-0.31	1.99	6.38*	6.38*	-0.27**	-0.04	-0.20**	-0.23	-386.46**
IJ-31	-2.07**	-1.13	-29.89**	-0.87*	-3.01*	-0.88	-3.29	0.30**	0.93	-0.07	0.48	-245.31**
DRMR 2019	-4.41**	-0.79	-19.39**	-0.77**	-6.07**	-8.05**	3.88	0.12	1.33*	-0.29**	0.59	-354.78**
DRMR 2035	5.59**	3.20	-1.73	-0.21	1.10	3.35	1.54	-0.33**	0.46	-0.84**	-0.91**	-581.12**
SE ±	0.16	1.94	3.68	0.35	1.48	2.69	2.96	0.08	0.55	0.04	0.30	34.66
CD (P=0.05)	0.33	3.95	7.49	0.72	2.99	5.48	6.01	0.17	1.13	0.08	0.62	70.43
CD (P=0.01)	0.45	5.31	10.05	0.96	4.03	7.36	8.07	0.23	1.51	0.11	0.83	94.56
Testers												
NPJ-112	3.24**	2.17*	21.96**	0.78**	0.69	1.73	4.53**	0.48**	0.61*	0.73**	-0.25	426.89**
Dwarf (RRN-727)	-3.24**	-2.17*	-21.96**	-0.78**	-0.69	-1.73	-4.53**	-0.48**	-0.61*	-0.73**	0.25	-426.89**
SE ±	0.08	0.92	1.74	0.17	0.69	1.27	1.39	0.04	0.26	0.02	0.14	16.34
CD (P=0.05)	0.16	1.86	3.53	0.34	1.41	2.58	2.83	0.08	0.53	0.04	0.29	33.20
CD (P=0.01)	0.21	2.50	4.74	0.45	1.90	3.47	3.81	0.11	0.71	0.05	0.39	44.58

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

Table 4: Specific combining ability (SCA) effects of lines and testers for various agro-morphological traits

Crosses	Days to flowering	Days to maturity	Plant height (cm)	Number of primary branches	Number of secondary branches	Number of siliqua on main shoot	Main shoot length (cm)	Siliqua length (cm)	Number of seeds /siliqua	1000 seed weight (g)	Oil content (%)	Seed yield (kg/ha)
RH-749×NPJ112	0.76**	2.67	19.70**	0.96	0.84	5.47	4.54	0.29*	-0.98	0.31**	-0.22	182.58**
RH-749×RRN727	-0.76**	-2.67	-19.70**	-0.96	-0.84	-5.47	-4.54	-0.29	0.98	-0.31**	0.22	-182.58**
RH-406×NPJ112	-3.07**	-3.00	-32.79**	-0.34	0.44	0.54	-8.36	-0.84**	-0.04	-1.61**	0.82	-464.34**
RH-406×RRN727	3.07**	3.00	32.79**	0.34	-0.44	-0.54	8.36	0.84**	0.04	1.61**	-0.82	464.34**
Rohini×NPJ112	0.26	-0.83	5.54	0.16	0.28	9.74*	4.14	-0.02	-1.74*	0.25**	-0.49	-37.17
Rohini×RRN727	-0.26	0.83	-5.54	-0.16	-0.28	-9.74*	-4.14	0.02	1.74*	-0.25**	0.49	37.17
NRCDR-2×NPJ112	0.09	0.17	-3.13	-0.48	-1.09	-3.73	-0.24	-0.31*	-1.08	-0.004	-0.43	-52.81
NRCDR-2×RRN727	-0.09	-0.17	3.13	0.48	1.09	3.73	0.24	0.31*	1.08	0.004	0.43	52.81
NRCHB-101×NPJ112	3.09**	6.67*	4.70	-0.91	-1.89	-2.83	-1.26	0.48**	2.46**	0.23**	-0.03	271.47**
NRCHB-101×RRN727	-3.09**	-6.67*	-4.70	0.91	1.89	2.83	1.26	-0.48**	-2.46**	-0.23**	0.03	-271.47**
SEJ-2×NPJ112	2.09**	-7.83**	7.70	-0.01	0.28	-0.63	-0.03	0.17	0.39	0.48**	0.27	159.95**
SEJ-2×RRN727	-2.09**	7.83**	-7.70	0.01	-0.28	0.63	0.03	-0.17	-0.39	-0.48**	-0.27	-159.95**
IJ-31×NPJ112	-2.07**	1.17	-4.13	0.09	-1.46	-7.29	-4.03	0.12	-0.91	0.32**	0.55	-181.21**
IJ-31×RRN727	2.07**	-1.17	4.13	-0.09	1.46	7.29	4.03	-0.12	0.91	-0.32**	-0.55	181.21**
DRMR-2019×NPJ112	-1.07**	0.50	0.04	0.19	0.41	-5.59	-2.19	0.15	0.42	0.20**	-0.25	146.36**
DRMR-2019×RRN727	1.07**	-0.50	-0.04	-0.19	-0.41	5.59	2.19	-0.15	-0.42	-0.20**	0.25	-146.36**
DRMR-2035×NPJ112	-0.07	0.50	2.37	0.36	2.18	-4.34	7.47	-0.02	1.49	-0.18**	-0.22	-24.83
DRMR-2035×RRN727	0.07	-0.50	-2.37	-0.36	-2.18	4.34	-7.47	0.02	-1.49	0.18**	0.22	24.83
No of crosses withdesirable SCA effects	6	2	2	0	0	1	0	4	2	8	0	6

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

Table 5: Mean performance and estimates of standard heterosis (SP) for seed yield in *Brassica juncea* genotypes

Lines	Tester		Mean seed yield of lines (g)
	NPJ 112	RRN-727	
RH-749	2716.87 (15.10**)	1497.94 (-36.54**)	2360.49
RH-406	2534.16 (7.36*)	2609.06(10.53**)	2026.34
Rohini	2588.48(9.66**)	1809.05(-23.36**)	1970.37
NRCDR-2	2455.14(4.01)	1707.00(-27.68**)	2434.57
NRCHB-101	3293.01(39.51**)	1896.30(-19.67**)	2886.09
SEJ-2	2197.53(-6.90*)	1023.87(-56.62**)	1687.24
DRMR IJ-31	1997.53(-15.38**)	1506.17(-36.19**)	2212.35
DRMR- 2019	2215.64(-6.14*)	1069.14(-54.71**)	2159.67
DRMR- 2035	1818.11(-22.98**)	1013.99(-57.04**)	2724.28
Mean seed yield of testers (g)	2354.73	829.63	

Values in parentheses represent standard heterosis
**,*: SP with SCA effects significant at P=0.01 and P=0.05, respectively.

siliqua length, number of seeds per siliqua and 1000-seed weight (g). These parents can be used in further breeding programmes in Indian mustard. Verma (2000), Singh *et al*. (2005), Yadava *et al*. (2012), Singh *et al*. (2013) and Meena *et al*. (2015) reported similar results in Indian mustard with a different set of material. 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 were not good for various other yield-contributing traits, therefore, one should breed to improve the combining ability of yield-contributing traits which would ultimately improve the GCA of seed yield directly. RH-749, RH-406, Rohini, NRCHB-101 and NPJ-112 possessing high GCA for seed yield and yield contributing traits like reduced plant height, higher siliqua length, higher main shoot length, more number of seeds / siliqua, improved 1000 seed weight, and early flowering shall be included in the breeding programme for accumulation of favorable alleles in a single genetic background.

The estimates of SCA effect are presented in the Table 4. None of the cross combination was found to be a common combiner for all the characters under study. For plant height two crosses *viz*. RH-749/ RRN-727, RH-406/ NPJ-112 recorded highly significant but negative SCA effects. Similar effects

were observed in six crosses for days to flowering and two cross for days to maturity. This indicates that the reduction in plant height, days to flowering and days to maturity may be due to negative heterosis in these crosses for these traits, which was considered as desirable. The results are in accordance with Yadava *et al*. (2012). Highly significant and positive SCA effects were observed for seed yield in 6 hybrids, 1000-seed weight in 8 hybrids, siliqua length in 4 hybrids, number of seeds / siliqua in 2 hybrids and number of siliqua on main shoot in 1 hybrid. However, none of the hybrid revealed significant positive SCA effect for oil content, main shoot length, number of primary branches and number of secondary branches. The outcomes clearly indicated that the parents involved in these crosses are good specific combiners; however, the relative contribution of the parents to specific combining ability effect for seed yield is through various yield attributing traits in different hybrids. Again, the results indicated that there is no direct relationship between SCA effects and heterobeltiosis or standard heterosis.

The estimates of standard heterosis for seed yield are presented in Table 5. The commercial variety RH-749 was utilized as selected standard parent for estimating standard heterosis (SP). Out of 18 hybrids, 4 hybrids exhibited highly significant and

Table 6: Top ranking crosses for seed yield per hectare in Indian mustard (*Brassica juncea* L.)

Cross Combination	Per se performance	Heterosis			SCA effect	Magnitude of GCA		Other characters with significant SCA effect
		Mid parent (MP)	Better parent (heterobeltiosis) (BP)	Selected standard parent (SP)		P_1	P_2	
RH-749×NPJ-112	2716.87	15.24**	15.10**	15.10**	182.58**	110.24**	426.89**	Siliqua length, 1000- seed weight
RH-406×RRN-727	2609.06	82.71**	28.76**	10.53**	464.34**	574.44**	-426.89**	Siliqua length, 1000- seed weight
NRCHB-101×NPJ-112	3293.01	25.67**	14.10**	39.51**	271.47**	597.49**	426.89**	Siliqua length,Number of seeds / siliqua, 1000- seed weight

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

positive selected parent heterosis (standard heterosis) and of them 3 hybrids NRCHB-101/ NPJ-112, RH-749/ NPJ-112, and RH-406/ RRN-727 showed >10% standard heterosis for seed yield (kg/ ha). These three crosses also exhibited highly significant positive heterosis over mid parent (MP) and better parent (BP) for seed yield with more than 10 percent. Yadava *et al.* (2012) reported 54.38% heterobeltiosis in hybrid Pusa mustard-25/ RGN-145 and Vaghela *et al.* (2011) reported 44.8% heterobeltiosis in the hybrid RSK 28/RH(0E)0103 with highly significant SCA effects and higher *per se* performance. Similarly, Hirve and Tiwari (1992) reported 161% better parent heterosis in hybrid RAU RP-4/ PR-18, Dhillon *et al.* (1990) reported 113.6% in RLM-198 / RK-2, Duhoom and Basu (1981) reported 102.7% in YS-51/ YS-9 and Yadava *et al*. (1974) reported 204% better parent heterosis in hybrid F-48/ IB-494. Heterosis for seed yield to the extent of 24.36 to 80.97% was also reported by Verma *et al.* (2011) in 15 crosses and moderate level of heterosis for seed yield/plant, number of siliquae/ plant and number of secondary branches/plant was reported by Aher *et al.* (2009). Similarly, Meena *et al.* (2014) reported >15% standard heterosis in seven crosses of Indian mustard.

The information on gca effects of the parents shall be considered along with highly significant sca effect and higher *per se* performance of hybrids for predicting the value of any hybrid. The top ranking crosses on the basis of various parameters are summarized in Table 6. The three hybrids NRCHB-101/ NPJ-112, RH-749/ NPJ-112 and RH-406/ RRN-727 showed higher *per se* performance, high heterosis over mid parent, better parent as well as selected standard parent with desirable sca effects for seed yield per hectare. The high yielding cross combinations can further be exploited for selection of high yielding pure lines or transgressive segregants with desirable traits during further generations and the parents involved in developing heterotic hybrids in the present study shall be converted to well adapted cytoplasmic male sterile or restorer lines for development of highly heterotic commercial hybrids.

References

Aher CD, Shelke LT, Chinchane VN, Borgaonkar SB and Gaikwad AR. 2009. Heterosis for yield and yield components in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Int J Plant Sci* **4:** 30-32.

Allard RW. 1960. *Principles of Plant Breeding*. John Wiley and Sons. New York.

Dhillon SS, Labana KS and Banga SK. 1990. Studies on heterosis and combining ability in Indian mustard (*B. juncea* L.). PAU *J Res* **27**: 1-8.

Duhoom SS and Basu AK. 1981. Note on heterosis in yellow seeded Indian colza. *Indian J Agri Sci* **51:** 121–124.

Gupta P, Chaudhary and Lal SK. 2011. Heterosis and combining ability analysis for yield and its components in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Acad J Plant Sci* **4**: 45-52.

Hirve CD and Tiwari AS. 1992. Heterosis and inbreeding depression in Indian mustard. *Indian J Genet* **51:** 190-193.

Kempthorne O. 1957. An Introduction to Genetic Statistics, pp. 545. Wiley, New York.

Meena HS, Kumar A, Ram B, Singh VV, Singh BK, Meena PD and Singh D. 2015. Combining ability and heterosis for seed yield and its components in Indian mustard (*B. juncea*). *J Agri Sci Tech* **17:** 1861-1871.

Meena HS, Ram B, Kumar A, Singh BK, Meena PD, Singh VV and Singh D. 2014. Heterobeltiosis and standard heterosis for seed yield and important traits in *B. juncea*. *J Oilseed Brassica* **5:** 134-140.

Pratap P, Meena PD, Singh BK, Meena HS, Meena SS, Sharma P, Majumdar R and Singh Dhiraj. 2014. Development and evaluation of Alternaria blight tolerant lines in Indian mustard (*B. juncea*). *J Oilseed Brassica* **5:** 141-148.

Singh A, Avtar R, Singh D, Sangwan O, Thakral NK, Malik VS, Goyat B and Dalal U. 2013. Combining ability analysis for seed yield and component traits in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Res Plant Biol* **3:** 26–31.

Singh A, Avtar R, Singh D, Sangwan O, Thakral NK, Malik VS, Goyat B and Dalal U. 2013. Combining ability analysis for seed yield and component traits in Indian mustard [*B. juncea* (L.) Czern & Coss.]. *Res Plant Biol* **3:** 26–31.

Singh RK and Chaudhury BD. 1977. Biometrical Techniques in Breeding and Genetics. Scholarly Pubns, Delhi, India. Pp: 350.

Singh SK, Haider ZA and Ram S. 2005. Combining ability and heterosis for seed yield and its components in Indian mustard (*B. juncea*). *Indian J Agri Sci* **75:** 228–229.

Spragme GF. 1966. Quantitative genetics in plant improvement. In Plant Breeding, Fey, K J (Eds). Iowa State University Press Iowa Pp: 315-354.

Vaghela PO, Thakkar HS, Bhadauria HS, Sutariya DA, Parmar SK and Prajapati DV. 2011. Heterosis and combining ability for yield and its component traits in Indian mustard (*B. juncea*). *J Oilseed Brassica* **2:** 39–43.

Verma OP, Yadav R, Kumar K, Singh R, Maurya KN and Ranjana. 2011. Combining ability and heterosis for seed yield and its components in Indian mustard (*B. juncea*). *Plant Archives* **11:** 863–865.

Verma RR. 2000. Combining ability analysis for seed yield and its components through diallel crosses in indica coiza [*B. juncea* (L.) Czern & Coss.]. *Indian J Agric Res* **34:** 91–96.

Yadava DK, Singh N, Vasudev S, Singh R, Singh S, Giri SC, Dwivedi VK and Prabhu KV. 2012. Combining ability and heterobeltiosis for yield and yield-contributing traits in Indian mustard (*Brassica juncea*). *Indian J Agri Sci* **82:** 563–567.

Yadava TP, Singh H, Gupta VP and Rana RK. 1974. Heterosis and combining ability in raya for yield and its components. *Indian J Genet* **34:** 684-695.