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Jagdish Prasad Chaurasiya
Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Mahak Singh
Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

RK Yadav
Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Lokendra Singh
Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Correspondence
Jagdish Prasad Chaurasiya
Department of Genetics and Plant Breeding, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India

Hetrosis and combining ability analysis in Indian mustard (*Brassica juncea* (L.) Czern and Coss.)

Jagdish Prasad Chaurasiya, Mahak Singh, RK Yadav and Lokendra Singh

Abstract
A study of Diallel analysis excluding reciprocal cross, of seven parents was carried out to identify high heterotic crosses and their relationship in terms of general and specific combining ability (GCA and SCA) in Indian mustard in year 2015-16 and 2016-17. Out of 21 specific crosses, highest economic heterosis was observed in case of five crosses viz ; NRCHB-101 X Pusa M-21 (9.56), Urvashi X Pusa Bold (9.03), NRCDR-2 x Urvashi (8.69), Maya X Pusa Bold (8.65) and Maya X NRCDR-2 (8.30). ANOVA study of GCA variances significant for all the characters and SCA variances significant for nine characters except in case of days to maturity, plant height and biological yield per plant. The ratio of GCA and SCA variances were below unity in Six characters Out of twelve characters,. Urvashi, Pusa Bold are the best parent for almost all traits as their GCA and per se performance are highest. Maya X NRCDR-2, Maya x Urvashi, Maya x Pusa Bold, NRCDR-2 X Urvashi, NRCHB-101 X Pusa M-21 and Urvashi X Pusa Bold showed high per se performance as well as SCA effects. The above best parent and best crosses can be used in hybridization and heterosis breeding respectively.

Keywords: *Brassica juncea, Indian mustard*, Diallel, Hetrosis, Combining ability, GCA, SCA.

Introduction
Indian mustard (*Brassica juncea)* is a naturally autogamous species, yet in this crop frequent out-crossing occurs which varies from 5 to 30% depending upon the environmental conditions and random variation of pollinating insects. Oilseed *Brassicas* grown in India *are B.juncea, B. rapa, B. napus, B. carinata. and B. compestris* predominates and accounts for about 90% area under rapeseed-mustard crops. These crops are grown in diverse agro-climatic conditions varying from north-eastern/north-western hills down south under irrigated/ rainfed, timely/late sown and sole/mixed cropping in leading states Rajasthan, Uttar Pradesh, Madhya Pradesh, Gujarat, Haryana, West Bengal, Assam, Bihar and Punjab. India is the second largest importer of edible oilseeds after China. In India the area of Rape and Mustard 5.76 Mha, Production 6.82 MT and yield 1184 kg/ha in. (**Anonymous 2015-16) [1]**. In terms of area under oilseeds, India holds premier position in the world but the yield of the most of oilseeds is less than the world average. On the other hand the demand of edible oils is increasing very rapidly with increasing population and has been estimated to be 20.20 million tonne for year 2020, 28.40 million tonne for the year 2030 and 41.6 million tonne for the year 2050. **(Arvind kumar, 2017) [5].**
Seed quality, Seed yield and other yield related parameters of Brassica oil seed crop has been tried to improve by several Researchers (Rakow, 1995, Singh, 2003, Saini, 2015 and Kumar, 2017) [25, 27, 11, 5]. Heterosis is the best way to improve crop varieties. Heterosis is the interpretation of increased vigor, size, fruitfulness, development speed, resistance to disease and insect pests or climatic vigor's, manifested by cross-bred organisms as compared with Corresponding inbreds (Shull, 1952; Jinks and Jones, 1958) [26, 22]. Development of hybrid cultivars has been successful in many *Brassica spp*. (Miller, 1999) [23]. For the study of inheritance of Quantitative characters and evaluation of various possible Breeding procedures in heterosis phenomena, the Comprehensive study of combining ability is immensely Essential (Allard, 1960) [22]. Combining ability studies emphasized the preponderance effect of GCA on yield and most of the yield components, indicating the importance of additive gene action (Wos *et al*., 1999 and Singh, 2017) [29, 12]. On the other hand, Pandey *et al*. (1999) and Saini, (2015) reviewed evidences for the presence of significant SCA effects for yield and yield components, indicating the importance of non-additive gene action. Singh *et al*. (2005) reported that non-additive genetic effects in addition to additive effects accounted for yield heterosis. In Indian mustard Singh *et al*. (2006 & 2017) [12] observed that general and specific combining ability variance were highly significant for almost all the characters and

reported that high GCA for 1000 seed weight and oil content, high SCA for seed yield and oil content. Kumar *et al*. (2017) [5] observed that high heterosis is the result of high sca effects. Lal *et al*. (2013) [19] reported that heterosis was of high order for no. of primary branches, no. of secondary branches,no. of siliqua per plant, biological yield per plant, harvest index,1000-seed weight and seed yield per plant the range of hetrosis was quite low for days to flowering and days to maturity a large no. of crosses exhibited significant negative hetrosis for days to maturity for seed yield, pusa bahar x pusa basant recorded highest standard hetrosis of 28.04%. In general crosses involving at least one of the parent with high performing yielded hetrotic results.However standard hetrosis exhibited by pusa bahar x pusa basant indicates manifestation of hetrosis even when both the parents are low performing. Nasrin *et al* (2011) [8] reported that GCA effect was significant for plant height days to 50% flowering, days to maturity and thousand seed weight and significant SCA was also observed for the entire trait except days to flowering and number of seeds per siliqua. Therefore, this paper deals with estimation of relative importance of GCA and SCA variances and heterosis for yield and its components.

Table 1: ANOVA of parents vs F_1's for 12 characters in a 7 x 7 parental diallel cross of Indian mustard (*Brassica juncea* L. Czern & Coss): mean sum of squares.

Sources of variance	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	No. of siliquae per plant	No. of seeds per siliqua	1000-seed weight (g)	Biological yield per plant (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
Replication	2	0.04	0.74	4.30	0.96	0.87	8.05	0.75	0.01	1.92	2.37	0.44	0.38
Treatments	27	4.08**	2.38**	9.27**	6.82**	2.06**	487.92**	1.87**	1.28**	7.56**	3.88**	3.52**	1.81**
Parents	6	5.41**	2.32*	19.21**	7.94**	2.98**	925.21**	2.41**	1.06**	6.38	2.48*	1.97**	0.71*
F_1s	20	2.88**	1.92*	6.13**	4.06**	0.45	303.87 **	0.94	1.17**	2.00	3.06**	2.01**	0.91**
Parents vs F_1s	1	20.00**	12.00**	12.44**	55.25**	28.67**	1545.14**	17.29**	4.96**	125.83**	28.91**	43.21**	26.38**
Error	54	0.79	0.92	2.67	0.82	0.82	35.78	0.58	0.02	3.77	0.82	0.43	0.16
Total	83	1.84	1.39	4.85	2.77	1.22	182.19	1.00	0.43	4.96	1.86	1.44	0.70

*, ** significant at 5 and 1 per cent level, respectively.

Table 2: ANOVA for combining ability and related statistics of 12 characters in a 7 x 7 parental diallel cross of F1's in Indian mustard.

Sources of variances	d.f.	Days to 50% flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	No. of siliquae per plant	No. of seeds per siliqua	1000-seed weight (g)	Biological yield per plant (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
GCA	6	4.22**	2.41**	12.38*	6.76**	1.02**	504.24**	1.27**	1.45**	3.79**	3.46**	1.86**	0.65*
SCA	21	0.54*	0.33	0.44	0.99**	0.59*	65.04**	0.44**	0.14**	2.16	0.68**	0.98**	0.59**
Error	54	0.26	0.31	0.89	0.27	0.27	11.93	0.19	0.01	1.26	0.27	0.14	0.05
σ^2gca		0.44	0.23	1.28	0.72	0.08	54.70	0.12	0.16	0.28	0.35	0.19	0.07
σ^2sca		0.28	0.02	-0.45	0.72	0.32	53.11	0.25	0.13	0.90	0.40	0.84	0.53
GPR		1.57	11.5	-2.44	1.00	0.25	1.02	0.48	1.23	0.31	0.87	0.22	0.13

*, ** significant at 5 and 1 per cent level, respectively. GCA = General combining ability, SCA = Specific combining ability, GPR = General productivity

Table 3: Estimates of gca effects for 7 parents along with their mean performance for 12 characters in F_1's of a diallel cross in Indian mustard.

Parents	Days to 50% flowering		Days to maturity		Plant height (cm)		No. of primary branches per plant		No. of secondary branches per plant		No. of siliquae per plant	
	gca effect	Mean	gca effect	Mean	gca effect	Mean	gca effect	Mean	gca effect	Mean	gca effect	Mean
Maya	-0.02	73.33	0.15	133.33	-1.68**	172.00	-0.32*	9.00	0.30	17.66	12.33**	343.66
NRCDR-2	1.13**	75.66	0.56**	134.00	0.46	176.66	-0.14	9.33	0.00	17.00	-11.47**	288.00
NRCHB-101	0.58**	75.00	-0.55**	132.66	-0.72*	174.33	-0.77**	8.00	-0.32*	15.33	5.33**	331.00
RGN-73	-0.68**	72.33	-0.51**	132.33	-0.24	175.33	-0.99**	7.00	-0.03	17.00	-1.36	322.33
Pusa M-21	-0.20	73.00	0.67**	134.33	2.12**	180.33	0.45**	10.33	0.45**	18.00	-2.14*	320.00
Urvashi	-0.83**	72.00	-0.47**	132.00	0.23	176.33	0.19	10.00	-0.51	15.66	1.26	326.33
Pusa Bold	0.02	73.66	0.15	133.66	-0.16	176.00	1.59**	12.00	0.11	17.33	-3.95**	310.00
$\overline{X}_p$		73.56		133.81		175.85		9.38		16.85		320.18
SE (g_i) ±	0.15		0.10		0.29		0.16		0.16		1.06	
SE (g_i - g_j) ±	0.24		0.26		0.44		0.24		0.24		1.62	

Table-3: Continue……………

Hybrid combinations	Days to 50 % flowering		Days to maturity		Plant height (cm)		No. of primary branches per plant		No. of secondary branches per plant		No. of siliquae per plant	
	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean
Maya x NRCDR-2	0.16	74.00	-0.25	133.00	0.04	174.00	0.02	10.33	0.49	18.66	17.52**	346.00
Maya x NRCHB-101	-0.29	73.00	-0.14	132.00	0.22	173.00	0.31	10.00	0.49	18.33	-3.30	342.00
Maya x RGN-73	-0.03	72.00	-0.51	131.66	0.41	173.66	0.20	9.66	-0.14	18.00	-0.26	338.33
Maya x Pusa M-21	-1.18*	71.33	-0.36	133.00	-0.63	175.00	0.43	11.33	0.05	18.66	0.19	338.00
Maya x Urvashi	-0.21	71.66	0.12	132.33	-0.07	173.66	0.35	11.00	0.68	18.33	-0.89	340.33
Maya x Pusa Bold	0.27	73.00	0.16	133.00	-0.33	173.00	0.94*	13.00	0.05	18.33	4.00	340.00
NRCDR-2X NRCHB-101	0.56	75.00	-0.21	132.33	-0.59	174.33	0.46	10.33	0.45	18.00	18.52**	340.00
NRCDR-2x RGN-73	-0.84	72.33	-0.58*	132.00	-0.41	175.00	0.69*	10.33	0.16	18.00	1.89	316.66
NRCDR-2 x Pusa M-21	-0.01	73.66	-0.10	133.66	0.89*	178.66	0.57	11.66	0.01	18.33	-2.33	311.66
NRCDR-2 x Urvashi	-0.69	72.33	0.05	132.66	-0.56	175.33	0.17	11.00	0.64	18.00	-0.74	316.66
NRCDR-2x Pusa Bold	-0.55	73.33	0.42	133.66	-0.48	175.00	0.43	12.66	0.01	18.00	-1.52	310.66

NRCHB-101 x RGN-73	-0.29	72.33	-0.47	131.00	-0.22	174.00	0.31	9.33	0.82*	18.33	-1.93	329.66
NRCHB-101xPusa M-21	-0.44	72.66	-0.32	132.33	-0.59	176.00	0.54	11.00	0.68	18.66	3.19	334.00
NRCHB-101 x Urvashi	-1.14*	71.33	-0.51	131.00	0.30	175.00	0.13	10.33	0.64	17.66	-3.89	330.33
NRCHB-101xPusaBold	-0.66	72.66	-0.81*	131.33	-0.30	174.00	0.72*	12.33	0.68	18.33	2.00	331.00
RGN73 x PusaM-21	0.16	72.00	-0.03	132.66	-0.41	176.66	0.43	10.66	0.38	18.66	0.89	325.00
RGN-73 x Urvashi	-0.21	71.00	0.12	131.66	-0.85*	174.33	0.69*	10.66	0.34	17.66	1.81	329.33
RGN-73 x Pusa Bold	-0.73	71.33	-0.18	132.00	0.22	175.00	1.28*	12.66	0.05	18.00	2.70	325.00
Pusa M-21 x Urvashi	0.31	72.00	0.27	133.00	0.11	177.66	0.57	12.00	-0.14	17.66	1.93	328.66
Pusa M-21 xPusa Bold	-0.21	72.33	-0.36	133.00	-1.15*	176.00	0.17	13.00	0.56	19.00	2.81	324.33
Urvashi x Pusa Bold	0.08	72.00	-0.88*	131.33	-0.26	175.00	0.43	13.00	0.19	17.66	9.41**	334.33
$\overline{X}$		72.44		132.31		174.96		11.25		18.20		330.09
SE (s_{ij}) ±	0.46		0.49		0.84		0.46		0.46		3.09	
SE ($s_{ij} - s_{ik}$) ±	0.68		0.73		1.25		0.69		0.69		4.60	

*, ** significant at 5 and 1 per cent level, respectively

Table 4: Estimate of sca effects and mean performance for 12 characters of 21 F_1's derived from a 7 x 7 parental diallel cross in Indian mustard.

Hybrid combinations	No. of seeds per siliqua		1000-seed weight (g)		Biological yield per plant (g)		Harvest index (%)		Oil content (%)		Seed yield per plant (g)	
	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean	sca effect	Mean
Maya x NRCDR-2	-0.06	13.00	-0.01	5.63	0.77	58.10	1.12*	28.53	0.90**	40.73	0.75**	16.19
Maya x NRCHB-101	0.72*	13.33	0.12	5.62	0.74	57.40	-0.32	26.32	0.23	40.25	-0.11	14.93
Maya x RGN-73	0.50	13.66	-0.07	5.05	0.99	57.20	-0.24	26.97	0.38	39.78	0.02	15.06
Maya x Pusa M-21	0.83*	14.33	0.13	5.09	0.91	56.86	0.03	27.19	0.46	40.99	-0.09	15.01
Maya x Urvashi	0.39	13.00	-0.13	4.96	0.41	56.50	0.64	28.98	0.15	40.89	0.58*	16.18
Maya x Pusa Bold	0.46	13.33	0.51**	6.62	0.23	56.88	0.77	28.97	-0.08	40.00	0.61**	16.29
NRCDR-2 x NRCHB-101	1.09*	14.33	-0.18*	5.76	-0.01	56.23	0.36	27.34	1.86**	41.32	0.00	15.11
NRCDR-2 x RGN-73	-0.13	13.66	0.27**	5.84	0.82	56.67	0.15	27.68	-0.54	38.30	0.21	15.31
NRCDR-2 x Pusa M-21	0.20	14.33	0.42**	5.82	0.61	56.20	0.01	27.50	0.44	40.41	0.10	15.26
NRCDR-2 x Urvashi	0.43	13.66	0.19*	5.72	1.25	56.98	0.88	29.56	0.69	40.86	0.62**	16.29
NRCDR-2 x Pusa Bold	-0.17	13.33	0.19*	6.74	0.51	56.79	0.45	28.99	-0.18	39.34	0.44*	16.18
NRCHB-101 x RGN-73	-0.35	13.00	0.16*	5.59	1.13	56.31	0.31	27.08	-0.15	38.87	0.10	14.80
NRCHB-101xPusa M-21	-0.02	13.66	0.17*	5.43	1.16	56.08	0.29	27.02	0.47	40.63	1.67**	16.42
NRCHB-101 x Urvashi	0.20	13.00	0.11	5.50	0.79	55.86	0.03	27.94	0.08	40.45	0.13	15.40
NRCHB-101x Pusa Bold	-0.06	13.00	0.42**	6.83	0.60	55.21	-0.20	27.57	0.51	40.22	-0.20	15.13
RGN-73 x Pusa M-21	0.43	14.66	-0.01	4.88	1.32	55.80	0.25	27.54	0.47	40.01	0.34	15.09
RGN-73 x Urvashi	-0.02	13.33	-0.12	4.89	0.55	55.16	0.00	28.47	1.19**	40.94	0.54*	15.80
RGN-73 x Pusa Bold	0.72	14.33	0.28**	6.32	0.66	55.82	0.62	28.95	0.15	39.24	0.35	15.68
PusaM-21 x Urvashi	-0.02	13.66	-0.08	4.77	0.14	54.50	0.50	28.93	0.16	41.04	-0.04	15.28
PusaM-21 x Pusa Bold	0.39	14.33	0.30**	6.17	0.31	55.20	0.86	29.15	0.61	40.83	0.32	15.71
Urvashi x Pusa Bold	-0.06	13.00	0.26**	6.26	0.96	56.01	0.60	30.07	0.92**	41.35	0.44*	16.34
$\overline{X}$		13.61		5.69		56.32		28.13		41.30		15.59
SE (s_{ij}) ±	0.39		0.07		1.00		0.46		0.33		0.20	
SE ($s_{ij} - s_{ik}$) ±	0.58		0.10		1.49		0.69		0.50		0.30	

. *, ** significant at 5 and 1 per cent level, respectively

Table 5: Estimate of heterosis over economic parent for 12 characters in 21 F_1's derived from a 7 x 7 diallel cross in Indian mustard.

Hybrid combinations	Days to 50 % flowering	Days to maturity	Plant height (cm)	No. of primary branches per plant	No. of secondary branches per plant	No. of siliquae per plant
	EH	EH	EH	EH	EH	EH
Maya x NRCDR-2	-2.20*	-0.99	-3.51**	-13.89*	3.70**	0.68
Maya x NRCHB-101	-3.52**	-1.74**	-4.07**	-16.67**	1.85*	-0.48
Maya x RGN-73	-4.85**	-1.99**	-3.70**	-19.44**	0.00	-1.55
Maya x Pusa M-21	-5.73**	-0.99	-2.96**	-5.56	3.70**	-1.65
Maya x Urvashi	-5.29**	-1.49*	-3.70**	-8.33	1.85*	-0.97
Maya x Pusa Bold	-3.52**	-0.99	-4.07**	8.33	1.85*	-1.07
NRCDR-2 x NRCHB-101	-0.88	-1.49*	-3.33**	-13.89*	0.00	-1.07
NRCDR-2 x RGN-73	-4.41**	-1.74**	-2.96**	-13.89*	0.00	-7.86**
NRCDR-2 x Pusa M-21	-2.64**	-0.50	-0.92	-2.78	1.85*	-9.31**
NRCDR-2 x Urvashi	-4.41**	-1.24*	-2.77**	-8.33	0.00	-7.86**
NRCDR-2 x Pusa Bold	-3.08**	-0.50	-2.96**	5.56	0.00	-9.60**
NRCHB-101 x RGN-73	-4.41**	-2.48**	-3.51**	-22.22**	1.85*	-4.07**
NRCHB-101 x Pusa M-21	-3.96**	-1.49*	-2.40**	-8.33	3.70**	-2.81
NRCHB-101 x Urvashi	-5.73**	-2.48**	-2.96**	-13.89*	-1.85*	-3.88**
NRCHB-101 x Pusa Bold	-3.96**	-2.23**	-3.51**	2.78	1.85*	-3.69*
RGN-73 x Pusa M-21	-4.85**	-1.24*	-2.03**	-11.11	3.70**	-5.43**
RGN-73 x Urvashi	-6.17**	-1.99**	-3.33**	-11.11	-1.85	-4.17**
RGN-73 x Pusa Bold	-5.73**	-1.74**	-2.96**	5.56	0.00	-5.43**
Pusa M-21 x Urvashi	-4.85**	-0.99	-1.48**	0.00	-1.85*	-4.36**
Pusa M-21 x Pusa Bold	-4.41	-0.99	-2.40**	8.33	5.56**	-5.36**
Urvashi x Pusa Bold	-4.85	-2.23**	-2.96**	8.33	-1.85*	-2.72
SE(EP)=	0.72	0.78	1.33	0.73	0.73	4.88

Table no. 5 continue….

Hybrid combinations	No. of seeds per siliqua	1000-seed weight (g)	Biological yield per plant (g)	Harvest index (%)	Oil content (%)	Seed yield per plant (g)
	EH	EH	EH	EH	EH	EH
Maya x NRCDR-2	-4.88**	-6.53**	4.38**	0.85	3.14*	8.03**
Maya x NRCHB-101	-2.44**	-6.64**	3.11**	-6.97**	1.92	-0.40
Maya x RGN-73	0.00	-16.10**	2.77**	-4.69*	0.73	0.47
Maya x Pusa M-21	4.88**	-15.49**	2.15**	-3.89*	3.80**	0.11
Maya x Urvashi	-4.88**	-17.70**	1.51*	2.44	3.54**	7.96**
Maya x Pusa Bold	-2.44**	9.85**	2.18**	2.39	1.30	8.65**
NRCDR-2 x NRCHB-101	4.88**	-4.37**	1.13*	-3.38*	4.63**	0.80
NRCDR-2 x RGN-73	0.00	-3.10*	1.81*	-2.16	-3.02*	2.16
NRCDR-2 x Pusa M-21	4.88**	-3.43*	0.96	-2.79	2.33	1.82
NRCDR-2 x Urvashi	0.00	-5.09**	2.37**	4.46*	3.48**	8.69**
NRCDR-2 x Pusa Bold	-2.44**	11.84**	2.02**	2.47	-0.37	7.91**
NRCHB-101 x RGN-73	-4.88**	-7.19**	1.16*	-4.29*	-1.56	-1.27
NRCHB-101 x Pusa M-21	0.00	-9.90**	0.75	-4.51*	2.88*	9.56**
NRCHB-101 x Urvashi	-4.88**	-8.74**	0.35	-1.24	2.42	2.71
NRCHB-101 x Pusa Bold	-4.88**	13.33**	0.98	-2.54	1.85	0.96
RGN-73 x Pusa M-21	7.32**	-18.97**	0.24	2.66	1.31	0.67
RGN-73 x Urvashi	-2.44*	-18.75**	-0.90	0.62	3.66**	5.40*
RGN-73 x Pusa Bold	4.88**	4.87**	0.29	2.33	-0.63	4.62*
Pusa M-21 x Urvashi	0.00	-20.80**	-2.10**	2.24	3.92**	1.96
Pusa M-21 x Pusa Bold	4.88**	2.38*	0.80	3.03*	3.39*	4.80*
Urvashi x Pusa Bold	-4.88**	3.87*	0.62	6.28*	4.72**	9.03**
SE(EP)=	0.62	0.11	1.58	0.74	0.53	0.32

*, ** significant at 5 and 1 per cent level, respectively

Materials and Methods

There are seven morphological diverse genotypes / varieties viz., Maya, NRCDR-2, NRCHB-101, RGN-73, Pusa M-21, Urvashi and Pusa Bold, their 21 direct crosses i.e., the F1 populations. All the 28 treatments (7 parents and 21 F1s) were grown in Randomized Complete Block Design with three replications at Oilseed Research Farm, Kalyanpur, C. S. Azad University of Agriculture and Technology, Kanpur (UP) during Rabi 2015-2016. The parents and F1s were grown in single row of five meter length spaced 45 cm apart. The distance of 20 cm between the plants in a row was maintained by thinning. All the recommended agronomic practices were adopted for raising the crop. These genotypes/varieties have been taken on the basis of their differences in days to 50% flowering, days to maturity, plant height (cm), Number of primary branches per plant, number of secondary branches per plant, number of siliquae per plant, number of seeds per siliqua, 1000-seed weight (gm), biological yield per plant (gm), harvest index (%), oil content (%) and seed yield per plant(gm). The mean data of each plot was used for statistical analysis. The combining ability analysis was done by the procedure suggested by Griffing's (1956 b) Method 2, Model I. The mathematical model for the combining ability analysis is assumed to be:

Yijkl = u + gi + gj + sij + 1/bc Σi Σeijkl

(i,j) = 1, 2, 3… n;

k = 1, 2, 3…bi;

l = 1, 2, 3… c)

Where,

Yijkl= mean of i x jth genotype in kth replication

u= the population mean

gi= the general combining ability (gca) effect of ith parent

gj= the gca effect of jth parent

sij = the specific combining ability (gca) effect for the cross between ith, jth parent such that sij = sji

Σi Σeijkl= the environmental effect associated with the ijklth individual observation on ith individual in the kth block with ith as female parent and jth as male parent. The heterosis was calculated (in per cent) as increase or decrease in relation to economic parent. The formula used, are given below:

Heterosis over economic parent (%) = [F1 – EP/ EP] x 100

Where,

F1 and EP are the mean of F1 and economic parent, respectively.

Test of significance:

Significance of heterosis over economic parent was tested as:

EP = (2Mel/r) 0.5

Where,

Mel= error variance obtained from the ANOVA of parents and Fl combination

r = number of replication

Results and Discussion

The analysis of variance was carried out for twelve characters and showing the significant difference amongst all the parents except biological yield, among the F1's except number of secondary branches per plant, no. of seed per siliqua and biological yield per plant, parents vs F1's for all the characters revealed significant difference Vaghela *et al.* (2011) [15], Patel *et al.* (2012), Arifullah (2013) [21] Highly significant differences were recorded among the treatments for all the characters namely, days to (50%) flowering, days to maturity, plant height, number of primary branches per plant, number of secondary branches per plant, no. of siliquae per plant, number of seeds per siliqua, 1000- seed weight, biological yield per plant, harvest index, oil content and seed yield per plant. (Table 1) The analysis of variance for combing ability (Table 2) indicated that variance due to general combining ability (gca) and specific combining ability (sca), general combining ability (gca) shown highly significant for all the characters Vaghela *et al.* (2011) [15], Yadav *et al.* (1993) and specific combining ability shown highly significant differences majority of characters except days to maturity, plant height and biological yield per plant. The variance due to gca is higher than the sca for all the characters. The gca and sca ratio was less than one for majority of the characters except days to 50% flowering, days to maturity, no. of primary branches per plant,no. of siliquae per plant and 1000-seed weight. This indicated that non-additive component played more roles in inheritance of these characters. This is in agreement with the studies of Rao and Gulati (2001) [10] and Patel*et al*. (1993). The promising combiners based on per se performances and signficant gca effects (Table 3) were RGN-73 and Urvashi for days to 50%

flowering; Urvashi, and RGN-73 and NRCHB-101 for days to maturity; Maya and NRCHB-101 for plant height; pusa bold and Pusa M-21 for no. of primary branches per plant, Pusa M-21 for secondary branches per plant, Maya and NRCHB-101 for no. of siliquae per plant, RGN-73 and Pusa M-21 for no. of seed per siliqua, Pusa Bold, NRCHB-101 and NRCDR-2 for 1000- seed weight, Maya for biological yield, Urvashi and pusa bold for harvest index, Urvashi, Pusa M-21 and Maya for oil content and Urvashi and pusa bold for higher seed yield per plant were found more desirable combiners. These results accordance with Singh *et al*. (2005), Singh *et al*. (2007), Sadanand *et al*. (2009) [31], Patel *et al*. (2012) and Gami and Chauhan (2013) [30]. Urvahi and Pusa bold appeared to be good general combiner for most of the characters. The parents discussed above had high general combining ability and fixable component of gene action additive and additive x additive type of epistasis, these could be successfully exploited by developing homozygous line have used for improved character for which improvement was desired. These parental lines might be utilized for producing the intermatting population in order to get desirable recombinants in Indian mustard. Analysis of specific combining ability is important parameter for judging the specific combinations for exploiting it though heterosis breeding programme. The good specific cross combinations are selected based on their sca effects. The specific combining ability effects and per se performance obtained from the analysis presented in Table 4. A perusal of the table revealed that the F1 crosses, Maya x Pusa M-21 and NRCHB-101 x Urvashi for days to 50% flowering,RGN-73 x pusa bold for no. of primary branches, Maya x NRCDR-2 and NRCDR-2 x NRCHB-101 for no. of siliquae per plant, Maya x Pusa M-21 and NRCDR-2 x NRCHB-101 for no. of seeds per siliqua, Urvashi x Pusa bold, Pusa M-21 x Pusa bold, RGN-73 x Pusa bold,NRCHB-101 x Pusa bold,NRCDR-2 x Pusa bold and Maya x Pusa bold for 1000- seed weight, Urvashi x Pusa bold and NRCDR-2 x NRCHB-101 for oil content % and Maya x NRCDR-2, Maya x Urvashi, Maya x Pusa bold, NRCDR-2 x Urvashi, NRCHB-101 x Pusa M-21,Urvashi x Pusa bold for seed yield per plant were superior/best specific combiners these findings also reported by different workers viz; Dixit *et al*. (2007) [3], Yadav *et al*. (2009) Vaghela *et al*. (2011) [15] and Maurya *et al*. (2012) [17]. Therefore, based on outstanding performance of selective parents (donor to get high yield) and crosses concluded that possessing high SCA effect and high heterosis for grain yield may further be used for future under different breeding programmes. The heterosis are estimated of the entire cross combinations (Table-5) over the economic parent Maya. Tyagi *et al*. (2000) [14] and Chauhan *et al*. (2000) [2]. All the crosses show negative heterosis but the maximum negative and significant heterosis was observed RGN-73 x Urvashi (-6.17) for days to flowering; NRCHB-101 x RGN-73 and NRCHB-101 x Urvashi (-2.48) for days to maturity; Maya x NRCHB-101 and Maya x pusa bold (-4.07) for plant height, the cross NRCHB-101 X RGN-73 (-22.22) show highly negative heterosis and the positive significant heterosis Maya X Pusa bold, Pusa M-21 x Pusa bold, Urvashi x Pusa bold (8.33) for number of primary branches per plant, the cross pusa-M-21 x Pusa bold show highly positive hetrosis and the crosses NRCHB-101 x Urvashi, RGN-73 x Urvashi, Urvashi x Pusa bold (-1.85) for number of secondary branches per plant, the cross NRCDR-2 X Pusa M-21 (-9.60) show highly negative significant hetrosis for number of siliquae per plant, the crosses Maya x NRCDR-2, Maya x Urvashi, NRCHB-101 x RGN-73, NRCHB-101 x Urvashi, NRCHB-101 x Pusa bold and Urvashi x Pusa bold (-4.88) show highly negative significant hetrosis and RGN-73 x Pusa M-21 (7.32) show for highly positive significant hetrosis for no. of seeds per siliqua, the cross Pusa M-21 x Urvashi (-20.80) show highly negative significant hetrosis and the cross NRCHB-101 x Pusa bold (13.33) show highly significant hetrosis for 1000-seed weight. The cross Maya x NRCDR-2 (4.38) show highly positive significant hetrosis and the cross Pusa M-21 x Urvashi (-2.10) show highly negative significant hetrosis for biological yield. The cross Urvashi x Pusa bold (6.28) show highly positive significant hetrosis and the cross Maya x NRCHB-101(-6.97) show highly negative significant hetrosis for harvest index the cross Urvahi x pusa bold (4.72) show highly positive significant hetrosis and the cross NRCDR-2 x RGN-73(-3.02) show highly negative significant hetrosis for oil content. The cross NRCHB-101 x pusa M-21(9.56) show highly positive significant hetrosis for seed yield per plant. Kumar *et al*. (2007) [3]. Top ranking five economic crosses viz; NRCHB-101 X Pusa M-21(9.56), Urvashi X Pusa Bold (9.03), NRCDR-2 x Urvashi (8.69), Maya X Pusa Bold (8.65) and Maya X NRCDR-2 (8.30). These crosses have significant sca effect and high per se performance for seed yield.

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