



Combining ability and heterobeltiosis for yield and yield contributing traits in high quality oil Indian mustard (*Brassica juncea*) genotypes

NAVEEN SINGH¹, D K YADAVA², SUJATA VASUDEV³, RAJENDRA SINGH⁴, S C GIRI⁵, B DASS⁶, SIDDHARTHA BARUN⁷ and K V PRABHU⁸

Indian Agricultural Research Institute, New Delhi 110 012

Received: 4 November 2013; Revised accepted: 27 January 2015

ABSTRACT

Heterosis and combining ability estimates were worked out using Line × Tester analysis of 72 hybrids developed by crossing 12 lines with 6 testers including four double zero, ten single zero and four conventional Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] genotypes. Analysis of variance revealed sufficient differences among parents, hybrids and parent vs. hybrids for most of the traits studied. Both additive and non additive type of gene effects for seed yield and yield related traits were observed. Estimates of GCA effects indicated that Pusa Mustard 22, Pusa Mustard 29, Pusa Agrani, EC 597318 and Pusa Karishma were good general combiners. One hybrid low in erucic acid and glucosinolates content (PDZ 3 × EC 597318), six low in erucic acid content (Pusa Mustard 22 × Pusa Karishma, Pusa Mustard 24 × Pusa Karishma, EC 597325 × Pusa Karishma, TERI M 21 × EC 597318, ELM 132 × EC 597318, Pusa Mustard 29 × Pusa Mustard 21) and six conventional hybrids (EC 597325 × Pusa Agrani, RH(00)7003 × Varuna, ALM 936A × Varuna, Pusa Musatrd 29 × Pusa Agrani, Pusa Tarak × Pusa Mustard 21 and PDZ 3 × Varuna) had significantly high sca effects, >15% heterobeltiosis and high per se performance for seed yield/plant. These high quality oil genotypes involved in developing heterotic hybrids, in this study, shall be converted to cytoplasmic male sterile and/or restorer lines. Identified high yielding cross combinations can further be exploited for improving the yield and quality of Indian mustard.

Key words: Combining ability, Gene effects, Heterobeltiosis, Quality oil, *Brassica juncea*, Yield contributing traits

Seed yield of mustard [*Brassica juncea* (L.) Czern. & Coss.] is a quantitative trait that is largely influenced by the different environmental factors and hence in most of the cases it has low heritability (Rameeh 2010). The erucic acid content is governed by two genes acting in an additive manner, with recessive homozygous alleles at both loci, are responsible for less than 2% erucic acid in total fatty acid profile (Gupta *et al.* 2004), whereas, total glucosinolates content is controlled by multiple QTLs with additive effects (Bisht *et al.* 2009). Efforts directed towards development of high yielding varieties possessing low erucic and/or low glucosinolates through pyramiding the responsive genes/QTLs separately or in combination led to the development of a good number of single and double zero genotypes. Backcrossing of elite genotypes to donors of diverse exotic/indigenous origin results in severe linkage drags, therefore,

leading to significant reduction in seed yield potential of these newly developed quality genotypes. The negative correlation between productivity and oil quality, is thus, experienced.

Improvement of *Brassica juncea* for both productivity and oil quality are essential to meet the demands of the national as well as the international markets. Heterosis breeding can be one of the most effective means to break the yield barrier (Yadava *et al.* 2012). Development of improved parental lines with improved oil and seed meal quality would help in improving the production and quality of oil and seed meal cake in the country. Knowledge of gene action, their relative contribution in the genetic variance and estimation of general and specific combining ability effects (GCA and SCA) are important parameters for the improvement of rapeseed crops. This important information could provide an essential tool for the rapeseed breeders in the selection of better parental combination for further improvement (Khan *et al.* 2009, Panhwar *et al.* 2008) and development of commercial high yielding hybrids. Therefore, there is an urgent need to study the combining ability of the locally developed high quality oil cultivars so that suitable parental lines can be developed and specific combiners, if any, can be identified. Furthermore, it would

¹Senior Scientist (e mail: n.singhk@rediffmail.com), ²Principal Scientist (e mail: dkygenet@gmail.com), ³Principal Scientist (e mail: sujatavasudev@gmail.com), ⁴Assistant Chief Technical Officer (e mail: rajendraslakra@gmail.com), ⁵ Senior Technical Officer (e mail: satishgirigenet@gmail.com), ⁶Chief Technical Officer (e mail: bhagwandass391@gmail.com), ⁷Senior Research Fellow (e mail: s.barun@yahoo.com), ⁸Head (e mail: kvinodprabhu@rediffmail.com), Division of Genetics

be interesting to access the level of heterosis between/ among improved and conventional quality genotypes. The present study was, thus, undertaken to determine type of gene action, general and specific combining ability of parental lines and heterobeltiosis of the cross combinations as most of the genotypes taken for conducting this study are commercial varieties.

MATERIALS AND METHODS

Twelve female lines of Indian mustard including three double zero (low erucic acid and low glucosinolates content; EC 597325, Heera and PDZ 3, eight single zero (low erucic acid; Pusa Mustard 22, Pusa Mustard 24, RH(00) 7003, ALM 936 A, TERI M 21, ELM 123, ELM 132 and Pusa Mustard 29) and one conventional mustard (Pusa Tarak) genotypes were crossed with six testers during *rabi* 2010-11. These testers include one double zero (EC 597318), two single zero (Pusa Karishma and Pusa Mustard 21) and three conventional (Varuna, Pusa Jaikisan and Pusa Agrani) mustard genotypes. Twelve female lines, six testers and their resultant F₁ crosses, 72 in numbers were evaluated in randomized block design with three replications at Indian Agricultural Research Institute, New Delhi during *rabi* 2011-12. Each plot consisted of three rows of five meter length. Row to row and plant to plant distance were kept 30 cm and 15 cm, respectively. All recommended agronomical practices and plant protection measures were adopted for raising the good crop. Observations were recorded for twelve quantitative traits, viz. seed yield (g), plant height (cm), point to first branch (cm), number of primary branches, number of secondary branches, main shoot length (cm), point to first siliqua (cm), number of siliquae on main shoot, 1000 seed weight (g), siliqua length (cm), number of seeds/siliqua and maturity (days). Data on these traits were recorded on six random but competitive plants in each replication for every entry for all the characters except days to maturity, where the observations were recorded on plot basis. The mean values were used for statistical analysis. Line × tester analysis was done following Kempthorne (1957). Per cent heterosis over the better parent was calculated as deviation of F₁ value from the better parent.

RESULTS AND DISCUSSION

Several *Brassica* breeders have used line × tester analysis for the genetic analysis of agro-morphological traits, estimation of GCA and SCA, evaluation of gene action and heterosis in Brassicas and other oilseed crops (Dar *et al.* 2013, Frasad *et al.* 2013, Dey *et al.* 2013, Parmar *et al.* 2011, Yadava *et al.* 2012, Farshadfar *et al.* 2013 and Singh *et al.* 2013). In the present study, analysis of variance displayed highly significant differences among parents and hybrids for almost all the traits under study (Table 1), depicting wide range of variability among genotypes and hybrids. Significant differences of mean squares among parents and crosses indicated the suitability of the genotypes for combining ability studies. Mean squares due to males were higher than those of females for most of the traits

Table 1 Analysis of variance for parents and hybrids in L × T design for twelve characters of high oil quality Indian mustard

Source of variation	Degree of freedom	Plant height (cm)	Days to maturity	Point to first branch (cm)	Primary branches	Secondary branches	Siliquae on main shoot	Main shoot length (cm)	Point to first siliqua (cm)	Siliqua length (cm)	Seeds/siliqua	Seed yield/plant (g)	1000-seed weight (g)
Replications	2	1027.32** (7.93)	6.28 (1.82)	307.57* (4.11)	3.76* (3.15)	104.76** (7.70)	83.6 (2.92)	252.50** (5.80)	6.37* (3.83)	0.31** (5.10)	1.63 (1.48)	34.57 (2.05)	0.95* (4.14)
Parents	17	1490.53**	83.42**	1073.59**	15.13**	128.0**	397.18**	396.86**	33.66**	1.20**	25.95**	69.64**	1.84**
Females	11	1251.72 (0.81)	34.26 (0.74)	746.97 (0.54)	4.28 (0.70)	33.02 (0.63)	402.43** (4.12)	0.16 (0.00)	29.08 (1.40)	0.80* (2.30)	6.64 (1.06)	60.26 (0.46)	1.87 (1.38)
Males	5	2215.21 (1.43)	196.40** (4.25)	1964.66 (1.42)	41.36** (6.70)	359.15** (6.95)	464.92** (4.75)	599.40 (1.69)	43.85 (2.20)	1.57** (4.20)	65.62** (10.50)	93.10 (0.71)	1.51 (1.10)
Females vs males	1	494.25 (3.82)	59.31** (17.01)	211.09 (2.83)	3.29 (2.76)	16.99 (1.29)	0.78 (0.02)	1967.88** (45.26)	33.19** (19.90)	2.95** (49.00)	39.96** (36.00)	55.59 (3.31)	3.10** (13.40)
Hybrids	71	1540.29** (11.89)	46.12** (13.30)	1376.36** (18.43)	6.18** (5.19)	51.67** (3.79)	97.69** (3.41)	352.98** (8.12)	20.11** (12.14)	0.37** (6.20)	6.23** (5.61)	130.97** (7.80)	1.36** (5.91)
Parents vs hybrids	1	17556.25** (135.54)	40.13** (11.60)	7869.06** (105.30)	1.35 (1.13)	332.5** (24.40)	505.32** (17.65)	1472.02** (33.86)	00.01 (0.00)	5.39** (89.80)	14.67** (13.02)	1014.22** (60.40)	7.89** (34.3)
Error	178	129.52	3.46	74.68	1.19	13.6	28.63	43.47	1.66	0.06	1.11	16.79	0.23
Mean		227.73	147.37	67.24	7.08	19.2	49.87	72.07	6.73	3.5	14.82	22.2	4.01
CV (%)		4.99	1.26	12.85	15.41	19.2	10.73	9.15	19.14	7	7.11	18.46	11.96

**Significant at P=0.01 and *significant at P=0.05

revealed higher genetic variability among testers than in lines. Significant mean squares of parents vs hybrids, on the other hand, revealed good scope for manifestation of heterosis in all the traits except primary branches and point to first siliqua. Further, significance of mean sum of squares due to hybrids for all the traits indicated the importance of both additive and non-additive variance.

Predominant role of non-additive gene effects in manifestation of heterosis for point to first branch, siliqua length and seeds/siliqua was demonstrated by higher value of specific combining ability variance (σ^2_{sca}) than general combining ability variance (σ^2_{gca}) and degree of dominance being more than one (Table 2). For plant height, number of primary branches, main shoot length and 1000-seed weight

the degree of dominance was more than one indicating the preponderance of non-additive gene effects for these traits. Further, both additive and non-additive types of gene actions were important for rest of the traits. Similar results were also reported by Yadava *et al.* (2012) in Indian mustard. 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.

Results revealed that none of the parents showed significant GCA effect in the desired direction for all the traits (Table 3). Among females, Pusa Mustard 22 was found to be a good general combiner for main shoot length,

Table 2 Estimates of genetic components of variance for twelve characters of high oil quality Indian mustard

Components of variance	Plant height (cm)	Days to maturity	Point to first branch (cm)	Primary branches	Secondary branches	Siliquae on main shoot	Main shoot length (cm)	Point to first siliqua (cm)	Siliqua length (cm)	Seeds/siliqua	Seed yield/plant (g)	1000-seeds weight (g)
σ^2_{gca}	176.89	3.97	136.09	0.86	0.28	4.20	56.33	0.76	0.03	0.58	2.60	0.18
σ^2_{sca}	175.37	9.90	214.59	0.48	12.03	14.20	22.18	5.04	0.04	0.87	35.25	0.04
$\sigma^2_{gca}/\sigma^2_{sca}$	1.01	0.40	0.63	1.79	0.01	0.29	2.54	0.15	0.75	0.67	0.07	4.50
σ^2_A	353.79	7.93	272.18	1.73	0.57	8.39	112.65	1.52	0.06	1.17	5.20	0.35
σ^2_D	175.36	9.91	214.59	0.48	12.03	14.21	22.19	5.05	0.04	0.86	35.25	0.05
Degree of dominance	1.42	0.89	1.13	1.90	0.22	0.77	2.25	0.55	1.22	1.17	0.38	2.65

Table 3 GCA effects of lines and testers and variance components for twelve characters in high quality oil *Brassica juncea*

Lines/ Testers	Plant height (cm)	Days to maturity	Point to first branch (cm)	Primary branches	Secondary branches	Siliquae on main shoot	Main shoot length (cm)	Point to first siliqua (cm)	Siliqua length (cm)	Seeds/siliqua	Seed yield/plant (g)	1000-seed weight (g)
<i>Lines</i>												
Pusa Mustard 22	7.04	0.88	1.83	0.11	0.03	0.98	2.73**	1.26	0.24**	0.21	3.59**	0.27**
Pusa Mustard 24	-8.58**	-1.51**	-11.30**	-0.05	-0.59	-0.24	1.20	-0.66	-0.21	0.38	0.45	-0.39
EC 597325	-3.28	-1.07**	-2.73	0.00	-0.61	2.74**	2.04	0.41	-0.51	-1.27	-2.66	-0.71
Heera	26.68	0.32	17.11	1.23**	1.77**	5.20**	-3.65	-1.69**	-0.15	0.16	1.48	-0.30
RH(00) 7003	8.57	-0.01	21.34	0.00	-0.30	-2.91	-10.02	-1.64**	0.10*	0.44**	-0.33	-0.15
ALM 936A	3.55	1.49	11.61	-0.08	-0.51	2.41*	-0.76	1.75	-0.08	0.55**	0.07	-0.32
TERI M 21	-12.29**	-1.18**	-8.65**	-1.06	-2.82	-2.35	6.36**	0.63	0.39**	0.24	-3.63	-0.15
ELM 123	-2.10	-0.01	-4.29	-0.01	-1.81	0.29	8.08**	-0.20	0.18**	-0.77	0.72	0.53**
ELM 132	6.40	0.82	2.06	-0.57	1.37	-6.75	-6.05	1.30	0.09	-0.09	0.11	0.41**
Pusa Mustard 29	-6.12	0.99	-13.04	0.28	1.45	-0.69	3.09	0.64	0.05	-0.20	3.35**	0.74**
Pusa Tarak	-26.51**	-0.35	-11.75**	-0.90	-1.52	-3.52	-2.99	-0.71**	0.24**	-0.66	-4.70	0.59**
PDZ 3	6.63	-0.35	-2.18	1.04**	3.55**	4.84**	-0.02	-1.08**	-0.32	1.00**	1.54	-0.52
Standard error	2.33	0.33	1.78	0.20	0.75	1.03	1.30	0.24	0.04	0.21	0.80	0.09
CD (P=0.05)	5.44	0.77	4.15	0.47	1.75	2.40	3.03	0.65	0.09	0.49	1.87	0.21
CD (P=0.01)	7.74	1.10	5.91	0.66	2.49	3.42	4.32	0.80	0.13	0.70	2.66	0.30
<i>Testers</i>												
Varuna	2.05	1.24	-0.86	-1.37	-0.30	3.08**	14.69**	1.68	-0.17	-0.95	-4.02	-0.38
Pusa Jaikisan	-3.09*	0.68	4.14	-0.01	-0.41	-2.47	-3.01	-1.09**	0.24**	-1.29	-2.44	0.53**
Pusa Agarni	-26.91**	-5.18**	-25.67**	-1.30	-1.37	-0.27	6.45**	0.82	0.01	0.50**	2.80**	0.25**
Pusa Karishma	4.59	-0.18	9.01	0.67**	-0.09	-1.34	-5.00	-0.58	0.01	1.18**	2.03**	-0.21
Pusa Mustard 21	16.33	0.79	11.60	0.95**	-0.28	1.33	-4.41	0.45	0.05	0.13	-0.03	0.28**
EC 597318	7.03	2.65	1.79	1.06**	2.45**	-0.33	-8.72	-1.28**	0.13**	0.42**	1.67**	-0.47
Standard error	1.57	0.22	1.20	0.13	0.51	0.69	0.88	0.16	0.03	0.14	0.54	0.06
CD (P=0.05)	3.66	0.51	2.80	0.30	1.19	1.61	2.05	0.37	0.07	0.33	1.26	0.14
CD (P=0.01)	5.22	0.73	3.99	0.43	1.69	2.29	2.92	0.53	0.10	0.47	1.79	0.20

**Significant at $P=0.01$ and ; *significant at $P=0.05$

siliqua length, 1000-seed weight and seed yield/plant, whereas, Pusa Mustard 29 expressed good general combining ability for 1000-seed weight and seed yield. Among males Pusa Agrani was observed to be a good general combiner for plant height, days to maturity, point to first branch, main shoot length, seeds/siliqua, 1000-seed weight and seed yield. Pusa Karishma and EC 597318 also expressed good general combining ability for seed yield indicating the presence of additive gene action or additive × additive interaction effects for this trait. Similar

observations were also made by Singh *et al.* (2005), Yadava *et al.* (2012) and Singh *et al.* (2013) with a different set of material. These outcomes reveal that there is a scope for improving combining ability of parents for component traits, since good combiners for seed yield traits were not good for number of other yield-contributing traits. Therefore, efforts need to be made to improve the combining ability of yield-contributing traits which would, in turn, improve the gca of seed yield indirectly. Double low genotype EC 597318, single low genotypes Pusa Mustard 22, Pusa

Table 4 Highly significant (positive except for plant height, maturity and point to first branch) SCA effects for twelve yield and yield-contributing traits in crosses involving high quality oil Indian mustard genotypes

Plant height (cm)	Pusa Mustard 24 × Pusa Mustard 21(-45.79), EC 597325 × Pusa Mustard 21(-16.7), EC 597325 × EC 597318 (-14.17), Heera × EC 597318 (-16.28), ALM 936A × Pusa Mustard 21(-10.83), TERI M 21 × Pusa Jaikisan (-13.72), TERI M 21 × Pusa Karishma (-13.23), Pusa Mustard 29 × Pusa Karishma (-29.96), Pusa Mustard 29 × EC 597318 (-11.36), Pusa Tarak × Varuna (-24.92), Pusa Tarak × EC 597318 (-21.45), PDZ 3 × Pusa Agrani (-10.67), PDZ 3 × EC 597318 (-17.75)
Maturity	Pusa Mustard 22 × EC 597318 (-5.71), Pusa Mustard 24 × Varuna (-3.90), EC 597325 × Pusa Agrani (-0.93), EC 597325 × EC 597318 (-14.17), Heera × Pusa Karishma (-3.32), Heera × Pusa Mustard 21 (-3.29), RH(00)7003 × Pusa Karishma (-1.99), RH(00)7003 × Pusa Mustard 21 (-1.96), ALM 936A × Varuna (-2.90), ALM 936A × Pusa Agarni (-4.49), ALM 936A × Pusa Mustard 21(-2.46), TERI M 21 × Varuna (-4.24), TERI M 21 × Pusa Agarni (-3.82), ELM 123 × Pusa Mustard 21 (-2.96), ELM 123 × EC 597318 (-2.82), ELM 132 × Varuna (-1.60), ELM 132 × Pusa Jaikisan (-2.68), ELM 132 × EC 597318 (-5.65) Pusa Mustard 29 × Pusa Jaikisan (-3.85), Pusa Mustard 29 × Pusa Karishma (-2.99), Pusa Tarak × Varuna (-5.07), Pusa Tarak × Pusa Jaikisan (-2.51), PDZ 3 × Pusa Mustard 21 (-3.62)
Point to first branch (cm)	Pusa Mustard 22 × Pusa Mustard 21 (-21.50), Pusa Mustard 24 × Pusa Karishma (-15.31), EC 597325 × Pusa Mustard 21 (-11.70), EC 597325 × EC 597318 (-19.11), Heera × Pusa Mustard 21 (-43.26), RH(00)7003 × Varuna (-11.20), ALM 936A × Vauna (-12.97), ALM 936A × Pusa Jaikisan (15.63), ALM 936A × Pusa Agrani (11.26), TERI M 21 × Pusa Karishma (-12.52), ELM 123 × Pusa Mustard 21 (18.24), Pusa Mustard 29 × Pusa Agarni (-11.17), Pusa Mustard 29 × Pusa Karishma (-20.58), Pusa Tarak × Varuna (-21.00), PDZ 3 × EC 597318 (-31.05)
Primary branches	Pusa Mustard 24 × Pusa Jaikisan (1.23), EC 597325 × Pusa Jaikisan (1.24), EC 597325 × Pusa Karishma (1.23), ELM 132 × EC 597318 (1.35), Pusa Tarak × Pusa Mustard 21(1.17)
Secondary branches	Pusa Mustard 24 × Pusa Jaikisan (5.85), EC 597325 × Pusa Jaikisan (5.70), EC 597325 × Pusa Karishma (3.94), RH(00)7003 × Varuna (5.07), TERI M 21 × EC 597318 (4.95), Pusa Tarak × Pusa Mustard 21(5.98)
Siliquae on main shoot	ALM 936A × Pusa Karishma (6.57), TERI M 21 × EC 597318 (7.33), ELM 132 × Pusa Mustard 21 (6.40), PDZ 3 × EC 597318 (7.14)
Main shoot length (cm)	EC 597325 × Pusa Agrani (7.66), EC 597325 × EC 597318 (11.72), Pusa Mustard 29 × Pusa Mustard 21 (7.92), Pusa Tarak × Pusa Mustard 21 (11.84), PDZ 3 × EC 597318 (10.17)
Point to first siliqua (cm)	Pusa Mustard 24 × Pusa Jaikisan (-2.14), Pusa Mustard 24 × Pusa Mustard 21 (-2.96), EC 597325 × Pusa Mustard 21 (-2.08), Heera × Varuna (-2.38), ALM 936A × Pusa Agrani (-2.07), TERIM 21 × Pusa Karishma (-2.93), ELM 123 × Pusa Musatrd 21 (-3.81), ELM 132 × EC 597318 (-3.58), Pusa Mustard 29 × Varuna (-2.10), Pusa Mustard 29 × Pusa Karishma (-3.17)
Siliqua length (cm)	Pusa Mustard 22 × Pusa Jaikisan (0.33), Pusa Mustard 24 × Pusa Karishma (0.28), ALM 936A × Varuna (0.26), ELM 123 × Pusa Mustard 21 (0.26), Pusa Mustard 29 × EC 597318(0.69), Pusa Tarak × EC 597318 (0.28), PDZ 3 × Pusa Agrani (0.63)
Seeds/Siliqua	Pusa Mustard 22 × Pusa Jaikisan (1.65), Pusa Mustard 24 × Varuna (1.57), Pusa Mustard 24 × EC 597318 (1.64), Heera × Pusa Jaikisan (1.45), ALM 936A × Pusa Karishma (1.60), Pusa Tarak × Pusa Karishma (1.35), PDZ 3 × Pusa Agrani (2.9)
Seed yield/plant (g)	Pusa Mustard 22 × Pusa Karishma (7.26), Pusa Mustard 24 × Pusa Karishma (11.35), EC 597325 × Pusa Jaikisan (4.75), EC 597325 × Pusa Agarni (9.53) EC 597325 × Pusa Karishma (6.09), RH(00)7003 × Varuna (6.33), TERI M 21 × EC 597318 (14.53), ALM 936A × Varuna, ELM 132 × EC 597318 (8.44), Pusa Mustard 29 × Pusa Agrani (6.73), Pusa Mustard 29 × Pusa Mustard 21 (6.92), Pusa Tarak × Pusa Mustard 21 (12.47), PDZ 3 × Varuna (7.17), PDZ 3 × EC 597318 (8.57)
1000-seed weight (g)	Pusa Mustard 22 × Pusa Karishma (0.87), TERI M 21 × Pusa Agrani (0.57), ELM 132 × Pusa Jaikisan (0.61)

Mustard 29 and Pusa Karishma and conventional short duration variety Pusa Agrani, possessed significantly high gca for seed yield as well as some of its contributing traits. These genotypes shall be included in the breeding programme for accumulation of favourable alleles.

For seed yield, 13 hybrids, viz. Pusa Mustard 22 × Pusa Karishma, Pusa Mustard 24 × Pusa Karishma, EC 597325 × Pusa Jaikisan, EC 597325 × Pusa Agrani, EC 597325 × Pusa Karishma, RH(00)7003 × Varuna, TERI M 21 × EC 597318, ELM 132 × EC 597318, Pusa Mustard 29 × Pusa Agrani, Pusa Mustard 29 × Pusa Mustard 21, Pusa Tarak × Pusa Mustard 21, PDZ 3 × Varuna and PDZ 3 × EC 597318 observed highly significant sca effects (Table 4). High sca effects for seed yield using line × tester analysis have earlier been reported (Yadava *et al.* 2012, Singh *et al.* 2013, Farshadfar *et al.* 2013). Thirteen hybrids for plant height, 23 for maturity, 15 for point to first branch and 10 for point to first siliqua had significant negative sca effects. Significant positive sca effects for primary branches, secondary branches, siliqua on main shoot, main shoot length, point to first siliqua, siliqua length, seeds per siliqua and 1000-seed weight were observed in 5, 6, 4, 5, 14, 7, 7 and 3 hybrids, respectively.

It is quite evident that the parents involved in these crosses were good specific combiners, however, relative

contribution of the parents to sca effect for seed yield is through different yield contributing traits in different hybrids (Table 4). In general, the results indicate that there was no strong direct association between sca effects and heterobeltiosis (Table 5) which is in accordance with the previous results of Yadava *et al.* (2012). Out of 72 hybrids evaluated in this study, 13 displayed highly significant sca effect, heterobeltios >15% and higher *per se* performance. Out of these, one hybrid (PDZ 3 × EC 597318) was low in erucic acid and glucosinolates content (00), six (Pusa Mustard 22 × Pusa Karishma, Pusa Mustard 24 × Pusa Karishma, EC 597325 × Pusa Karishma, TERI M 21 × EC 597318, ELM 132 × EC 597318, Pusa Mustard 29 × Pusa Mustard 21) were low in erucic acid content and rest six (EC 597325 × Pusa Agrani, RH(00)7003 × Varuna, ALM 936A × Varuna, Pusa Musatrd 29 × Pusa Agrani, Pusa Tarak × Pusa Mustard 21 and PDZ 3 × Varuna) were inferior for both quality traits, as one of the parents involved in the development of these hybrids was high in erucic acid and glucosinolates. Similar results were observed by Yadava *et al.* (2012) for nine yield and yield contributing traits and recorded upto 67.71% heterobeltiosis for seed yield/plant. Heterobeltiosis to the extent of 44.8% was reported along with highly significant sca effect and higher *per se* performance by Vaghela *et al.* (2011). Verma *et al.* (2011)

Table 5 Estimates of heterobeltiosis and SCA effects of 72 hybrids for seed yield in Indian mustard genotypes

Line	Tester						Mean seed yield/plant of lines (g)
	Varuna	Pusa Jaikisan	Pusa Agrani	Pusa Karishma	Pusa Mustard 21	EC 597318	
Pusa Mustard 22	38.2** (-2.77)	47.57** (-3.00)	83.52** (-1.79)	102.49** (7.26**)	14.01** (3.65*)	38.75** (-3.36)	14.45
Pusa Mustard 24	11.52** (-1.88)	46.18** (2.04)	65.51** (-0.13)	107.81** (11.35**)	-49.71 (-10.19)	33.44** (-1.18)	15.88
EC 597325	-48.79 (-5.06)	2.32 (4.75**)	47.28** (9.53**)	28.39** (6.09**)	-49.87 (-7.12)	-37.3 (-8.19)	22.29
Heera	81.09** (3.16)	136.75** (2.72)	93.52** (1.84)	29.48** (-3.63)	-28.35 (-5.52)	53.61** (1.43)	9.32
RH(00) 7003	39.00** (6.33**)	-9.84 (-4.09)	63.58** (3.95)	32.2** (-0.95)	2.3 (4.46*)	-18.2 (-9.71)	18.09
ALM 936A	16.94** (4.99**)	14.98** (3.00)	42.31** (3.42)	31.95** (2.05)	-43.15 (-8.05)	-5.81 (-5.41)	20.69
TERI M 21	-58.8 (-5.66)	-45.11 (-3.97)	-8.24 (-0.39)	-17.8 (-1.91)	-36.57 (-2.60)	49.41** (14.53**)	23.91
ELM 123	-27.17 (-4.12)	11.81** (2.72)	32.37** (1.93)	4.43 (-3.34)	-7.02 (0.93)	26.93** (1.88)	21.61
ELM 132	36.93** (1.76)	28.13** (-1.18)	-0.7 (-10.84)	45.86** (0.66)	-8.39 (1.17)	84.81** (8.44**)	15.34
Pusa Mustard 29	-6.56 (-0.74)	0.23 (-0.74)	54.82** (6.73**)	2.58 (-4.66)	25.35** (6.92**)	-11.2 (-7.51)	23.29
Pusa Tarak	-51.43 (-3.17)	-34.51 (-0.83)	-27.72 (-4.49)	-30.99 (-4.48)	16** (12.47**)	-11.1 (0.50)	23.21
PDZ 3	36.75** (7.17**)	2.32 (-1.43)	-12.85 (-9.76)	-10.1 (-8.43)	7.12* (3.87*)	71.6** (8.57**)	20.36
Mean seed yield/ plant of testers (g)	13.13	10.53	15.13	17.80	26.65	18.06	

Values in parenthesis represent SCA effects; **significant at $P=0.01$ and ; *significant at $P=0.05$

also recorded heterosis for seed yield up to the extent of 80.97% in *Brassica juncea* crosses.

The perusal of SCA effects along with heterobeltiosis revealed that a good number of crosses developed through utilizing high quality oil genotypes, expressed desirable values for these components, indicating that development of commercial heterotic hybrids with high oil quality, with low erucic acid and low glucosinolates content, is possible. For this, good specific combiners possessing single zero and/or double zero traits are suitable candidates for their conversion to cytoplasmic male sterile and/or restorer lines. This study would help in overcoming the yield barrier in high quality oil *Brassica juncea*.

REFERENCES

- Bisht N C, Gupta V, Ramachari N, Sodhi Y S, Mukhopadhyaya A, Arumugam N, Pental D and Pradhan A K. 2009. Fine mapping of loci involved with glucosinolate biosynthesis in oilseed mustard (*Brassica juncea*) using genomic information from allied species. *Theoretical and Applied Genetics* **118**: 413–21.
- Bouis H E, Hotz C, McClafferty B, Meenakshi J V and Pfeiffer W H. 2011. Biofortification: a new tool to reduce micronutrient malnutrition. *Food and Nutrition Bulletin* **32**(1): 31–40.
- Dar Z A, Wani S A, Habib G M, Ali G, Sofi P A, Dar S A and Iqbal A M. 2013. Analysis of combining ability in brown sarson (*Brassica rapa* L.) under temperate conditions. *African Journal of Agricultural Research* **8**: 1 603–7.
- Dey S S, Singh N, Bhatia R, Parkash Chander and Dey C C. 2013. Genetic combining ability and heterosis for important vitamins and antioxidant pigments in cauliflower (*Brassica oleracea* var. *botrytis* L.). *Euphytica* DOI 10.1007/s10681-013-0981-4 published online 3 Aug 2013.
- Downey R K and Rimer S R. 1993. Agronomic improvement in oilseed brassicas. *Advances in Agronomy* **50**:1–150.
- FAO. 2013. Statistical databases of the Food and Agricultural Organization (FAO), Rome (www.fao.org).
- Farshadfar E, Kazemi Z and Yaghotipoor A. 2013. Estimation of combining ability and gene action for agro-morphological characters of rapeseed (*Brassica napus* L.) using line \times tester mating design. *International Journal of Advanced Biological and Biomedical Research* **1**: 711–7.
- Frasat S, Hamad N T M, Kang S A, Jehanzeb F and Madeeha S. 2013. Heterosis and combining ability for seed yield and its components in *Brassica juncea* L. *Albanian Journal of Agricultural Sciences* **12**: 203.
- Gupta V, Mukhopadhyay A, Arumugam N, Sodhi Y S, Pental D and Pradhan A K. 2004. Molecular tagging of erucic acid trait in oilseed mustard (*Brassica juncea*) by QTL mapping and single nucleotide polymorphisms in *FAE1* gene. *Theoretical and Applied Genetics* **108**: 743–9.
- Kempthorne O. 1957. *An Introduction to Genetic Statistics*. John Wiley and Sons Inc., New York.
- Khan A S, Ahmad H, Khan A, Saeed M, Khan S M and Ahmad B. 2009. Using line \times tester analysis for earliness and plant height traits in Sunflower (*Helianthus annuus* L.). *Recent Research in Science and Technology* **1**: 202–6.
- Kumar A, Kumar V and Kandpal B K. 2012. Production barriers and technological options for sustainable production of rapeseed mustard in India. (in) *Souviner 1st National Brassica Conference on Production Barriers and Technological Options in Oilseed Brassica* organized by Society for Rapeseed Mustard Research, Bharatpur.
- Panhawar S A, Baloch M J, Jatoti W A, Veessar N F and Majeedano M S. 2008. Combining ability estimates from line \times tester mating design in upland cotton. *Proceedings Pakistan Academy of Science* **45**: 69–74.
- Parmar S A, Jaimini S N and Ram B. 2011. Combining ability analysis for seed yield and its components over environments in Indian mustard (*Brassica juncea* L.). *Journal of Oilseed Brassica* **2**: 61–6.
- Rameeh V. 2010. Combining ability and factor analysis in F_2 diallel crosses of rapeseed varieties. *Plant Breeding and Seed Science* **62**: 73–83.
- Singh S K, Haider Z A and Ram S. 2005. Combining ability and heterosis for seed yield and its components in Indian mustard (*Brassica juncea*). *Indian Journal of Agricultural Sciences* **75**: 228–9.
- Singh A, Avtar R, Singh D, Sangwan O, Thakral N K, Malik V S, Goyat B and Dalal U. 2013. Combining ability analysis for seed yield and component traits in Indian mustard [*Brassica juncea* (L.) Czern & Coss]. *Research in Plant Biology* **3**: 26–31.
- Vaghela P O, Thakkar H S, Bhadauria H S, Sutariya D A, Parmar S K and Prajapati D V. 2011. Heterosis and combining ability for yield and its component traits in Indian mustard (*Brassica juncea*). *Journal of Oilseed Brassica* **2**: 39–43.
- Verma O P, Yadav Rashmi, Kumar K, Singh R, Maurya K N and Ranjana 2011. Combining ability and heterosis for seed yield and its components in Indian mustard (*Brassica juncea*). *Plant Archives* **11**: 863–5.
- Yadava D K, Singh Naveen, Sujata V, Singh Rajendra, Singh Sanjay, Giri S C, Dwivedi S K and Prabhu K V. 2012. Combining ability and heterobeltiosis for yield and yield attributing traits in Indian mustard (*Brassica juncea*). *Indian Journal of Agricultural Sciences* **82**: 563–70.