Heterosis and combining ability analysis for seed yield and its attributes in *Brassica rapa* ssp. *brown sarson*

Z. A. Dar, Shafiq A. Wani., M. Altaf Wani., Gulzaffar, M. H. Khan, M. Habib, Ahmed, Z. and A. Ishfaque

Division of Plant Breeding and Genetics, SKUAST-K, Shalimar, J&K, India
Corresponding author: zahoor3@rediffmail.com

Abstract

Combining ability analysis in *Brassica rapa* ssp. *brown sarson* revealed significant mean squares for general and specific combining ability for all the traits studied. The estimates of variance due to dominance deviation (σ^2_D) were much higher than the corresponding additive genetic variance (σ^2_A) for all the traits. The predictability ratio was less than unity for all the traits which indicated that performance on general combining ability of parents alone would not be advisable to select materials in segregating generations, but a combination involving both general and specific combining ability of the parents and particular crosses along with their *per se* performance would be more useful in selecting materials in the segregating generations. Heterosis was estimated over mid and better parent, respectively under present study. The most desirable cross combination CR-1485 x CR-1607 for seed yield plant^{-1} also showed desirable mid and better parent heterosis for 1000-seed weight, primary branches plant^{-1} and seeds siliqua^{-1}. Highest mid and better parent heterosis showed the cross combinations *viz.*, CR-1485 x CR-1607 (primary branches plant^{-1}), CR-1630 x KS-101 (secondary branches plant^{-1}), CR-2638 x KOS-1 (siliquae on main shoot), CR-1630 x CR-2871 (siliquae plant^{-1}), CR-1607 x KOS-1 (days to maturity) and KOS-1 x KS-101 (oil content). These cross combinations also revealed high *per se* performance.

Key words: *Combining ability, heterosis, brown sarson, germplasm*

Introduction

*Brown sarso*n (*Brassica rapa L.*) occupies an important position in temperate conditions of Kashmir valley as it is the only oilseed crop cultivated. Genetic improvement approaches in this crop are limited and based mainly on selection methods. In any breeding program, the common approach of selecting the parents on the basis of *per se* performance does not necessarily lead to fruitful results (Allard, 1960). Therefore, breeding methods for improvement should be based on the nature and magnitude of genetic variance (combining ability) governing the inheritance of quantitative trait (Joshi and Dhawan, 1966). Breeding for heterosis is one of the most successful technological options being employed for the improvement of crop varieties. For brown sarson improvement, breeding methods like inter-varietal hybridization and inter-specific hybridization have promise to broaden the genetic base either through creation of variability or introgression of desirable genes from wild species. The choice of the parents is an important step in hybridization program to create variation for selection of useful recombinants. Therefore, in the present investigation an attempt was made to study combining ability and estimate heterosis for yield, and other related attributes.

Materials and methods

The experimental material for the present investigation comprised of ten diverse genotypes of brown sarson *viz.*, CR-1485, CR-1630, CR-1607,

CR-1480, CR-2871, CR-2638, CR-1617, CR-2677 (from ITK, Germany) KOS-1 and KS-101(local lines) selected from the germplasm collection maintained at Regional Rice and Research Station, Khudwani. Forty five F_1 crosses (excluding reciprocals) were generated through a 10 x 10 diallel mating design during *rabi* 2007-08. The experiment was laid out in a completely randomized block design with two replications at Regional Rice and Research Station, Khudwani, Anantnag (E_1) and Experimental Farm of the Division of Plant Breeding & Genetics, SKUAST-K, Shalimar, Srinagar (E_2) during *rabi* 2008-09. Experimental plot comprised 2 rows each of 3 meter length. Row to row and plant to plant spacing was maintained at 30 and 10 cm. From each parent and F_1's five plants were randomly taken from each replication and observations were recorded for plant height, **primary branches plant⁻¹**, siliquae on main shoot, **seeds siliquae⁻¹**, siliquae plant⁻¹, 1000-seed weight and seed

yield plant⁻¹. The estimates of variance for gca and sca and their effects were computed according to model-1 (fixed effect model) and method-II (parents and crosses, excluding reciprocals) as given by Griffing (1956). Heterosis (pooled over environments) was estimated in relation to mid-parent and better parent. This was calculated as increase or decrease of F_1's over mid-parent and better parent, respectively.

Results and discussion

Analysis of variance of combining ability (table 1) reflected that both the general combining ability (gca) and specific combining ability (sca) mean squares were highly significant. This revealed that additive and non-additive gene effects seemed important in controlling the inheritance of all the traits. The estimates of variance due to dominance deviation (σ^2_D) were much higher than the corresponding

Table 1: Analysis of variance for combining ability and estimates of components of variance for yield and yield attributing traits in brown sarson [Pooled over environments]

Source of variation	d.f.	Plant height (cm)	Primary branches plant⁻¹	Siliquae on main shoot	Siliquae plant⁻¹	Seeds siliqua⁻¹	1000-seed weight (g)	Seed yield plant⁻¹ (g)
Environments	1	42.9**	0.4**	88.3**	42.50**	4.41**	1.07**	1.61**
gca	9	551.3**	7.8**	58.1**	3051.88**	30.71**	1.11**	10.52**
sca	45	60.5	1.5**	28.4**	584.37**	2.85**	0.17**	1.61**
gca x environments	9	15.4**	0.1**	30.1**	5.80	0.01**	0.04**	0.02**
sca x environments	45	9.2**	0.0**	14.5**	20.18**	0.02**	0.02*	0.03**
Pooled	108	0.3	0.0	0.2	7.03	0.005	0.01	0.002
$\hat{\sigma}^2 g$	-	22.9	0.3	2.4	126.86	1.22	0.06	0.43
$\hat{\sigma}^2 s$	-	30.1	0.7	14.1	288.67	1.46	0.08	0.61
$\hat{\sigma}^2 A$	-	91.8	1.3	9.6	507.44	4.88	0.24	1.72
$\hat{\sigma}^2 D$	-	120.3	2.9	56.4	1154.68	5.84	0.32	2.44
$\hat{\sigma}^2 A / \hat{\sigma}^2 D$	-	0.8	0.4	0.2	0.43	0.83	0.75	0.70
$2\hat{\sigma}^2 g / 2\hat{\sigma}^2 g + \hat{\sigma}^2 s$	-	0.5	-0.5	0.3	0.46	0.62	0.60	0.58
$[\hat{\sigma}^2 D / \hat{\sigma}^2 A]^{1/2}$	-	1.1	1.5	2.4	1.50	1.09	1.33	1.19

*, ** = significant at 5% and 1% level of significance, respectively

additive genetic variance (σ^2_A) for all the traits, indicating preponderance of non-additive gene action as compared to additive gene action (pooled analysis over environments).

Combining ability gives useful information for the choice of parents in terms of expected performance of their crosses and progenies (Dhillon, 1975). The gca effect is controlled by fixable additive gene and the cross involving parents with high gca will give better trangressive segregants in later generations. Therefore, selection of parents based on gca effects would have an impact on breeding program. High gca coupled with high *per se* performance is the indication of an outstanding parent with reservoir of superior genes. Hence, both mean performance and gca effects may be taken into account for parental selection (Singh and Dixit, 2007, Dar *et.al*, 2010).

A perusal of the general combining ability effects for parents (table 2) indicated that none of the parents were good general combiner for all the traits studied. However, CR-2871, CR-2638, CR-2677 were observed to be good combiners for primary branches plant[-1]; CR-2638, CR-1617, CR-2677, KOS-1 and KS-101 for plant height; CR-1480, CR-2638, CR-1617 and CR-2677 for siliquae on main shoot; CR-1607, CR-2871, CR-2638, CR-1617 and KOS-1 for siliquae plant[-1]; CR-1607, CR-1480, CR-2871 and CR-1617 for 1000-seed weight; CR-2871, and CR-2638, CR-1617 and CR-2677 for seed yield plant[-1]. Hence, these parents may therefore be used in crop breeding programme aimed at improvement of the respective traits. Further, consideration of *per se* performance in combination with combining ability estimates was reported to provide a better criteria for choice of superior parents in hybridization program (Khan and Khan, 2005). The parents CR-2638, CR-1617, CR-1607 and CR-2871 exhibited significant and desirable gca effects for most of the traits and had also recorded *per se* performance for the traits. Further, these parents also recorded desirable gca effects for seed yield per plant.

Among the best combinations, parents involved were of low × low or low x average gca effects. This

Table 2: General combining ability (gca) effects for yield and yield attributing traits in brown sarson (Pooled over environments)

Parent	Plant height (cm)	Primary branches/ plant	Siliquae on main shoot	Siliquae plant[-1]	Seeds siliqua[-1]	1000-seed weight (g)	Seed yield plant[-1] (g)
CR-1485	108.6	4.3	46.5	95.0	15.6	2.1	3.1
	-4.81**	-0.10**	0.31**	-16.26**	1.05**	-0.17**	-0.59**
CR-1630	102.0	3.8	37.0	80.7	13.9	2.2	3.8
	-9.15**	-0.70**	-3.66**	-12.58	-0.32**	-0.24**	-0.92**
CR-1607	111.7	'#''	41.6	120.6	12.9	2.7	4.0
	-3.20**	**4.7****	-0.41**	1.89**	-0.58**	0.04**	-0.01
CR-1480	116.1	5.8	47.4	112.3	13.1	3.1	4.3
	-0.07	-0.14**	1.57**	-8.79**	-0.73**	0.25**	-0.20**
CR-2871	109.8	7.4	47.1	124.9	15.3	3.4	6.4
	-0.71**	1.34**	0.39**	6.34**	0.52**	0.43**	1.33**
CR-2638	118.5	5.7	41.8	176.4	12.0	2.4	5.1
	0.94**	0.18**	0.33**	23.51**	-0.82**	-0.09**	0.56**
CR-1617	**130.3**	5.3	49.2	129.8	14.0	2.9	5.1
	6.22**	0.00	1.85**	2.64**	-0.14**	0.15**	0.34**
CR-2677	124.8	5.99	50.1	124.5	18.1	2.1	4.7
	4.31**	0.35**	0.95**	-3.13**	2.97**	-0.18**	0.38**
KOS-1	113.7	5.2	40.3	135.5	12.2	2.4	3.7
	0.99**	-0.48**	-0.34**	6.02**	-1.06**	-0.17**	-0.50**
KS-101	118.3	4.8	43.3	114.2	13.2	2.5	3.7
	5.47**	-0.49**	-0.99**	0.35	-0.91**	-0.02	-0.38**
SE± (g)	0.11	0.02	0.07	0.2	0.0	0.01	0.01
SE± (g$_i$-g$_j$)	0.16	0.03	0.11	0.3	0.0	0.04	0.02

Table 3: Top ranking specific cross combinations for different traits on the basis of sca,
per se performance and gca in brownsarson (pooled analysis)

Trait	Best Cross Combinations per se	sca effect	gca effect of parents
Plant height (cm)	CR- 1617 x KS-101	7.555*	High x High
	CR- 1617 x KOS-1	8.877*	High x High
	CR- 2677 x KOS-1	6.885*	High x High
	CR- 2677 x KS-101	0.738	High x High
	CR- 1480 x KS-101	4.230*	Average x High
Primary branches plant^{-1}	CR- 1485 x CR-2871	1.355*	Poor x High
	CR- 2871 x CR-2677	0.155*	High x High
	CR- 1607 x CR-2871	0.211*	High x High
	CR- 2871 x CR-2638	0.047	High x High
	CR- 2871 x KOS-1	0.691*	High x Low
Siliquae on main shoot	CR- 2638 x KOS-1	8.280*	High x Low
	CR- 1480 x CR-1617	3.543*	High x High
	CR- 1485 x CR-1480	3.620*	High x High
	CR- 1607 x CR-1617	3.118*	Low x High
	CR- 1617 x CR-2677	0.555*	High x High
Siliquae plant^{-1}	CR- 2638 x KS-101	46.560*	High x Average
	CR- 2638 x KOS-1	29.162*	High x High
	CR- 1630 x CR-2871	42.393*	Low x High
	CR- 1607 x CR-2638	8.396*	High x High
	CR- 1485 x CR-2871	39.722*	Low x High
Seeds siliqua^{-1}	CR- 1607 x CR-2677	1.384*	Low x High
	CR- 1630 x CR-2677	1.121*	Low x High
	CR- 2638 x CR-2677	1.511*	Low x High
	CR- 2677 x KOS-1	1.737*	High x Low
	CR- 2871 x CR-2677	-0.016	High x High
1000-seed weight (g)	CR- 2871 x CR-2638	0.595*	High x Low
	CR- 2871 x KS-101	0.349*	High x Average
	CR- 2871 x CR-2677	0.479*	High x Low
	CR- 2871 x KOS-1	0.445*	High x Low
	CR- 1607 x CR-2871	0.082*	High x High
Seed yield plant^{-1} (g)	CR- 2871 x CR-2638	0.126*	High x High
	CR- 2871 x KS-101	0.402*	High x Low
	CR- 2871 x CR-2677	0.012	High x High
	CR- 1485 x CR-2871	0.940	Low x High
	CR- 1607 x CR-2871	0.337*	Average x High

may be due to the presence of genetic diversity in the form of dispersed genes for these characters. Some of the crosses showed significant sca effects (table 3) which had the combination of high × high sca effects. Such high × high gca combinations indicates type of interaction between parents for the expression of the characters which matched with the results obtained by Yogeshwar and Sachan, 2003 and Amiri-Oghan *et al.*, 2009. In view of the importance of additive × additive effects and its possibility of fixation, single plant selection could be practiced in further segregating generations to isolate superior pure lines from such combinations. Cross combinations *viz.,* CR- 1607 x CR-2638 for primary branches plant^{-1}, CR- 1485 x CR-1480 and CR- 1480 x CR-1617 for siliquae on main shoot, CR- 2638 x KOS-1 and CR- 1607 x CR-1617 for siliquae plant^{-1} and CR- 1630 x KOS-1 for days to

Table 4a: Heterosis (%) over mid parent for yield and its contributing characters in brown sarson

Cross	Plant height (cm)	Primary branches plant^{-1}	Siliquae on main shoot	Siliquae plant^{-1}	Seeds of siliqua^{-1}	1000-seed weight (g)	Seed yield plant^{-1} (g)
CR-1485 x CR-1630	5.89**	53.65**	18.37**	8.29*	12.60**	20.14**	34.82**
CR-1485 x CR-1607	8.60**	**80.21****	13.88**.	-2.66	24.86**	**41.71****	**79.10****
CR-1485 x CR-1480	6.83**	43.14**	18.71**	-5.19	11.93**	26.34**	35.25**
CR-1485 x CR-2871	1.12	56.12**	9.27**	40.07**	5.26**	3.88	49.20**
CR-1485 x CR-2638	2.89**	20.60**	20.18**	-15.49**	**29.08****	20.20**	37.57**
CR-1485 x CR-1617	-0.12	45.14**	3.36**	-6.85*	11.97**	21.72**	26.39**
CR-1485 x CR-2677	-0.75	26.85**	6.37**	10.36**	10.27**	12.19**	33.27**
CR-1485 x KOS-1	1.19	23.02**	20.40**	-15.83**	16.43**	18.95**	17.70**
CR-1485 x KS-101	7.24**	37.27**	13.10**	-17.33**	17.67**	24.33**	17.77**
CR-1630 x CR-1607	-9.49**	36.37**	27.60**	-0.86	7.72**	19.11**	23.05**
CR-1630 x CR-1480	-4-29**	29.54**	18.97**	-2.75	11.47**	21.59**	30.73**
CR-1630 x CR-2871	10.44**	42.42**	11.17**	**50.13****	0.05	1.69*	42.20**
CR-1630 x CR-2638	-6.25**	33.11**	26.85**	6.53**	11.30**	-0.16	34.13**
CR-1630 x CR-1617	5.79**	33.48**	18.37**	8.29*	12.60**	17.27**	39.81**
CR-1630 x CR-2677	2.04**	40.58**	13.88**.	-2.66	24.86**	19.53**	23.14**
CR-1630 x KOS-1	4.93**	25.35**	18.71**	-5.19	11.93**	4.48	26.13**
CR-1630 x KS-101	**13.06****	21.65**	9.27**	40.07**	5.26**	28.87**	26.31**
CR-1607 x CR-1480	5.45**	36.43**	20.18**	-15.49**	**29.08****	11.17**	36.10**
CR-1607 x CR-2871	8.09**	34.59**	3.36**	-6.85*	11.97**	14/05**	35.63**
CR-1607 x CR-2638	4.45**	48.87**	6.37**	10.36**	10.27**	6.24*	41.66**
CR-1607 x CR-1617	-2.42**	52.06**	20.40**	-15.83**	16.43**	11.37**	45.16**
CR-1607 x CR-2677	4.66**	35.79**	13.10**	-17.33**	17.67**	18.23**	45.78**
CR-1607 x KOS-1	5.73**	16.15**	27.60**	-0.86	7.72**	7.28**	12.75**
CR-1607 x KS-101	7.44**	21.32**	18.97**	-2.75	11.47**	15.22**	16.09**
CR-1480 x CR-2871	6.90**	17.00**	11.17**	**50.13****	0.05	-1.81	22.78**
CR-1480 x CR-2638	7.77**	15.46**	26.85**	6.53**	11.30**	22.23**	21.31**
CR-1480 x CR-1617	-2.06**	13.36.**	18.40**	-3.20	12.19**	8.14**	23.45**
CR-1480 x CR-2677	5.17**	7.49**	4.00**	12.65**	21.17**	22.76**	35.74**
CR-1480 x KOS-1	5.08**	5.77**	20.44**	-3.50	5.92**	11.45**	16.69**
CR-1480 x KS-101	10.80**	7.75**	17.84**	0.79	5.36**	16.16**	19.94**
CR-2871 x CR-2638	11.35**	23.84**	18.55**	-22.24**	17.51**	32.59**	28.81**
CR-2871 x CR-1617	6.91**	24.56**	11.34**	4.94	11.20**	2.10	19.20**
CR-2871 x CR-2677	8.22**	25.09**	6.88**	-13.56**	13.77**	32.00**	28.59**
CR-2871 x KOS-1	5.26**	28.40**	18.17**	-1.86	12.40**	24.01**	41.25**
CR-2871 x KS-101	11.30**	26.34**	14.26**	3.78	12.67**	24.78**	34.24**
CR-2638 x CR-1617	-0.06	22.68**	14.03**	-10.92**	16.16**	22.35**	20.12**
CR-2638 x CR-2677	2.87**	27.48**	14.45**	-12.28**	27.66**	22.73**	33.94**
CR-2638 x KOS-1	9.71**	30.48**	**42.49****	16.90**	10.75**	9.74**	47.75**
CR-2638 x KS-101	6.94**	28.63**	15.60**	34.23**	-2.82**	11.31**	4387**
CR-1617 x CR-2677	0.37	32.11**	10.09**	0.31	14.91**	23.91**	28.48**
CR-1617 x KOS-1	11.27**	9.44**	19.76**	-14.12**	10.42**	15.15**	7.40**
CR-1617 x KS-101	12.22**	35.38**	17.14**	11.58**	12.20**	17.18**	42.36**
CR-2677 x KOS-1	11.07**	20.66**	17.92**	6.43*	26.60**	8.22**	47.12**
CR-2677 x KS-101	7.34**	32.96**	9.31**	6.91*	17.05**	22.58**	54.46**
KOS-1 x KS-101	10.86**	3.38**	9.81**	14.53**	5.07**	2.76	27.41**

Table 4b: Heterosis (%) over better parent for yield and its contributing characters in brown sarson

Cross	Plant height (cm)	Primary branches plant^{-1}	Siliquae on main shoot	Siliquae plant^{-1}	Seeds of siliqua^{-1}	1000-seed weight (g)	Seed yield plant^{-1} (g)
CR-1485 x CR-1630	2.63**	45.29**	6.33**	4.71	6.51**	18.09**	28.13**
CR-1485 x CR-1607	7.11**	**72.89**	7.91**	-13.00**	13.98**	**27.50**	**58.83**
CR-1485 x CR-1480	3.38**	24.41**	17.51**	-12.49**	3.16**	6.84**	16.86**
CR-1485 x CR-2871	0.59	23.26**	8.49**	23.31**	4.42**	-15.75**	12.86**
CR-1485 x CR-2638	-1.38**	5.93**	14.17**	-35.00**	14.15**	13.36**	10.56**
CR-1485 x CR-1617	-8.43**	31.66**	0.51	-19.35**	6.17**	5.63*	1.56
CR-1485 x CR-2677	-7.18**	8.89	2.53*	-2.73	2.45**	11.66**	10.77**
CR-1485 x KOS-1	-1.06	12.43**	12.38**	-28.41**	3.86**	11.42**	8.28**
CR-1485 x KS-101	2.85**	30.05**	9.27**	-24.28**	8.79**	15.59**	8.67**
CR-1630 x CR-1607	-13.34**	24.01**	20.58**	-13.97**	3.73**	8.85**	4.40*
CR-1630 x CR-1480	-10.13**	-0.90	5.92**	-12.96**	8.45**	4.32	8.23*
CR-1630 x CR-2871	6.50**	7.95**	-0.77	**28.39**	-4.64**	-16.41**	3.57**
CR-1630 x CR-2638	-12.78**	11.43**	19.55**	-19.96**	3.62**	-4.28	3.75**
CR-1630 x CR-1617	-5.72**	15.17**	-4.43**	-7.14*	9.86**	3.29	8.12**
CR-1630 x CR-2677	-7.30**	15.19**	-6.71**	-19.33**	6.58**	16.95**	-1.70
CR-1630 x KOS-1	0.49	8.91**	22.35**	-17.21**	9.35**	-0.51	10.77**
CR-1630 x KS-101	5.24**	9.32**	3.69**	-11.04**	5.60**	21.76**	11.25**
CR-1607 x CR-1480	3.44**	23.03**	8.53**	10.26**	2.00*	3.66	32.09**
CR-1607 x CR-2871	7.16**	9.71**	11.01**	6.49*	10.74**	1.39	10.29**
CR-1607 x CR-2638	1.48**	35.75**	21.66**	-10.51**	**17.96**	1.04	26.42**
CR-1607 x CR-1617	-9.39**	43.41**	11.39**	13.61**	7.53**	6.93**	29.52**
CR-1607 x CR-2677	-0.83**	20.86**	2.45*	-3.08	6.59**	5.93*	35.30**
CR-1607 x KOS-1	4.80**	10.41**	21.65**	-6.40*	4.53**	2.73	8.31**
CR-1607 x KS-101	4.44**	19.74**	21.58**	-0.89	-1.42	11.21**	11.16**
CR-1480 x CR-2871	3.97**	4.38**	7.49**	7.73*	4.90**	-6.74**	2.25*
CR-1480 x CR-2638	6.72**	14.05**	13.64**	-33.19**	7.64**	8.79**	11.24**
CR-1480 x CR-1617	-7.38**	8.08**	16.29**	-9.74**	8.87**	4.89*	13.18**
CR-1480 x CR-2677	1.52**	5.92**	1.24	-16.94**	4.44**	3.42	29.62**
CR-1480 x KOS-1	3.98**	0.04	11.36**	-11.77**	2.19**	-0.16	8.93**
CR-1480 x KS-101	**9.78**	-1.68	12.75**	-0.04	5.01**	4.80*	11.61**
CR-2871 x CR-2638	7.27**	9.30**	11.87**	-33.62**	4.65**	12.42**	15.81**
CR-2871 x CR-1617	-1.51**	6.57**	9.03**	2.93	6.25	-5.79**	7.18**
CR-2871 x CR-2677	1.71	13.08**	3.74**	-13.68**	4.92**	6.67**	11.34**
CR-2871 x KOS-1	3.45**	9.10**	9.57**	-5.72*	0.98	6.15**	11.38**
CR-2871 x KS-101	7.29**	4.04**	9.65**	-0.66	4.95**	7.55**	5.59**
CR-2638 x CR-1617	-4.60**	18.35**	5.50**	-22.69**	7.89**	11.96**	20.09**
CR-2638 x CR-2677	0.25	24.11	5.01**	-25.19**	5.94**	15.24**	28.37**
CR-2638 x KOS-1	7.51**	24.87**	**39.85**	3.33	9.67**	8.95**	27.30**
CR-2638 x KS-101	6.88**	18.70**	13.60**	10.54**	-7.62**	9.62**	23.60**
CR-1617 x CR-2677	-1.76**	24.20**	9.10**	-1.73	1.65**	7.11**	23.10**
CR-1617 x KOS-1	4.17**	8.53**	8.91**	-15.92**	3.49**	6.07*	-7.49**
CR-1617 x KS-101	7.05**	29.29**	10.16**	4.85	9.23**	8.75**	22.28**
CR-2677 x KOS-1	6.13**	12.56**	6.37**	2.12	5.89**	0.93	31.58**
CR-2677 x KS-101	4.45**	19.73**	1.94	2.47	1.17*	13.46**	37.74**
KOS-1 x KS-101	8.70**	-0.48	5.94**	5.52*	1.04	1.92	26.99**

maturity showed low sca effects though the parents showed high × high gca effects. Thus, it revealed that high × high type of combinations not necessarily results into high sca effects. This is probably due to internal cancellation of gene effects in these parents.

The manifestations of heterosis in percentage for different characters over mid-parent and better parent were analyzed (table 4a & b)). For plant height 34 and 26 crosses showed positive heterosis over mid-parent and better parent, respectively. Highest significant positive heterosis was exhibited by the cross CR-1630 x KS-101 (13.1%) over the mid parent, while highest significant positive heterobeltiosis for plant height was noted in the cross CR-1480 x KS-101 (9.8 %). Similarly for number of primary branches plant^{-1}, all the cross combinations showed significant positive heterosis over mid parent and forty-one cross combinations exhibited significant positive heterobeltiosis. The best heterotic combination for mid and better parent heterosis was CR-1485 x CR-1607. All the cross combinations showed significant positive heterosis over mid parent in number of siliquae on main shoot, while 39 cross combinations exhibited better parent heterosis of which CR-2638 x KOS-1 showed the highest percentage (39.9%).

Out of 45 crosses, 18 and 8 cross combinations showed significant positive heterosis over mid and better parent for siliquae plant^{-1} among which maximum positive heterosis was observed in CR-1630 x CR-2871 (50.1%) and CR-1630 x CR-2871 (28.4%), respectively. Similarly, for seeds siliqua^{-1} CR-1485 x CR-2638 (29.1%) and CR-1607 x CR-2638 (18.0%) showed maximum positive significant heterosis over both mid and better parent, respectively. Significant positive better parent heterosis for 1000-seed weight was noted with 32 crosses among which high estimates were expressed by CR-1485 x CR-1607 (27.5%) followed by CR-1630 x KS-101 and CR-1485 x CR-1630. For seed yield plant^{-1}, the highest estimate of relative heterosis over the mid-parent was exhibited by CR-1485 x CR-1607 (79.1%) and over the better parent it was exhibited by CR-1485 x CR-1607

(58.8%) followed by CR-2677 x KS-101 and CR-1607 x CR-2677.

The characters like, reduced plant height and length of main axis are preferred in *Brassica* group, which imparts tolerance to abiotic stresses like heat, lodging and full seed formation due to the large seed filling period. Therefore, the negative heterosis is desirable for these traits. Remaining yield-related characters, such as the primary branches per plant, seed yield per 100 siliquae, seed yield per plant, provide more opportunities for increasing yield, and hence, the positive heterosis are preferred. Therefore, estimation of heterosis over mid-parent (relative heterosis) may be useful in identifying true heterotic cross combinations. Since higher yields in F_1 may be due to fixable (additive) and/or non-fixable (non-additive) gene action, the total effect partition of F_1 progeny into general and specific combining ability effects deciphers the causes of heterosis. Yield is a complex character and highly influenced by environment. Grafius (1959) suggested that there might not be genes for yield *per se* but for the components. Therefore, it would be interesting to know the relationship between the heterosis for seed yield and its components. Significant heterosis for yield, yield components and maturity traits in brown sarson and other oilseed *Brassicas* have been reported by several workers (Chauhan *et al.,* 2000; Tyagi *et al.,* 2000; Singh *et al.*, 2003; Turi *et al.*, 2006; Prajapati *et al.*, 2007 and Singh and Dixit, 2007) who attributed increased vigour mainly to dominance. The results obtained in the present investigation suggest that judicious selection of parents having one or more important maturity as well as yield attributing traits is needed to exploit heterosis provided, a mechanism for hybrid seed production is available in the self-incompatible background of brown sarson.

References

Allard, R.W. 1960. *Principles of Plant Breeding.* John Wiley and Sons, Inc. New York, pp 463-470.

Amiri-Oghan, H., Fotokian, M.H., Javidfar, F. and Alizadeh, B. 2009. Genetic analysis of grain yield

days to flowering and maturity in oilseed rape (*B.napus*) using diallel crosses. *International J Pl Production* **3**: 19-26.

Chauhan, S.S., Srivastava, R.K. and Kumar, K. 2000. Heterosis in single and three way crosses in Indian mustard (*B. juncea*). *Indian J Genet* **60**: 131-132.

Dar, Z.A., Wani, Shafiq, A., Ahmad, I. and GulZaffar. 2010. Heterosis and combining ability in brown sarson (*B. rapa*). *Cruciferae Newsletter* **29**: 46-50.

Dhillon, B.S. 1975. The application of partial diallel crosses in Plant Breeding. *A Review Crop Improvement* **2:** 1-7.

Grafius, J. E. 1959. Heterosis in barley. *Agronomy Journal* 51: 551-554

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing systems. *Aus J Biological Science* **9**: 463-493.

Joshi, A. B. and Dhawan, N. L. 1966. Genetic improvement in yield with special reference in self-fertilizing crops. *Indian J Genet* **26**: 21-36.

Khan, F.A. and Khan, R.S.A. 2005. Inheritance pattern of quantitative characters in *Brassica napus*. *International J Agri and Biology* **7** (3): 420-423.

Prajapati, C.H. Patel, K.M., Patel, M.P. and Pathak, H.C. 2007. Heterosis for seed yield and its components in Indian rapeseed, *B. campestris* ssp *yellow sarson*. *J Oilseeds Research* **24**: 309-310.

Singh, M., Lallu, Swarnkar, G.B., Lalta, P., Dixit, R. K. 2003. Heterobeltiosis and inbreeding depression in Indian mustard. (*B. juncea*) . *Crop Res* 26: 318–325.

Singh, R.K. and Dixit, P. 2007. Heterosis and combining ability studies for seed yield, its attributes and oil content in Indian mustard (*B. juncea*). *Crop Improvement* **34**: 192-196.

Turi, N.A., Raziuddin, Shah, S.S. and Ali, S. 2006. Estimation of heterosis for some important traits in mustard (*B. juncea*). *J Agric Biol Sci,* **4**(1): 6-10.

Tyagi, M.K., Chauhan, J.S., Yadav, S.K., Kumar, P.R. and Tyagi, P. 2000. Heterosis in Inter- sspietal crosses in mustard (*B. juncea*). *Annals of Biology* **16**: 191-194.

Yogeshwar and Sachan, J.N. 2003. Combining ability analysis for seed yield and its components in Indian mustard (*B. juncea*). *Indian J Genet* **63**: 83-84.

●