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HETEROSIS AND COMBINING ABILITY IN A DIALLEL CROSS OF TURNIP RAPE GENOTYPES

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ABSTRACT

This study was undertaken to estimate the combining ability in turnip rape through diallel analysis involving five diverse genotypes. A 5 x 5 full diallel crosses study, including the reciprocals, with turnip rape (*Brassica rapa* L.) was performed to determine both the magnitude of gene action and heterotic performance of the crosses for seed yield and important yield components. Field experiments were conducted at Uludag University, Bursa, Turkey, during the 2008-2009 and 2009-2010 growing seasons. All 20 F_1 hybrids and their parents were sown in a randomized complete block design with 3 replicates. During both years, the mean squares of the general combining ability (GCA), specific combining ability (SCA) and reciprocal combining ability (RCA) were statistically significant for all traits evaluated. The parent Malvira was a good general combiner because this parent had the highest significant positive GCA effects for all the characteristics evaluated. In addition, Lenox proved to be a good general combiner for plant height. The significant positive mid-parent and high-parent heterosis values were obtained with several crosses in important yield components. In conclusion, the parents used in this study exhibited positive GCA effects for seed yield. Therefore they could be considered as promising parents in the production of F_1 hybrids and in further breeding studies.

Key words: *Brassica rapa* L., general combining ability, seed yield, specific combining ability, reciprocal combining ability, yield components

INTRODUCTION

Brassica rapa is an obligate out-crossing, self-incompatible crop with high genetic diversity within cultivars (Zhao et al., 2005). Among the different breeding methods suggested for the improvement of *Brassica* populations, full-sib selection makes direct use of both combining ability and heterosis (Lambeth et al., 2001). Dar et al. (2011) hypothesized that for the improvement of brown sarson (*Brassica rapa* syn. *Brassica campestris*), breeding methods such as inter-varietal hybridization and inter-specific hybridization may broaden the genetic base either by creating variability or introgressing desirable genes from wild species. In addition, the same authors emphasized that the choice of parents is an important step in the hybridization program to create variation for the selection of useful recombinants.

A number of studies on heterosis and combining ability have been performed for yield and certain agronomic traits in *Brassica* species. Falk et al. (1994) observed that heterosis for seed yield was greatest in crosses between genetically diverse cultivars but seed oil content was not heterotic in turnip rape. Dar et al. (2011) reported that both the GCA and SCA were highly significant for different traits in turnip rape. In the previous studies, a significant GCA and SCA effects were generally reported for the number of pods per main raceme, pods per plant, number of seeds per pod, 1000 seed weight and seed yield in *Brassica* species (Singh and Murty, 1980; Thakur and Sagwal, 1997; Sabaghnia et al., 2010; Verma, 2000; Vaghela et al., 2011). Significant mid-parent and high-parent heterosis for seed yield and certain yield components in *Brassica rapa* and other *Brassica* species have been also reported by several researchers (Sernyk and Stefansson, 1983; Brandle and Mc Vetty, 1989; Leon, 1991; Tyagi et al., 2000; Sincik et al., 2011).

Combining ability and hybrid vigor are the most important genetic parameters for breeding improved cultivars. The variances of general combining ability (GCA) and specific combining ability (SCA) are related to the type of gene action involved. The variance for GCA includes the additive portion of the total variance, whereas that for SCA includes the non-additive portion of the total variance, arising largely from dominance and epistatic deviations (Malik et al., 2004). Information on the relative importance of the additive (GCA) and non-additive (SCA) gene actions within a breeding population is significant because it is used to determine which breeding procedure will efficiently improve the performance of the characters of interest (Dudley and Moll, 1969). Most previous studies on combining abilities have shown significant GCA and SCA effects for yield and its component characters. These results indicate that both additive and non-additive gene action are important in the inheritance of these traits (Rameah et al., 2003; Akbar et al., 2008; Huang et al., 2010)

Turnip rape (*Brassica rapa* L.) is an important edible oilseed crop, green fodder and a potential source of biodiesel production in Turkey (Bilgili et al., 2003; Sincik et al., 2007). The objectives of this study were to estimate the effects of GCA and SCA and to evaluate the magnitude of mid-parent and high-parent heterosis for both seed yield and yield components of F_1 progeny in a diallel cross in turnip rape.

MATERIALS AND METHODS

Five standard open pollinated turnip rape varieties, Buko (PR_1), Hanko (PR_2), Lenox (PR_3), Malvira (PR_4), and Polybra (PR_5) which were selected on the basis of high seed yield potential and related agronomic characters were used in this study. The genetic material used in the experiment consisted of F_1 hybrid seed resulting from 5 x 5 diallel crosses among these five varieties, including selfs and reciprocals. Hybrid seed was produced by emasculation and hand pollination of immature buds. Averages of 20 plants from each parent variety were used for crossing.

The field experiments were conducted in Bursa (latitude 40° 22′ N, longitude 29° 12' E, altitude 155 m). Bursa is located in the southern Marmara region with Mediterranean type climate. It has an average annual rainfall of 713 mm and a mean monthly temperature of 14.4 °C. The soil on the site is classified as Vertisol typic habloxrert. A soil analysis indicated that the soil was clay loam, slightly alkaline (pH = 7.3), rich in potassium (933 kg ha^{-1}), medium in phosphorus (70 kg ha^{-1}) and containing 1.2% organic matter.

The field experiments were arranged in a randomized complete block design with three replications. Twenty F_1 populations from a 5 x 5 diallel cross, along with their parents, were sown in October 16, 2008 and October 20, 2009. Each plot consisted of four rows, 5 m in length, with 45 cm between rows and 3 cm within rows spacings. A 50 kg ha^{-1} N-P-K each as a composed fertilizer was applied before seeding and 100 kg ha^{-1} N as urea was applied in the early spring. Weeds were controlled by hand pulling and hoeing. The field experiments were harvested with a small-plot combine in 19 June 2009 and 25 June 2010 at maturity.

The following agronomic traits were recorded from the same 10 randomly selected plants of the central rows of each plot just prior to harvest: plant height, number of pods per main raceme, and number of seeds per pod. After harvest, the seed yield and 1000-seed weight was determined for each plot.

Analysis of variance was performed according to Steel and Torrie (1980). The analysis of diallels for combining ability was performed using mean values, following Model I Method II of Griffing's method (1956). The t-test was applied to examine the effects of GCA, SCA and RCA. All statistical analyses were performed using MSTAT-C (Version 2.1, Michigan State University 1991) and MINITAB (Version 15, University of Texas, Austin) software Significant differences between hybrids and parents were detected using the F-test. Mid-parent and high-parent heterosis values were estimated in relation to mid-parent and high-parent. These were calculated as increase or decrease of F_1's over mid-parent and high-parent, respectively (Dar et al., 2011).

RESULTS

The analysis of variance of the combining ability showed that the mean squares of the GCA, SCA and RCA were statistically significant for all the characteristics evaluated (Table 1). The analysis of variance revealed that significant genotype effect for all the characters. This provides evidence of presence of sufficient genetic variability among parents and crosses.

Table 1. Mean squares obtained from preliminary analysis and combining abilities in 5 x 5 diallel turnip rape crosses at F_1

Source of variance	d.f.	Plant height		Number of pods/main raceme		Number of seeds/pod		Seed yield		1000-seed weight	
		2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Preliminary Analysis of Anova											
Replications	2	3.8^{ns}	7.2^{ns}	2.1^{ns}	6.3^{ns}	0.6^{ns}	1.6^{ns}	26352*	78732**	0.01^{ns}	0.02*
Genotypes	24	690.0**	324.8**	135.0**	63.1**	12.5**	9.8**	182367**	217233**	0.32**	0.27**
Error(P)	*48*	*5.54*	*5.20*	*2.73*	*3.51*	*0.82*	*1.21*	*6327*	*12694*	*0.006*	*0.004*
Anova of Griffing											
GCA	4	550.8**	130.2**	104.2**	3.6**	7.5**	5.2**	89118**	76347**	0.07**	0.05**
SCA	10	192.5**	184.1**	44.2**	26.2**	4.7**	3.0**	88736**	117372**	0.21**	0.18**
RCA	10	139.2**	23.7**	22.1**	8.8**	2.3**	2.7**	21510**	25875**	0.02**	0.02**
Error(CA)	*48*	*1.84*	*1.73*	*0.91*	*1.17*	*0.27*	*0.40*	*2109*	*4231*	*0.002*	*0.001*

df: degrees of freedom; ns: not significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; P: Preliminary; CA: Combining ability

There were significant differences among the average values of the crosses and reciprocal crosses for all the traits measured in our study. The plant heights of the crosses and reciprocals of the turnip rape averaged 140.0 cm (98.7 – 172.0 cm) in 2009 and 174.0 cm (158.7 – 181.7 cm) in 2010 (Table 2). The average values for the number of pods per main raceme of the crosses and reciprocal crosses varied significantly over the two years of the study. The highest seed yields were obtained from the reciprocal crosses PR_5 x PR_4 (2370.2 kg ha^{-1}) and PR_4 x PR_1 (2310.8 kg ha^{-1}) in 2009 and the reciprocal crosses PR_3 x PR_2 (2970.8 kg ha^{-1}), PR_5 x PR_4 (2940.6 kg ha^{-1}) and PR_4 x PR_3 (2940.5 kg ha^{-1}) in 2010. The crosses and reciprocals produced higher seed yield than the parents during both experimental years. Two year average seed yields of parents, crosses and reciprocals were 1938, 2289, and 2468 kg ha^{-1} respectively. The 1000 seed weight values of the hybrids varied between 3.83 g (PR_3 x PR_2) and 4.67 g (PR_4 x PR_3) in 2009 and 3.70 g (PR_3 x PR_2) and 4.47 g (PR_4 x PR_5) in 2010.

Table 2. Mean values of parents (P) and the hybrids (H) for measured characteristics

	Plant height (cm)		**Number of pods / main raceme**		**Number of seeds / pod**		**Seed yield (kg ha^{-1})**		**1000-seed weight (g)**	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
Parents										
Buko (PR_1)	122.7 kl	151.3 k	31.0 j	51.7 g-ı	16.7 ıj	20.0 f-h	1710.3 gh	2130.0 jk	3.63 kl	3.53 j
Hanko (PR_2)	124.3 k	140.0 l	32.7 ıj	49.0 ı-j	14.3 k	17.7 l	1410.1 ı	2040.5 k	3.53 l	3.40 k
Lenox (PR_3)	129.3 ıj	156.3 j	36.3 gh	44.0 kl	17.7 f-ı	21.0 d-f	1890.0 f	2250.7 h-j	3.67 jk	3.60 ıj
Malvira (PR_4)	132.0 hı	173.3 e-g	34.0 hı	52.7 f-h	17.7 f-ı	21.0 d-f	1830.4 fg	2340.8 g-ı	3.77 ıj	3.60 ıj
Polybra (PR_5)	126.3 jk	156.0 j	35.0 hı	49.7 h-j	17.0 h-j	19.7 f-h	1650.5 h	2130.2 jk	3.57 kl	3.40 k
Crosses										
PR_1 x PR_2	134.0 gh	168.0 hı	33.0 ıj	53.7 d-g	18.3 e-h	22.0 b-e	1830.2 fg	2220.4 ı-k	4.17 de	4.13 de
PR_1 x PR_3	156.3 bc	176.3 c-f	42.0 de	55.7 c-f	21.7 a	23.7 ab	2130.0 cd	2520.9 d-g	4.20 de	4.03 e
PR_1 x PR_4	150.3 d	178.0 a-d	44.0 cd	57.0 a-c	18.3 e-h	20.7 d-g	2280.7 ab	2850.6 ab	4.03 fg	3.8 6 f
PR_1 x PR_5	143.3 e	177.3 b-d	36.3 gh	42.0 l	19.0 d-f	21.0 d-f	2070.3 de	2490.5 d-g	4.40 c	4.17 cd
PR_2 x PR_3	143.7 e	174.3 d-g	34.0 hı	59.0 ab	15.7 jk	18.3 hı	1710.1 gh	2550.7 d-f	3.87 hı	3.73 gh
PR_2 x PR_4	131.7 hı	158.7 j	38.0 fg	57.7 a-c	16.7 ıj	19.0 g-ı	1950.6 ef	2430.0 e-h	3.97 gh	3.83 fg
PR_2 x PR_5	136.7 fg	175.7 c-f	33.7 h-j	57.7 a-c	17.7 f-ı	20.0 f-h	2070.4 de	2490.3 d-g	3.97 gh	3.87 f
PR_3 x PR_4	152.7 cd	179.0 a-c	45.0 c	55.3 c-f	18.7 d-g	21.0 d-f	2130.2 cd	2670.2 b-d	4.53 b	4.27 bc
PR_3 x PR_5	141.3 e	173.0 e-g	34.0 hı	57.3 a-c	22.0 a	24.0 a	1860.0 f	2400.7 f-ı	4.57 ab	4.37 ab
PR_4 x PR_5	144.0 e	176.0 c-f	42.0 de	56.0 b-e	20.7 a-c	23.7 ab	2280.7 ab	2850.8 ab	4.53 b	4.47 a
Reciprocals										
PR_2 x PR_1	98.7 m	176.7 b-e	26.7 k	46.7 j-k	17.7 f-ı	21.3 c-f	2190.4 b-d	2490.4 d-g	4.40 c	4.17 cd
PR_3 x PR_1	154.7 c	180.3 ab	39.7 ef	53.0 e-g	21.3 ab	22.3 a-d	2070.3 de	2640.7 cd	4.17 de	4.03 e
PR_3 x PR_2	134.0 gh	177.7 b-d	33.7 h-j	55.7 c-f	17.3 g-ı	20.3 e-g	1920.6 f	2970.8 a	3.83 l	3.70 hı
PR_4 x PR_1	140.3 ef	177.3 b-d	55.0 a	48.3 j	21.0 a-c	24.0 a	2310.8 ab	2820.1 a-c	3.87 hı	3.83 fg
PR_4 x PR_2	132.0 hı	171.3 hı	42.3 c-e	53.3 e-g	21.3 ab	23.0 a-c	2250.5 a-c	2610.6 de	4.17 de	4.03 e
PR_4 x PR_3	172.0 a	174.3 d-g	48.7 b	59.7 a	21.0 a-c	24.0 a	2280.9 ab	2940.5 a	4.67 a	4.37 ab
PR_5 x PR_1	122.0 l	172.7 fg	31.0 j	55.7 c-f	18.7 d-g	21.3 c-f	2280.1 ab	2820.0 a-c	4.27 d	4.13 de
PR_5 x PR_2	122.3 l	164.7 ı	35.0 hı	56.0 b-e	19.7 c-e	23.0 a-c	2190.4 b-d	2580.9 d-f	4.17 de	4.03 e
PR_5 x PR_3	158.7 b	176.7 b-e	48.3 b	56.7 a-d	20.0 b-d	22.3 a-d	2130.6 cd	2550.3 d-f	4.13 ef	3.87 f
PR_5 x PR_4	142.0 e	181.7 a	44.7 cd	53.3 e-g	20.7 a-c	23.0 a-c	2370.2 a	2940.6 a	4.40 c	4.27 bc
LSD (% 5)	*3.86*	*3.74*	*2.71*	*3.07*	*1.48*	*1.80*	*130.6*	*185.0*	*0.13*	*0.10*

s: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level ;
Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test.

The estimates of the GCA effects for the parents indicated that Malvira (PR_4) was a good general combiner for all the characteristics evaluated (Table 3). This parent also gave higher mean values for the most of the characteristics measured compared to the other parents. Lenox (PR_3) was a good general combiner for plant height only. In addition, it exhibited the highest significant positive GCA effect and higher average values for the number of pods per main raceme, the number of seeds per pod and the 1000 seed weight in 2009 but not 2010. Therefore, Lenox (PR_3) was not considered to be a stable and good general combiner for these characteristics. In contrast, Polybra (PR_5) displayed higher mean values and significant positive GCA effects for 1000 seed weight both years, indicating Polybra (PR_5) was determined to be a good general combiner for this trait (Table 2 and 3).

None of the crosses showed stability over the years for plant height. The cross PR_3 x PR_4 and the reciprocal cross PR_4 x PR_3 had higher plant heights and significant positive SCA and RCA effects and were the best general combiners for plant height. Among the crosses, significant positive combining ability effects for the number of pods per main raceme were obtained from PR_3 x PR_4 and PR_5 x PR_3 in 2009 and from the PR_2 x PR_5, PR_3 x PR_5, PR_4 x PR_3 and PR_5 x PR_1 in 2010. Differences between the years for combining ability effects of the crosses were due to significant genotype x year interactions for the number of pods per main raceme. Several crosses and reciprocals showed positive significant SCA effects for the number of seeds per pod in both years. The parents PR$_3$, PR$_4$ and PR$_5$ of these crosses were good general combiners. For the 1000 seed weight, the PR$_4$ x PR$_5$ and the reciprocal cross PR$_4$ x PR$_2$ produced significant positive combining ability effects, whereas the reciprocal cross PR$_3$ x PR$_2$ showed non-significant RCA effects during both experimental years. The cross PR$_4$ x PR$_5$ with a significant positive SCA effect had the best parents as good general combiners for the 1000 seed weight. The significant positive combining ability actions (RCA effects) were obtained from the reciprocal crosses PR$_4$ x PR$_1$, PR$_4$ x PR$_3$, PR$_5$ x PR$_1$ and PR$_5$ x PR$_4$ for two years. These crosses were promising cross combinations for the seed yield (Table 3). There are maternal effects for observed characters because of significant RCA variances.

Table 3. General combining ability (GCA), special combining ability (SCA) and reciprocal combining ability (RCA) effects for measured characteristics

Parents/Hybrids	Plant height (cm)		Number of pods / main raceme		Number of seeds / pod		Seed yield (kg ha^{-1})		1000-seed weight (g)	
	2009	2010	2009	2010	2009	2010	2009	2010	2009	2010
GCA effects										
Buko (PR$_1$)	-3.31**	0.27^{ns}	-1.27**	-1.93**	0.11^{ns}	0.14^{ns}	26.4*	-37.8*	-0.02^{ns}	-0.01^{ns}
Hanko (PR$_2$)	-9.64**	-5.97**	-4.07**	0.30^{ns}	-1.53**	-1.26**	-137.6**	-106.8**	-0.14**	-0.12**
Lenox (PR$_3$)	9.39**	1.77**	1.56**	0.57^{ns}	0.47**	0.31^{ns}	-30.6*	25.2^{ns}	0.03*	0.01^{ns}
Malvira (PR$_4$)	5.08**	3.63**	4.53**	1.13**	0.54**	0.54**	119.4**	130.2**	0.07*	0.06**
Polybra (PR$_5$)	-1.51**	0.30^{ns}	-0.74**	-0.07^{ns}	0.41**	0.27^{ns}	23.4^{ns}	-10.8^{ns}	0.06**	0.05**
SCA effects										
PR$_1$ x PR$_2$	-8.52**	7.37**	-3.06**	-1.67**	0.59^{ns}	1.29**	90.6**	-49.2^{ns}	0.34**	0.32**
PR$_1$ x PR$_3$	11.61**	5.63**	2.31**	2.23**	2.09**	1.06**	72.6**	43.8^{ns}	0.07**	0.08**
PR$_1$ x PR$_4$	5.75**	3.10**	8.01**	0.00^{ns}	0.19^{ns}	0.16^{ns}	117.6**	193.8**	-0.20**	-0.16**
PR$_1$ x PR$_5$	-0.32^{ns}	3.77**	-2.56**	-2.63**	-0.51^{ns}	-0.74^{ns}	93.6**	154.8**	0.20**	0.16**
PR$_2$ x PR$_3$	1.28^{ns}	9.53**	-1.89**	3.00**	-1.27**	-1.21**	-47.4^{ns}	292.8**	0.14**	-0.12**
PR$_2$ x PR$_4$	-1.42^{ns}	-3.33**	1.47*	0.60^{ns}	1.16**	0.23^{ns}	87.6**	-52.2^{ns}	0.03^{ns}	0.04^{ns}
PR$_2$ x PR$_5$	2.85**	5.17**	0.91^{ns}	3.13**	0.96**	0.99**	213.6**	103.8**	0.05^{ns}	0.07**
PR$_3$ x PR$_4$	10.04**	0.60^{ns}	2.51**	2.33**	-0.01^{ns}	0.16^{ns}	84.6**	100.8*	0.40**	0.29**
PR$_3$ x PR$_5$	4.31**	2.10**	2.11**	3.03**	1.29**	1.09**	-29.4^{ns}	-88.2*	0.16**	0.11**
PR$_4$ x PR$_5$	1.61*	4.23**	1.31*	0.13^{ns}	0.89**	1.03**	150.6**	226.8**	0.24**	0.30**
RCA effects										
PR$_2$ x PR$_1$	-17.67**	4.33**	-3.17**	-3.50**	-0.33^{ns}	-0.33^{ns}	180.0**	135.0**	0.12**	0.02^{ns}
PR$_3$ x PR$_1$	-0.83^{ns}	2.00*	-1.17^{ns}	-1.33^{ns}	-0.17^{ns}	-0.67^{ns}	-30.0^{ns}	60.0^{ns}	-0.02^{ns}	0.00^{ns}
PR$_3$ x PR$_2$	-4.83**	1.67^{ns}	-0.17^{ns}	-1.67*	0.83**	1.00*	105.0**	210.0**	-0.02^{ns}	-0.02^{ns}
PR$_4$ x PR$_1$	-5.00**	-0.33^{ns}	5.50**	-4.33**	1.33**	1.67**	15.0^{ns}	-15.0^{ns}	-0.08**	-0.02^{ns}
PR$_4$ x PR$_2$	0.17^{ns}	6.33**	2.17**	-2.17**	2.33**	2.00**	150.0**	90.0^{ns}	0.10**	0.10**
PR$_4$ x PR$_3$	9.67**	-2.33*	1.83**	2.17**	1.17**	1.50**	75.0*	135.0**	0.07*	0.05*
PR$_5$ x PR$_1$	- 10.67**	-2.33*	-2.67**	6.83**	-0.17^{ns}	0.17^{ns}	105.0**	165.0*	-0.07*	-0.02^{ns}
PR$_5$ x PR$_2$	-7.17**	-5.50**	0.67^{ns}	-0.83^{ns}	1.00**	1.50**	60.0^{ns}	45.0^{ns}	0.10**	0.08**
PR$_5$ x PR$_3$	8.67**	1.83^{ns}	7.17**	-0.33^{ns}	-1.00**	-0.83^{ns}	135.0**	75.0^{ns}	-0.22**	-0.25**
PR$_5$ x PR$_4$	-1.00^{ns}	2.83**	1.33^{ns}	-1.33^{ns}	0.00^{ns}	-0.33^{ns}	45.0^{ns}	45.0^{ns}	-0.07*	-0.10**
Standard errors										
S. Error (g_i)	0.38	0.37	0.27	0.31	0.15	0.18	13.0	18.4	0.013	0.010
S. Error (s_{ij})	0.79	0.77	0.56	0.63	0.30	0.37	26.8	37.9	0.027	0.021
S. Error (r_{ij})	0.96	0.93	0.67	0.76	0.37	0.45	32.5	46.0	0.032	0.026

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level ;
Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test.

In this study, the best cross combinations involved the parents of high x high, low x average, high x low, average x low and high x average GCA effects for the seed yield and important yield components (Table 4). In general, the crosses that showed significant SCA effects for the seed yield had a combination of high x high (PR$_1$ x PR$_4$), low x average (PR$_2$ x PR$_5$), high x low (PR$_4$ x PR$_2$), high x average (PR$_4$ x PR$_5$) and average x low (PR$_4$ x PR$_2$) GCA effects.

Table 4. Top ranking combinations with the highest SCA effects on the basis of GCA effect of parent in certain traits

Components	**Hybrids**	**SCA effects**		**GCA effects of parent**
		2009	2010	
Plant height (cm)	PR_3xPR_4	10.04**	0.60^{ns}	High x High
	PR_4xPR_3	9.67**	-2.33*	High x High
Number of pods per main raceme	PR_3xPR_5	2.11**	3.03**	Average x Low
Number of seeds per pods	PR_2xPR_5	0.96**	0.99**	Low x Average
	PR_3xPR_5	1.29**	1.09**	Average x Average
	PR_4xPR_5	0.89**	1.03**	High x Average
	PR_3xPR_2	0.83**	1.00**	Average x Low
	PR_4xPR_1	1.33**	1.67**	High x Low
	PR_4xPR_3	1.17**	1.50**	High x Average
	PR_5xPR_2	1.00**	1.50**	Average x Low
Seed yield (kg ha^{-1})	PR_1xPR_4	117.6**	193.8**	High x High
	PR_2xPR_5	213.6**	103.8**	Low x Average
	PR_4xPR_2	150.0**	90.0^{ns}	High x Low
	PR_4xPR_5	150.6**	226.8**	High x Average
	PR_5xPR_3	135.0**	75.0^{ns}	Average x Low
1000 seed weight (g)	PR_4xPR_5	0.24**	0.30**	High x High
	PR_4xPR_2	0.10**	0.10**	High x Low

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level

Heterotic estimates of the cross combinations for seed yield are given in Table 5. All of the crosses and reciprocals yielded more seed yield than mean of their two parents (mid-parent heterosis) in both years. In 2009, eight crosses and nine reciprocals yielded more seed yield than the higher yielded parents (high-parent heterosis). In 2010, all of the crosses and reciprocals showed statistically significant high-parent heterosis.

Table 5. Mid-parent and high-parent effects for seed yield of hybrids

Hybrids	**Seed Yield (kg ha^{-1})**			
	Mid-parent		**High-parent**	
	2009	2010	2009	2010
Direct crosses				
PR_1 x PR_2	17.34**	6.46**	6.84**	4.22**
PR_1 x PR_3	18.50**	15.22**	12.86**	12.00**
PR_1 x PR_4	29.08**	27.82**	24.63**	21.92**
PR_1 x PR_5	23.65**	16.87**	21.05**	16.88**
PR_2 x PR_3	3.82**	18.90**	-9.52**	13.20**
PR_2 x PR_4	20.55**	11.11**	6.89**	3.84**
PR_2 x PR_5	35.29**	19.39**	25.68**	16.88**
PR_3 x PR_4	15.04**	16.47**	12.86**	14.23**
PR_3 x PR_5	5.61**	9.87**	-1.43^{ns}	6.80**
PR_4 x PR_5	31.08**	27.82**	24.63**	21.92**
Reciprocal crosses				
PR_2 x PR_1	40.46**	19.39**	27.89**	16.88**
PR_3 x PR_1	15.00**	20.57**	9.52**	17.20**
PR_3 x PR_2	16.39**	38.65**	1.43^{ns}	32.00**
PR_4 x PR_1	31.12**	26.20**	26.60**	20.38**
PR_4 x PR_2	38.89**	19.34**	23.15**	11.54**
PR_4 x PR_3	22.81**	28.23**	20.47**	25.76**
PR_5 x PR_1	36.02**	32.06**	33.15**	32.06**
PR_5 x PR_2	42.94**	27.70**	32.78**	21.09**
PR_5 x PR_3	20.92**	16.46**	12.85**	13.20**
PR_5 x PR_4	36.26**	31.85**	29.55**	25.77**

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level

DISCUSSION

Mean squares of the GCA, SCA and RCA were highly significant for all traits measured. Both the additive and non-additive gene effects for all traits resulted in significant GCA and SCA variances. Our results were consistent with the findings of Rahman et al. (2011) who identified the importance of both additive and dominance components for the inheritance of all traits in *B. rapa*. The additive gene action was important for the plant height, the number of pods per main raceme, the number of seeds per pod and the seed yield in 2009. It can be concluded that for the characteristics with additive gene action, breeding methods based on recurrent selection will be efficient, whereas for the other traits with non-additive gene effects, hybridization based methods should be used. Ofori and Becker (2008) reported that the selection of parental combinations with high SCA to produce synthetic cultivars could rapidly improve the biomass yield of *B. rapa*. The involvement of non-additive gene effects for seed yield and some yield components in *Brassica* species were previously reported (Singh and Murty, 1980; Rameah et al., 2003; Yadav et al., 2005; Teklewold and Becker, 2005).

Parents with significant GCA effects from additive gene effects for the traits observed are considered good combiners in the combining ability studies. The GCA effect is controlled by fixable additive gene effects, and the cross involving parents with high GCAs provide better transgressive segregants in later generations (Falconer 1989). Therefore, the selection of parents based on GCA would affect the breeding program (Dar et al., 2011). In the present study, the GCA effects for all the characteristics evaluated were highly significant for the majority of parents. As a result, the parent Malvira (PR_4) had significant positive GCA effects for all the observed traits and can therefore be considered a promising parent producing F_1 hybrids. Lenox (PR_3) was also a good general combiner for plant height. Our results were consistent with Akbar et al. (2008), Chapi et al. (2008), Aghao (2010) and Azizinia (2011) who found that promising parents were good general combiners for the traits evaluated in *Brassica* species.

Ofori and Becker (2008) reported that the importance of the SCA suggests that identifying the best combinations among parents is an efficient method of increasing the biomass yield. In this study, the SCA and RCA effects were highly significant for all traits in both years. The SCA effects in this study were consistent with Sabaghnia et al. (2010) who observed significant positive SCA effects in the crosses for all observed traits. Significant SCA mean square values for the seed yield and the other characteristics indicated that the crosses PR_2 x PR_5 and PR_4 x PR_5 and the reciprocal crosses PR_2 x PR_1 and PR_3 x PR_2 were promising cross combinations because of their mean values and significant positive SCA and RCA effects. Significant SCA effects for yield and yield components of *Brassica* species were identified by previous researchers (Pandey et al., 1999; Verma, 2000; Nassimi et al., 2006; Marjanovic et al., 2007).

The majority of crosses with significant positive SCA effects for the yield and yield components had combinations of high x high, low x average, high x low, average x low and high x average GCA effects. This may be due the presence of genetic diversity in the form of dispersed genes for these characters (Dar et al., 2011).

Mid-parent and high-parent heterosis values are important genetic parameters in plant breeding programs. In the present study, all of the cross combinations generally showed significant heterotic values over the mid-parent for seed yield in 2009 and 2010. Over two years, mid-parent heterosis values ranged from 3.82% and 42.94% for the seed yield. In close agreement with our results, Schuler et al. (1992) reported that the maximum significant positive relative heterosis value in crosses of turnip rape was 18% for the seed yield. Similarly, Dar et al. (2011) reported that the highest significant positive heterotic values over the mid-parent and high-parent in turnip rape were 79.1% and 58.8% for the seed yield, respectively.

In conclusion, the parents used in this study exhibited positive GCA effects for seed yield. Therefore they could be considered as promising parents in the production of F_1 hybrids and in further breeding studies. Particularly, the crosses PR_2 x PR_5 and PR_4 x PR_5 were identified as best combinations for high seed yield due to their higher SCA values. The levels heterosis reported in this study suggests that inter-cultivar turnip hybrids can be used to develop high yielding varieties.

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LITERATURE CITED

Akbar, M., B.M.A. Tahira and M. Hussain. 2008. Combining ability studies in *B. napus*. International Journal of Agriculture and Biology 10: 205–208.

Aghao, R.R., B. Nair, V. Kalamkar and P.S. Bainade. 2010. Diallel analysis for yield and yield contributing characters in Indian mustard (*Brassica juncea*). Journal of Oilseed Brassica 1(2): 75-78.

Azizinia, S. 2011. Combining ability analysis for yield component parameters in winter rapeseed genotypes (*Brassica napus* L.). Journal of Oilseed Brassica 2(2): 67-75.

Bilgili, U., M. Sincik, A. Uzun and E. Acikgoz. 2003. The influence of row spacing and seeding rate on seed yield and yield components of forage turnip (*Brassica rapa L.*). Journal of Agronomy Crop Science 189: 250-254.

Brandle, J.E. and P.B.E. McVetty. 1989. Heterosis and combining ability in hybrids derived from oilseed rape cultivars and inbred lines. Crop Science 29: 1191-1195.

Chapi, O.G., A.S. Hashemi, E. Yasari and G.A. Nematzadeh. 2008. Diallel analysis of seedling traits in canola. International Journal of Plant Breeding and Genetics 2: 28-34.

Dar, Z.A., S.A. Wani, M.A. Wani, M. Gulzaffar, H. Khan, M. Habib, Z. Ahmed and A. Ishfaque. 2011. Heterosis and combining ability analysis for seed yield and its attributes in

Brassica rapa ssp. brown sarson. Journal of Oilseed Brassica 2(1): 21-28.

Dudley, J.W. and R.H. Moll. 1969. Interpretation and use of estimates of heritability and genetic variances in plant breeding. Crop Science 9: 257-261.

Falconer, D.S. 1989. Introduction to Quantitative Genetics, Ed. 3. Longmans Green/John Wiley & Sons, Harlow, Essex, UK/New York.

Falk, K.C., G. Rakow, R.K. Downey and D.T. Spurr. 1994. Performance of inter-cultivar summer turnip rape hybrids in Saskatchewan. Canadian Journal of Plant Sciences 74: 441-445.

Huang, Z., P. Laosuwan, T. Machikowaa and Z. Chen. 2010. Combining ability for seed yield and other characters in rapeseed. Suranaree Journal of Science and Technology 17: 39-47.

Lambeth, C., B.C. Lee, D. O'Malleya and N. Wheeler. 2001. Polymix breeding with parental analysis of progeny: an alternative to fullsib breeding and testing. Theoretical and Applied Genetics 103: 930–943.

Leon, J. 1991. Heterosis and mixing effects in winter oilseed rape. Crop Science 31: 281-284.

Malik, S.I., H.N. Malik, N.M. Minhas and M. Munir. 2004. General and specific combining ability studies in maize. International Journal of Agriculture and Biology 6: 856-859.

Marjanović, A., A. Jeromel, R. Marinković and D. Miladinović. 2007. Combining Abilities of Rapeseed (*Brassica napus* L.) Varieties. Genetika 39: 53-62.

Nassimi, A.W., R. Raziuddin and N. Ali. 2006. Heterotic studies for yield associated traits in *Brassica napus* L. using 8 × 8 diallel crosses. Pakistan Journal of Biological Sciences 9: 2132–2136.

Ofori, A. and H.C. Becker. 2008. Breeding of *B. rapa* for biogas production: heterosis and combining ability of biomass yield. Bioenergy Research 1: 98-104.

Pandey, L.D., L. Singh and J.N. Sachan. 1999. Brassica hybrid research in India: Status and prospect. In Proceedings 10th International Rapeseed Conference, 26-29 September 1999, Canberra, Australia.

Rahman, M.M., M.A.Z. Chowdhury, M.G. Hossain, M.N. Amin, M.A. Muktadir and M.H. Rashid. 2011. Gene action for seed yield and yield contributing characters in turnip rape (*Brassica rapa* L.). Journal of Experimental Biosciences 2(2): 67-76.

Rameah, V., A. Rezai and G. Saeidi. 2003. Estimation of genetic parameters for yield, yield component and glucosinolate in rapeseed (*Brassica napus* L.). Journal of Agricultural Science and Technology 5: 143-151.

Sabaghnia, N., H. Dehghani, B. Alizadeh and M. Mohghaddam. 2010. Heterosis and combining ability analysis for oil yield and its components in rapeseed. Australian Journal of Crop Science 4: 390-397.

Schuler, T.J., D.S. Hutcheson and R.K. Downey. 1992. Heterosis in interval hybrids of summer turnip in western Canada. Canadian Journal of Plant Science 72: 127-136.

Sernyk, J.L. and B.R. Stefansson. 1983. Heterosis in summer rape (*Brassica napus* L.). Canadian Journal of Plant Science 63: 407-413.

Sincik, M., U. Bilgili, A. Uzun and E. Acikgoz. 2007. Harvest stage effects on forage yield and quality for rape and turnip genotypes. Spanish Journal of Agricultural Research 5(4): 510-516.

Sincik, M., A.T. Goksoy and Z.M. Turan. 2011. The heterosis and combining ability of diallel crosses of rapeseed inbred lines. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 39(2): 242-248.

Singh, J.N. and B.R. Murty. 1980. Combining ability and maternal effects in *Brassica campestris* variety yellow sarson. Theoretical and Applied Genetics 56: 265–272.

Teklewold, A. and H.C. Becker. 2005. Heterosis and combining ability in a diallel cross of Ethiopian mustard inbred lines. Crop Science 45: 2629-2635.

Thakur, H.L. and J.C. Sagwal. 1997. Heterosis and combining ability in rapeseed (*Brassica napus* L.). Indian Journal of Genetics 57: 163–167.

Tyagi, M.K., J.S. Chauhan, S.K. Yadav, P.R. Kumar and P. Tyagi. 2000. Heterosis in intervarietal crosses in Mustard (*Brassica juncea* (L.) Czern & Coss.). Annals of Botany 16(2): 191-194.

Vaghela, P.O., D.A. Thakkar, H.S. Bhadauria, D.A. Sutariya, S.K. Parmar and D.V. Prajapati. 2011. Heterosis and combining ability for yield and its component traits in Indian mustard [*Brassica juncea* (L.)]. Journal of Oilseed Brassica 2(1): 39-43.

Verma, R.P. 2000. Combining ability analysis of yield and its components through diallel crosses in Indica Colza (*Brassica juncea* (L.) Czern & Coss.). Indian Journal of Agricultural Research 34(2): 91-96.

Yadav, Y.P., R. Prakash, R. Singh, R.K. Singh and J.S. Yadav. 2005. Genetics of yield and its component characters in Indian mustard (*Brassica juncea* (L.) Czern and Coss.) under rainfed conditions. Journal of Oilseed Research 22: 255-258.

Zhao, J.Y., H.C. Becker, D.Q. Zhang, Y.F. Zhang and W. Ecke. 2005. Oil content in a European x Chinese rapeseed population: QTL with additive and epistatic effects and their genotype-environment interactions. Crop Science 45: 51–59.