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Heterosis and combining ability for quantitative traits in Canola (*Brassica napus* L.) using half diallel mating design

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Abstract

In the year 2021-22, a set of 5 × 5 diallel crosses of canola were analyzed with their parents, to estimate heterosis as well as general combining ability (GCA) and specific combining ability (SCA). Observations on numerous quantitative characters were recorded. Almost all of the variables showed significant differences in GCA and SCA. The presence of both additive and non-additive gene interactions for the inheritance of distinct traits was revealed by the large magnitude of GCA and SCA effects. Parent IC-338967 was shown to be an excellent general combiner for seed yield, whereas BM 91 was shown to be a good earliness combiner. In the desirable direction, the high-ranking specific crosses for yield and its component were BM91 × EC338973, BM 91 × EC338976, BM9 1 × EC338977, EC338973 × EC338976, EC338973 × EC338967 and EC338977 × EC338967. Heterosis was observed in the F_1 generation, and it differed by character. Most of the traits showed significant positive nature of heterosis when compared to a better parent and commercial check. For yield and associated parameters, all of the hybrids had a significant amount of heterobeltiosis. As a result, it might be further analyzed for detailed heterosis assessment or even in a breeding program to find the best cultivar/s.

***Keywords**: Characters, GCA, heterobeltiosis, SCA*

Introduction

Rapeseed is an important group of edible oilseeds in India. Canola is a name applied to edible oilseed rape. Rapeseeds are cool-season annuals of the Brassicaceae family belonging to genus *Brassica*. Rapeseed is basically a *rabi* season crop in India. Chromosome number of *Brassica napus* L. is 2n = 38. *Brassica napus* is also known as Argentine rape, summer rape and winter rape. *Brassica napus* is called Gobhi sarson in hindi. Canola is rapeseed cultivars which were produced to get very low levels of erucic acid which is taken into account for human & animal use. *Brassica napus* generally grows to 100-200 cm in height. These are hairless, fleshy & glaucous lower leaves which are stalked and there are no petioles on the upper leaves. They consist of four petals with alternating four sepals. Fruit type is known as siliqua whereas inflorescence is called raceme. The pungency in crop is due to allyl isothiocyanate and the yellow colour of mustard oil is due to Caroteinoid.

Rapeseed-mustard is currently third largest source of vegetable oil. India shares 12% of rapeseed mustard production after China and Canada. Rapeseed is grown for its oil-rich seed that naturally contains good amounts of erucic acid. Oil of rapeseed was initially used for lighting in burning lamps, medical purposes, cooking and frying foods and as well as biofuel. Seeds of rapeseed-mustard not only contain oil (33-46%) and protein (28-36%) but also the source of fat, soluble vitamins like A, D, E and K (Sharif *et al*., 2017). Green tender leaves are used as vegetable purpose and seeds as flavouring agent in food and preparing pickles.

Heterosis is a common occurrence in nature of where offspring from contrasting individuals by genetically show increase vigor than that to their parents (Shull, 1948). Heterosis has been explored and used for several quality traits for different crops. It has seen that heterosis is quick, cheap as well as easy method for increasing crop production (Pal and Sikka, 1956). Heterosis breeding can be one of the most viable options for breaking the present yield barrier. Heterosis may be positive or negative. Both positive as well as negative heterosis used in the crop improvement depend on breeding objectives. For example, positive heterosis is required for yield, whereas negative heterosis is required for traits like days to maturity & plant height.

Diallel mating has been widely used in both cross and self-pollinated species to know the nature of gene action which is involved in quantitative traits. It helps in the selecting suitable parents for hybridization as well as in the choice of appropriate breeding procedures (Griffing, 1956). Combining ability analysis is the powerful tool to test the parental lines value to produce superior F_1 and valuable recombinants. Combining ability is an important breeding method and delivers facts related to desirable parent magnitude and nature of gene action which control the quantitative characters (Ceyhan *et al*., 2008). The first attempt to estimate different types of gene action involved in single cross was provided by Sprague and Tatum (1942). The total gene variance in this concept is separated into general & specific combining ability. According to them, general combining ability measures the average performance of combinations of hybrid whereas specific combining ability is defined to those instances in which the performance of the hybrid is relatively better or worse that would be expected on the basis of average performance of the parents involved.

Materials and Methods

The present investigation was conducted during 2020-21 and 2021-22 at Experimental Farm, Mata Gujri College, Fatehgarh Sahib, which is situated at 30' 27° and 30' 46° N latitudes and 76' 04° and 76' 38° E latitudes and a mean height of 247 meters above sea level. The annual precipitation is around 710 mm, and soil is sandy loam.

The experimental material comprised five genetically divers lines (BM 91, EC 338973, EC 338976, EC 338977, EC 338967) along with their 10 hybrids developed by crossing them in a half diallel mating design. All the 16 genotypes (5 parents, 10 hybrids and 1 check) were evaluated; the seeds were sown in a randomized block design with three replications at the spacing of 30 cm between rows and 15 cm between plants. Recommended cultural practices and plant protection measures were followed. The observations were recorded for 12 traits i.e. first flowering, 50% flowering, days to maturity, primary branches, plant height, number of siliquae, seeds/ siliqua, siliqua length, test weight, biological yield, harvest index, seed yield and data were compiled for analysis of variance for all these traits using method suggested by Panse and Sukhatme (1967).

Results and Discussion

Analysis of variance for the design of experiment

The analysis of variance with five parents (BM91, EC338973, EC338976, EC338977 and EC338967) and 10 crosses were made for twelve yield and yield characters in winter season 2020-21 and 2021-22 (Table 1). The source of variation showed positive significance for all the yield traits; first flowering, 50% flowering, primary branches, plant height, number of siliquae, days to maturity, seeds/siliqua, biological yield, seed yield/plant, harvest index and test weight in table 1. Kumar *et al*. (2021) evaluated F_1 hybrids and their parents for quantitative traits and highly significant differences were detected for all the traits in Brassica.

Table 1: Analysis of variance for different qualitative traits in *Brassica napus*

Source of variation	Degree of freedom	Days to first flowering	Days to 50% flowering	Days to maturity	Number of primary branches	Plant height (cm)	Number of siliquae/ plant
Replications	2	0.2	3.5	0.3	0.1	58.4	34.8
Treatment	14	4.9**	59.4**	27.4**	2.8**	436.4**	4031.8**
Parents	4	0.9	109.1**	4.8**	0.4**	141.8**	373.8**
Hybrids	9	0.4	42.3**	14.3**	1.6**	114.3**	2283.6**
Parents Vs Hybrid	1	60.9**	13.8	235.3**	23.1**	4513.2**	34397.3**
Error	28	0.9	6.3	0.5	0.1	11.5	61.5

Conti………

Source of variation	Degree of freedom	Number of seeds/ siliqua	Siliqua length (cm)	Test weight (g)	Biological yield (g)	Harvest index (%)	Yield/ plant (g)
Replication	2	0.6	0.1	1.6	31.3	2.3	11.0
Treatment	14	12.9**	4.1**	2.0**	4562.6**	35.7**	350.4**
Parents	4	0.6	0.9**	0.3	153.4**	10.9**	19.2**
Hybrids	9	5.8**	0.6**	0.5	1764.5**	34.0**	40.4**
Parents Vs Hybrid	1	125.9**	48.0**	23.4**	47382.5**	150.2**	4465.0**
Error	28	0.8	0.1	0.4	31.9	3.5	4.6

*, ** significant at 5% and 1% level, respectively

Estimation of heterosis

Heterosis breeding has played an essential role in crop improvement programme for obtaining higher production. The pre-requisite is to know the magnitude and direction of heterosis so that it can be effectively exploited in crop improvement. The hybrid vigour has so far not been extensively exploited in self-pollinated crop in comparison to cross pollinated crops. However, heterosis as a means of increasing productivity has been an object of considerably study in *Brassica napus*. The heterosis is estimated for identification of batter hybrid in Canola. The results of the heterosis estimated for genotype are presented in table 2 to 5.

First flowering are important traits for early maturity. The mean performance for days to first flowering were varies in cross combinations like BM91 × EC 338977 (48.1) to EC 338976 × EC338977 (49.3). For first flowering cross exhibited significant negative heterobeltiosis ranging from -3.1% (BM 91 × EC 338967) to -5.3% (EC 338976 × EC 338967) over better parent. Ten cross combinations exhibited significant negative useful heterosis which ranging from -11.8% (BM 91 × EC 338977) to -9.5% (EC 338976 × EC 338977) over the standard check. The mean performance for days to 50% flowering were varies in cross combination from 56.6 (EC 338973 × EC 338976) days to 66.1 (EC 338976 × EC 338977) days. Two cross combinations exhibited significant positive heterobeltiosis for 50% flowering namely EC 338976 × EC 338977 (18.0%) and BM 91 × EC 338976 (7.3 %). Eight F_1 hybrids showed significant negative useful heterosis ranging from -8.2% (EC 338977 × EC 338967) to -20.0% (EC 338973 × EC338976) over the commercial check. The days to maturity was exploited by the cross-combination namely EC 338977 × EC 338967 (141 days) and late into EC 338976 × EC 338967 (147.2 days). Out of ten, four combinations for better parent exhibit significant negative heterosis ranging from -5.5% (EC 338977 × EC 338967) to -3.1% (BM 91 × EC 338976). Five hybrids showed significant negative for useful heterosis ranging from -2.9% (BM 91 × EC 338973) to -5.3% (EC 338977 × EC 338967). Grant and Beversdorf (1985) predicted negative heterosis for days taken to flowering. Saeed *et al*. (2013) observed highly significant better parent negative heterosis for days taken to 50% flowering and predicted medium negative heterobeltiosis for days taken to maturity. Days to flower in spring type *B. napus* is a quantitative trait controlled by genes with additive, dominance, and epistatic effects (Long *et al*., 2007). this trait correlates well with days to maturity in both *B. napus* and *B. juncea* (Mahmood *et al*., 2007). Earliness of flowering and maturity are a prime breeding objective for the development of hybrid canola cultivars. Long *et al*. (2007) also found that 10% of the total genetic effect for flowering time was contributed by dominance genes in winter *B. napus*.

The mean performance for primary branches varies in cross combination from 5.4 (EC 338976 × EC 338967) to 7.7 (BM 91 × EC 338967). Out of ten crosses, eight F_1 hybrids exhibited significant positive heterobeltiosis for primary branches ranging from 15.10% (EC 338977 × EC 338967) to 36.2% (BM 91 × EC338967) over better parent. Eight cross combinations exhibited significant positive useful heterosis ranging from 22.8% (EC 338977 × EC 338967) to 42.3% (BM 91 × EC 338967) over the standard check. According to plant height dwarf cross combination was identified as BM 91 × EC 338976 (179.7 cm) as well as tallest in EC 338976 × EC 338967 (196.6 cm). Cross combinations showed a significant positive heterosis varies from 11.3% (EC 338973 × EC 338977) to 19.3% (BM 91 × EC 338973). Out of ten cross combinations, six shows positively significant from 7.1% (EC 338973 × EC 338977) to 10.5% (EC 338976 × EC 338967). The mean performance for number of siliquae varies in cross combination ranging from 221.6 (EC 338973 × EC 338977) to 283.1 (BM 91 × EC 338977). Eight cross combinations exhibited significant positive heterosis ranging from 17.1% (EC 338976 × EC 338977) to 48.6% (BM 91 × EC 338977). Cross combination exhibited significant positive heterosis varies from 7.0% (EC 338973 × EC 338976) to 52.0% (BM91 × EC 338973) over the standard check. Out of ten higher cross combination, BM 91 × EC 338967 (21.2) showed minimum number of seeds/siliqua, EC 338976 × EC 338977 (25.4) showed maximum number of seeds/siliqua. Out of ten cross combinations, nine shows significant positive heterosis 9.3% (EC 338973 × EC 338967) to 26.6% (EC 338976 × EC 338977). Nine combinations showed significant positive heterosis ranging from 7.9% (BM 91 × EC 338973) to 24.0% (EC 338976 × EC 338977) rather none of the cross exhibits significant negative heterosis over the standard check. The shortest mean performance for siliqua length was observed for cross like BM 91 × EC 338973 (7.6 cm) and largest in EC 338976 × EC 339877 (9.2 cm). Ten cross combinations exhibited a significant positive heterosis varies in range as 17.5% (BM 91 × EC 338976) to 41.9% (BM 91 × EC 338977) while cross combination shows significant positive heterosis over the commercial check ranging from 16.9% (BM 91 × EC 338973) to 40.3% (EC 338976 × EC 338977). For the test weight was estimated minimum for genotype 7.3 (BM 91 × EC 338967) while the maximum in to 8.3 (EC 338973 × EC 339867). For test weight, seven cross combinations exhibited significant positive better parent heterosis ranging from 22.8% (EC 338973 × EC 338973) to 26.6 (EC

Table 2. Mean performance of F1 hybrids and extent of heterosis for hybrids in *Brassica napus* for days to first flowering, days to 50% flowering and days to maturity

Hybrids	Days to first flowering			Days to 50% flowering			Days to maturity		
	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis
BM 91 × EC338973	48	-4.1**	-11.7**	62	5.8*	-12.8**	145	-2.1*	-2.9**
BM91 × EC338976	48	-3.5*	-11.1**	60	7.3**	-15.1**	143	-3.1**	-3.9**
BM91 × EC338977	48	-4.2**	-11.8**	68	2.5	-4.4	143	-3.6**	-4.4**
BM91 × EC338967	49	-3.0*	-10.7**	63	1.4	-10.3**	145	-1.8	-2.6
EC 338973 × EC338976	48	-4.7**	-11.7**	56	1.0	-20.0**	146	-1.4	-2.0
EC 338973 × EC338977	48	-4.4**	-11.4**	58	0.2	-17.4**	146	-1.3	-1.9
EC 338973 × EC338967	48	-3.9**	-10.9**	59	1.8	-16.0**	142	-4.5**	-5.1**
EC 338976 × EC 338977	49	-3.7**	-9.5**	66.	18.0**	-6.6	147	-1.8	-1.7
EC 338976 × EC 338967	48	-5.3**	-11.0**	58	3.3	-18.2**	147	-2.2*	-1.4
EC 338977 × EC 338967	49	-5.1**	-10.8**	65	3.8	-8.2**	141	-5.5**	-5.3**
SEm±		0.8	0.78		2.0	2.0		0.6	0.6
CD at 5%		1.7	1.7		4.5	4.5		1.2	1.2

*, ** significant at 5% and 1% level, respectively

Table 3: Mean performance of F1 hybrids and extent of heterosis (%) for hybrids in *Brassica napus* L. for number of primary branches, plant height and number of siliqua/plant

Hybrids	Number of primary branches			Plant height (cm)			Number of siliquae/plant		
	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis
StandardHeterosis									
BM 91 × EC338973	7.3	29.9 **	35.8**	185.3	19.3**	4.2	314.9	46.9 **	52.0**
BM91 × EC338976	7.3	29.4 **	35.2**	179.7	15.6**	1.0	255.0	24.0 **	23.1**
BM91 × EC338977	5.8	-0.1	6.6	184.0	18.4**	3.4	283.1	48.6 **	36.7**
BM91 × EC338967	7.7	36.2**	42.3**	180.5	16.1**	1.5	276.9	33.8 **	33.7**
EC 338973 × EC338976	7.1	28.1 **	32.0**	190.6	11.6**	7.1**	221.6	3.4	7.0**
EC 338973 × EC338977	7.2	25.1 **	33.5**	190.5	11.3**	7.1**	227.4	6.1	9.8**
EC 338973 × EC338967	7.3	31.3 **	35.2**	194.0	14.6**	9.1**	262.2	22.3 **	26.6**
EC 338976 × EC 338977	7.2	25.6 **	34.0**	191.1	11.9**	7.4**	240.8	17.1 **	16.3**
EC 338976 × EC 338967	5.4	8.3	0.4	196.6	16.1**	10.5**	264.6	27.8 **	27.8**
EC 338977 × EC 338967	6.6	15.1**	22.8**	196.3	15.9**	10.3**	252.0	21.7 **	21.7**
SEm±		0.3	0.3		2.78	2.78		6.4	6.4
CD at 5%		0.6	0.6		6.2	6.2		14.2	14.2

*, ** significant at 5% and 1% level, respectively

338973 × EC 338968) over better parent. Cross combination found significant positive useful heterosis over commercial check for test weight ranging from 16.3% (BM 91 × EC 338967) to 33.9% (EC 338973 × EC 338967).

Genotype showed minimum biological yield was exploited in to EC 338973 × EC 338977 (165.9 g) and maximum in BM 91 × EC 338976 (222.3g). Cross combination showed significant positive heterobeltiosis varies from 31.8% (EC 338977 × EC 338967) to 78.0% (EC 338973 × EC 338976) over better parent. Cross combination exhibited significant positive useful heterosis ranging from 18.0% (EC 338973 × EC 338977) to 58.1% (BM 91 × EC 338976) over commercial check variety. The mean performance for harvest index (%) varies in cross combination from 19.3 (EC 338973 × EC 338976) to 30.2 (BM 91 × EC338977). Only four cross combination shows significant positive heterobeltiosis varies from 16.7% (EC 338973 × EC 338977) to 41.6% (BM 91 × EC 338977) but one cross combination showed significant negative heterosis EC 338973 × EC 338976 (-15.3%) over better parent. Eight cross combinations exhibited significant positive heterosis which ranging from 21.1% (BM 91× EC 338967) to 54.0% (BM 91 × EC 338977) over the commercial check for harvest index. Genotype showed minimum seed yield/ plant was exploited in to BM 91 × EC 338973 (41.6) and maximum to EC 338976 × EC 339877 (51.1). Ten cross combinations showed significant positive heterobeltiosis ranging from 52.5% (BM 91 × EC 338973) to 111.2% (BM 91 × EC 33897) and none of the cross combinations showed significant negative heterosis over better parent. Useful heterosis found to be significant positive for cross combinations varies from 50.7% (BM 91 × EC 338973) to 85.2% (EC 339876 × EC 338977). Heterosis for seed yield and morphological traits like number of siliquae/plant, and number of seeds per plant (Kaur *et al.* 2022). Nasim *et al.* (2014) predicted significant heterobeltiosis for 14 hybrids ranging 25.9 to 145.8%. Marjanovic-Jeromela *et al.* (2007) observed positive and negative effects of heterosis for seed yield/plant. Sincik *et al.* (2011) evaluated 4x4 diallel crosses were reportedly involved in different yield attributing characters. In term of seed yield, Teklewold and Becker (2005) showed highly positive heterosis.

Combining ability analysis

Any breeding program's success is greatly influenced by the parental selection. Combining ability is a useful tool for identifying both effective and ineffective combiners as well as for selecting the best parental lines for a hybridization programme. It also provides information of specific promising combinations to exploit heterosis.

Analysis of variance for combining ability

The analysis of variance (ANOVA) of combining ability for portioning the total genetic variance into general combining ability (gca representing additive type of gene action) and specific combining ability (sca measures of non-additive gene action) we carried out by the procedure suggested by Griffing (1956) Method 2 and Method 1. Variance due to gca as well as sca was significant for all the characters studied. Magnitude of gca variance component was higher than sca for all the characters.

Estimation of combining ability (gca and sca) effects

The estimates of general combining ability (GCA) effects parents and specific combining ability (SCA) effects of the crosses for all the thirteen traits been presented in table 6 and 7.

The estimates of *gca* effects revealed that out of five parents, none of the parent was recorded significant and positive as well as negative *gca* effects for days to first flowering. Out of ten crosses, eight crosses recorded significant positive *sca* effects ranging from -0.65 (BM 91 × EC 338973) to -1.1 (BM 91 × EC 339877).

For days to 50% flowering, out of five, two parents like BM 91 (1.8) and EC 338977 (3.9) recorded significant positive *gca* effects beside two parents EC 338973 (-2.8) and EC 338976 (-2.8) exhibited significant negative *gca* effects for days to 50% flowering. For the effects of *sca* among the cross-combination EC 338976 × EC 339877 (3.0) exhibited positive significant *sca* effect and EC 339873 × EC 338977 (-4.7) showed significant negative *sca* effect for this trait. Significant positive *sca* effect recorded for one cross combination like EC 338973 × EC 338977 (0.5). Cross combination namely BM 91 × EC 338973 (-0.4) to EC 338977 × EC 338967 (-4.8) showed negative *sca* effects for this character. The estimation of general combining ability effects for the primary branches/ plant revealed that out of five, two parents namely, BM 91(0.1) and EC 338973(0.2) expressed positive significant effects while two parents like EC 338976 (-0.2) and EC 338967 (-0.2) also exhibited significant negative effects for number of primary branches/plant. For positive significant *sca* effect, combination ranging from 0.4 (EC 338977 × EC 338967) to 1.4 (BM 91 × EC 338967) were recorded while two cross combinations namely BM 91 × EC 338977 (-0.8) and EC 338976 × EC 338967 (-0.6) showed negative significant *sca* effect. The *gca* effect were significant negative for one parent BM 91 (-7.2) since the significant positive *gca* was observed in three parents EC 338973 (1.7), EC 338977 (2.0) and EC 338967 (2.2) among five

Table 4: Mean performance of F1 hybrids and extent of heterosis (%) for hybrids in *Brassica napus* L. for number of seeds/siliqua, siliqua length and test weight

Hybrids	Number of seeds/siliqua			Siliqua length (cm)			Test weight (g)		
	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis
BM 91 × EC338973	22.1	13.6**	7.9**	7.64	22.2 **	16.9**	7.4	12.1	18.6**
BM91 × EC338976	23.4	18.7**	14.2**	7.87	17.5 **	20.4**	7.9	23.0 **	27.5**
BM91 × EC338977	22.3	11.0**	8.7**	8.67	41.9 **	32.8**	7.3	12.7	17.9**
BM91 × EC338967	21.1	3.6	3.3	8.04	19.0 **	23.1**	7.3	15.2	16.3**
EC 338973 × EC338976	23.5	19.4**	14.8**	8.59	28.3 **	31.5**	8.2	24.7**	31.9**
EC 338973 × EC338977	24.4	21.6**	19.2**	8.36	33.8 **	28.0**	8.1	22.7 **	29.8**
EC 338973 × EC338967	22.3	9.3*	8.9**	8.59	27.0 **	31.4**	8.3	26.6 **	33.9**
EC 338976 × EC 338977	25.4	26.6**	24.0**	9.17	36.9 **	40.3**	8.0	22.8 **	28.4**
EC 338976 × EC 338967	23.8	16.5**	16.2**	8.78	29.9 **	34.4**	8.0	24.5 **	29.1**
EC 338977 × EC 338967	25.1	23.0**	22.6**	8.65	28.0 **	32.4**	8.1	23.9 **	29.6**
SEm±		0.7	0.7		0.3	0.3		0.5	0.5
CD at 5%		1.6	1.6		0.7	0.7		1.1	1.1

*, ** significant at 5% and 1% level, respectively

Table 5: Mean performance of F1 hybrids and extent of heterosis (%) for hybrids in *Brassica napus* L. for biological yield/plant, harvest index and seed yield/plant

Hybrids	Biological yield/plant (g)			Harvest index (%)			Seed yield/plant (g)		
	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis	Mean	Heterobeltiosis	Standard Heterosis
BM 91 × EC338973	172.7	37.8 **	22.9**	24.1	5.3	22.6**	41.6	52.5 **	50.69**
BM91 × EC338976	222.3	77.4 **	58.1**	21.4	3.6	9.1	47.6	88.3 **	72.5**
BM91 × EC338977	168.1	34.1 **	19.6**	30.2	41.6**	54.0**	50.7	111.2 **	83.7**
BM91 × EC338967	178.6	35.5 **	27.1**	23.8	9.4	21.1**	42.4	48.3 **	53.8**
EC 338973 × EC338976	217.9	78.0 **	55.0**	19.3	-15.3*	-1.4	42.1	54.5 **	52.7**
EC 338973 × EC338977	165.9	39.1 **	18.0**	26.7	16.7*	35.9**	44.2	62.1 **	60.2**
EC 338973 × EC338967	176.4	33.9 **	25.5**	27.8	21.6**	41.5**	48.9	70.8 **	77.2**
EC 338976 × EC 338977	214.9	75.6 **	52.9**	23.9	11.8	21.6**	51.1	102.1 **	85.2**
EC 338976 × EC 338967	220.4	67.3 **	56.8**	22.3	2.6	13.6*	49.9	71.8 **	78.2**
EC 338977 × EC 338967	173.6	31.8 **	23.5**	28.0	28.9**	42.7**	48.3	68.9 **	75.2**
SEm±		4.6	4.6		1.5	1.5		1.7	1.7
CD at 5%		10.3	10.3		3.4	3.4		3.9	3.9

*, ** significant at 5% and 1% level, respectively

Table 6: Estimates for general combining ability effects in *Brassica napus* L

Parents	Days to first flowering	Days to 50% flowering	Days to maturity	Number of primary branches	Plant height (cm)	Number of siliquae/ plant	Number of seeds/ siliqua	Siliqua length (cm)	Test weight (g)	Biological yield (g)	Harvest index (%)	Yield/ plant (g)
BM91	-0.3	1.8 **	-0.7 **	0.1 *	-8.0 **	9.9 **	-0.7**	-0.5 **	-0.4 **	-2.3 *	-0.8 *	-1.5 **
EC338973	-0.2	-2.8 **	-0.2	0.2 **	1.7 *	1.8	-0.3	-0.1	0.1	-5.3 **	0.4	-0.9 *
EC338976	0.1	-2.8 **	1.0 **	-0.2 **	1.2	-6.9 **	0.4 *	0.2 **	0.1	15.9**	-1.8 **	0.4
EC338977	0.2	3.9 **	-0.2	0.0	2.0 **	-8.7 **	0.6 **	0.1	0.1	-8.8**	1.5 **	0.7
EC338967	0.1	-0.2	0.1	-0.2 **	2.2 **	4.0 *	0.1	0.2 *	0.0	0.5	0.7	1.2 **
SE (gi)	0.2	0.5	0.1	0.1	0.7	1.5	0.2	0.1	0.1	1.1	0.4	0.4

*, ** significant at 5% and 1% level, respectively

Table 7: Estimates for specific combining ability analysis for hybrids in *Brassica napus* L

Hybrids	Days to first flowering	Days to 50% flowering	Days to maturity	Number of primary branches	Plant height (cm)	Number of siliquae/ plant	Number of seeds/ siliqua	Siliqua length (cm)	Test weight (g)	Biological yield (g)	Harvest index (%)	Yield/ plant (g)
BM 91 × EC338973	-0.6 *	0.7	-0.4 *	0.5 **	9.0 **	62.9 **	0.9 **	0.5 **	0.2	12.2 **	1.0 *	4.34 **
BM91 × EC338976	-0.7 **	-1.0	-3.1 **	0.9 **	3.8 **	11.8 **	1.6 **	0.4 **	0.8 **	40.6 **	0.6	9.1 **
BM91 × EC338977	-1.1 **	-0.1	-2.7 **	-0.8 **	7.4 **	41.7 **	0.2	1.3 **	0.3	11.7 **	6.1 **	11.9 **
BM91 × EC338967	-0.5	-1.0	-0.2	1.4 **	3.7 **	22.8 **	-0.3	0.6 **	0.2	12.3 **	0.5	3.1 **
EC 338973 × EC338976	-1.8**	0.1	-0.7**	0.7 **	5.8 **	-13.6 **	1.3**	0.7 **	0.6**	39.3 **	-2.7**	3.0 **
EC 338973 × EC338977	-1.0 **	-4.7**	0.5 **	0.56 **	5.0 **	-6.0 **	1.9 **	0.6 **	0.5 **	11.9 **	1.3 *	5.8 **
EC 338973 × EC338967	-0.6 *	0.3	-4.4 **	0.9 **	8.3 **	16.0 **	0.4	0.8 **	0.8 **	13.1 **	3.3 **	9.0 **
EC 338976 × EC 338977	-0.4	3.0**	-0.3	1.0 **	6.0 **	16.2 **	2.2 **	1.1 **	0.4 **	39.6 **	0.6	10.4 **
EC 338976 × EC 338967	-1.1**	-1.2	-0.1	-0.6 **	11.4 **	27.3 **	1.2 **	0.7 **	0.5 **	35.8 **	-0.0	7.9 **
EC 338977 × EC 338967	-1.1 **	-0.8	-4.8**	0.4 **	10.3 **	16.4 **	2.3 **	0.6 **	0.6 **	13.7 **	2.4**	6.8 **
sca(ii)	0.45	1.3	0.3	0.2	1.7	3.9	0.4	0.2	0.3	2.8	0.9	1.1
sca(ij)	0.2	0.6	0.8	0.1	0.9	2.0	0.2	0.1	0.2	1.4	0.5	0.5

*, ** significant at 5% and 1% level, respectively

parents for plant height. The highest magnitude of positive significant *sca* effect ranging from) 3.7 (BM 91 × EC 338967 to 11.4 (EC 338976 × EC 338967). Two parents namely EC 338967 (4.0) and BM 91 (9.9) exhibit significant positive *gca* effects while two parents like EC 338976 (-6.9) and EC 338977 (-8.7) exhibit significant negative *gca* effect for number of siliquae. Two crosses viz EC 338973 × EC 338977 (-6.0) and EC 33 8973 × EC 338976 (-13.6) exhibit negative *sca* effect while positive *sca* effect significant ranging from 11.8 (BM 91 × EC 338976) to 62.9 (BM 91 × EC 338973). One parent like BM 91 (-0.7) shows negative and two parents namely EC 338976 (0.4) and EC 338977 (0.6) shows positive *gca* effects for number of seeds/ siliqua. Cross exhibited positive *sca* effects ranging from BM 91 × EC 338973 (0.9) to EC 338977 × EC 338967 (2.3). For the effect of *gca* among the cross combination one parent like BM 91 (-0.5) showed negative *gca* effect and two parents namely EC 338976 (0.2) and EC 338967 (0.2) showed positive *gca* effect for siliqua length. The highest magnitude of positive *sca* effect was observed in cross combination ranging from 0.4 (BM 91 × EC 338976) to 1.3 (BM 91 × EC 338977). The significant negative gca effect recorded for one parent like BM 91 (-0.4) while none of the parent shows positive gca effect for test weight. The *sca* effect were significant positive for cross combinations varies from 0.4 (EC 338976 × EC 338977) to 0.8 (EC 338973 × EC 338967). Three parents namely BM 91 (-2.3), EC 338973 (-5.3) and EC 338977 (-8.8) showed negative *gca* effects and one parent like EC 338976 (15.9) shows positive *gca* effect for biological yield. The significant positive effect for *sca* was recorded for cross combinations ranging from 11.1 (BM 91 × EC 338977) to 40.6 (BM 91 × EC 338976). The estimates of *gca* effect revealed that out of five parents, one parent like EC 338977 (1.5) showed positive *gca* effect for harvest index and two parents namely BM 91 (-0.8) and EC 338976 (-1.8) showed negative *gca* effects for this trait. Out of ten crosses, six crosses showed significant among one cross combination shows negative *sca* effect EC 338973 × EC 338967 (-2.7) and cross combinations showed positive significant effect for *sca* ranging from 1.0 (BM 91 × EC 338973) to 6.1 (BM 91 × EC 338976). The significant negative *gca* effect on seed yield/plant revealed that out of five, only two parents namely BM 91 (-1.5) and EC 338973 (-0.9) were expressed while one parent EC 338967 (1.2) showed positive *gca* effect for yield per plant. For the effect of *sca* in cross combinations varies from 3.0 (EC 338973 × EC 338976) to 11.9 (BM 91 × EC 338977) was shown.

However, the SCA effects found in this study agree with the findings of Rameah *et al.* (2003). Akbar *et al.* (2008) observed significant mean squares for SCA for all traits examined except for test weight. Sincik *et al*. (2011) explained results showed that all parameters like plant height, primary branches, test weight, seeds/siliqua, siliqua length and seed yield of plants had noteworthy GCA and SCA. Qian *et al*. (2007) determine the quantitative and qualitative traits of all these parents, hybrids and crosses of rapeseed. Results portrayed the highest seed yield heterosis of hybrids and additive gene action enhanced their performance. GCA mean square had higher values in comparison to SCA mean square.

Conclusion

IC-338967 is an excellent overall combiner, and the best specific combinations for the majority of the yield-contributing traits are BM91 × EC338973, BM91 × EC338976, BM91 × EC338977, EC338973 × EC338976, and EC338977 × EC338967. According to estimations of heterosis and per se performance, all cross combinations were highly significant for seed yield/ plant, hence could be evaluated further to exploit the heterosis and utilized in future breeding programme to obtain desirable and superior genotypes.

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