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Heterosis and inbreeding depression for yield and its component traits in F_1 hybrids and F_2 population of interspecific crosses in *Brassica species*.

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Abstract
Seven lines of oilseed *Brassica* species were studied for heterosis and inbreeding depression for nine yield and its contributing traits. In F1 hybrids, maximum heterosis was recorded for siliquae per plant followed by numbers of secondary branches and seed yield per plant. Considerable inbreeding depression was observed in F2 population which was highest for seed yield per plant followed by numbers of primary branches. Highest inbreeding depression for seed yield per plant was observed in cross GPM-O-5XT-42 followed by cross NGM-17XT-42. It was lowest in cross NGM-43XT-42. In F1 generation higher heterosis was observed in crosses NGM-17XBN-10, PL-58XBN-10, GPM-O-5XBN-10 and NGM-43XBN-10 for seed yield per plant. Inbreeding was lower when BN-10 was used as male parent in combination with NGM-17, PL-58, GPM-O-5 and NGM-43 as female parent.

Keywords: Heterosis, inbreeding depression, interspecific cross, *Brassica.*

Introduction
Heterosis has extensively been explored and utilized for boosting various agronomic and quality traits in brassica and other crops (Hassan *et al*., 2006 and Turi *et al*., 2006) [9, 30]. However, the manifestation of heterosis in F_1 and inbreeding depression in F_2 jointly in combination signifies the nature of gene action involved for the expression of the vigour in F_1 and inbreeding depression in F_2. The genetic mechanism of interspecific heterosis may be different from those found in intraspecific hybrids. The heterosis in hybrids between *B. napus* and *B. rapa* has been observed by several workers (Mackay, 1973; Shiga, 1970; McNaughton, 1973) [16, 24, 19] and F_1 hybrids were used directly for fodder production (Mackay, 1973) [16]. However, very few quantitative evidences are available on the degree of heterosis for the important agronomic characters and possibilities of commercial exploitation of hybrids between two different *Brassica* species.
In view of the economic importance of oilseed Brassica crop, a study was undertaken to evaluate the manifestation of heterosis in F1 hybrids and inbreeding depression in F2 population for yield and its contributing traits in oilseed *Brassica*. In present experiment evidences on interspecific heterosis in F1 hybrids and inbreeding depression in F2 population have been shown.

Material and Methods
Four lines of *Brassica juncea* (NGM-43, NGM-17, PL-58 and GPM-O-5), one variety of *Brassica rapa* var. toria (PT-303), one variety of *Brassica rapa* var. yellow sarson (T-42) and one line of *Brassica napus* (BN-10) were planted during rabi 2014-15 (Table 1). All four *B. juncea* lines were manually emasculated and pollinated with the pollen from PT-303, T-42 and BN-10. Twelve F_1 thus produced along with 7 parents were grown in randomised block design with two replications at Research Farm, College of Agriculture Gwalior during rabi 2015-16. Each line (F_1 and parental line) was sown in paired rows of three-meter length. The spacing of 45 cm x 15 cm was maintained. Data on five random plants for nine traits *viz*. nos. of primary branches per plant (PB), nos. of secondary branches per plant (SB), main shoot length (MSL), siliquae on main shoot (SOMS), siliquae per plant (SPP), siliqua length (SL), seeds per siliqua (SPS), test weight (TW) and seed yield per plant (SYPP) were recorded in F_1 and parents. Averages values were used for estimation of heterosis.
F_1s were selfed to produce F_2 population. To find out the inbreeding depression, an experiment was conducted during Rabi 2016-17 without replications as it was segregating Material.

Spacing of 45 X 15 cm was maintained. Each F2 was raised with minimum of 200 plant population. And all standard agronomic practices were followed to raise a good crop. At the time of harvest, observations were recorded on randomly selected 50 plants in all the populations for all eleven traits. The data were utilized to estimate the inbreeding depression.

Table 1: Salient features of parents used in the present study.

Parents	Genomic	Salient features
Female parent		
NGM-43	AABB (2n=36)	Adaptability, self-pollinated, high productivity, long pod
NGM-17	AABB (2n=36)	Adaptability, self-pollinated, high productivity, bold seed
PL-58	AABB (2n=36)	Adaptability, self-pollinated, high productivity, long pod
GPM-O-5	AABB (2n=36)	Adaptability, self-pollinated, high productivity, bold seed
Male parent		
PT-303	AA (2n=20)	Earliness, dwarfness, self-incompatible
T-42	AA (2n=20)	High oil content, seeds per siliqua, multivalve, self-pollinated, dwarfness
BN-10	AACC (2n=38)	High yield potential, tolerance to pests, diseases and frost, self-compatible

Statistical analysis

The heterosis was estimated by methods suggested by Matzinger, Mann and Cockerhan (1962) [18]. Heterosis was measured as superiority over better parent heterosis.

Heterosis was measured as H = (F_1- BP) x 100 / BP, in which BP represent the parent with larger value in a particular combination. The standard error of difference for BPH was calculated by formula SE $=\sqrt{\frac{2\,ems}{r}}$. The CD. Was computed by multiplying S.E. with respective'‘t' value at error d. f. at 5% level of significance. Error mean square wherever applicable, was calculated as usual from Randomised Complete Block design using parents and F_1. The C.D. was computed by multiplying the standard error with respective‘t' value for error d. f. at 5 percent level of significance.

Inbreeding depression was estimated by using formula ID= (F_1-F_2) x 100/F_1.

Results

Mean Performance

The mean performance of F1 hybrids, F2 populations and their parents has been presented in Table 2. Mean performance revealed that all the twelve F1 hybrids exhibited more numbers of primary & secondary branches per plant, longer main shoot length with more numbers of siliquae on main shoot, more siliquae per plant and higher seed yield per plant than their respective parents. While length of siliqua in hybrids was at par with their respective parents. Estimates of seeds per siliqua and test weight in hybrids were lower to their respective parents. Whereas majority of the F2s were superior to their respective parents for these traits except siliqua length and seeds per siliqua. These results are in accordance with the earlier reports on heterosis in hybrids of *B. napus* x *B. rapa* Shiga (1970) [24] and Mackay (1973) [16]. While poor growth in hybrids than both parents was reported by Kamala, 1976. In general, the mean performance of F1 hybrid NGM-43 x BN-10 was highest for all traits studied except for siliqua length and seeds per siliqua. Similarly, F1 hybrid PL-58 x BN-10 recorded high mean values for primary & secondary branches per plant, siliquae on main shoot, siliquae per plant, siliqua length, seed yield per plant and F1 hybrid GPM-O-5 x BN-10 recorded highest values of primary & secondary branches per plant, main shot length, siliquae on main shoot, siliquae per plant and seed yield per plant. This shows superior combining ability of male parent (BN-10) than other male parents for hybrid combination.

Heterosis and inbreeding depression

The data of heterosis in the F1 and inbreeding depression (%) in F2 for all the traits are furnished in Table 3 and discussed here under.

Number of primary branches (PB)

The range of heterosis for primary branches varied from -13.8% to 29.8% (Table 3). The cross GPM-O-5XBN-10 showed highest heterosis (29.8%) followed by NGM-43XT-42 (29.5%). Lowest heterosis was found in cross NGM-17XPT-303 (-13.8%).

The highest inbreeding depression for primary branches was observed in cross GPM-O-5XPT-303 (35.5%). It was lowest in cross NGM-43XBN-10 (-9.1%). The average value of inbreeding depression was observed to be 4.2% (Table 3).

Number of secondary branches (SB)

Heterosis for secondary branches ranged from -56.4% to 87.1%. Cross NGM-43XBN-10 exhibited highest heterosis (87.1%) followed by cross NGM-17XBN-10 (56.3%) and cross GPM-O-5XBN-10 (34.1%). Lowest heterosis was observed in cross GPM-O-5XT-42 (-56.4%).

The maximum and minimum inbreeding depression was observed in cross NGM-17XT-42 (12.8%) and NGM-43XBN-10 (-9.9%), respectively. The average inbreeding depression was 0.2%.

Main shoot length (MSL)

The range of heterosis and inbreeding depression was -18.7 to 20.7% and -6.6 to 24.3%, respectively (Table 3). The highest heterosis was observed in cross NGM-43XT42 (30.1%). Cross GPM-OXT-42 showed lowest heterosis of (-18.7%).

The highest inbreeding depression was observed in cross NGM-43XPT-303 (24.3%) while it was lowest in cross GPM-O-5XT-42 (-6.6%). Average value of inbreeding depression was 3.1%.

Siliquae on main shoot (SOMS)

Heterosis for trait was ranged from -21.3% to 42.2%. Cross NGM-43XT-42 exhibited highest heterosis (42.2%) followed by NGM-43XBN-10 (33.8%) and PL-58XT-42 (24.1%). Lowest was found in NGM-17XT-42 (-27.3%) followed by GPM-O-5XT-42 (-21.3%).

Inbreeding depression ranged from -9.2% to 27.0%. Highest ID was observed in cross NGM-17XPT-303 (27.0%). Lowest ID was in cross GPM-O-5XBN-10 (-9.2 %). Average value of ID was 4.8% table 3.

Siliquae per plant (SPP)

Heterosis for SPP ranged from -53.6% to 142.2%. The highest heterosis was found in cross NGM-43XBN-10 (142.2%) followed by 47.5% in NGM-43XT-42, 40.9% in GPM-O-5XBN-10 and 39.0% in NGM-17XBN-10.

Inbreeding depression was ranged from -17.6% to 16.6%. Highest value of 16.6% was observed in cross NGM-17XT-

42 while lowest ID was observed in cross NGM-43XT-42 (-17.6%). Average ID value for siliquae per plant was observed to be 0%.

Siliqua length (SL)

For siliqua length it ranged from -32.5% to 9.8%. None of cross showed significantly high value of heterosis. Lowest was observe in cross PL-58XPT-303 (-32.5%) followed by -30.6% in NGM-43XBN-10 and -29.9% in NGM-17XBN-10.

ID value for pod length was ranged from -25.4 % to 6.6%. Highest inbreeding depression was observed in NGM-17XPT-303 (6.6%) and lowest was in NGM-43XPT-303 (-25.4%). Average ID was -5.6%.

Seeds per siliqua (SPS)

Heterosis ranged from -66.3 % to 1.5%, respectively (Table 3). Highest was observed in GPM-O-5XPT-303 (1.5%) while lowest was found in cross NGM-17XT-42 (-66.3%) followed by cross NGM-43XT-42 (-61.1%) and PL-58XT-42 (-59.9%). Maximum inbreeding depression was observed in cross GPM-O-5XPT-303 (17.5%) and minimum was in PL-58XT-42 (-16.5%). Average inbreeding depression was -4.3%, table 3.

Test weight (TW)

Range of heterosis for test weight varied from -21.1% to 28.1%. Cross NGM-17XT-42 showed highest BPH (28.1%) followed by NGM-17XBN-10 (22.3%). Lowest heterosis was observed in cross GPM-O-5XPT-303 (-21.1%).

Range of inbreeding depression was from -14.4% to 8.8%. Cross NGM-17XPT-303 showed highest inbreeding depression (8.8%). Lowest ID was observed in cross NGM-17XT-42 (-14.4%). Average value of ID was -0.6%, table 3.

Seed Yield Per Plant (SYPP)

Heterosis for seed yield per plant ranged from -44.7% to 48.3%. it was highest in NGM-43XBN-10 (48.3%) followed by NGM-17XT-42 (41.4%) and GPM-O-5XPT-303 (37.4%). While lowest heterosis was found in cross PL-58XT-42 (-44.7%) followed by PL-58XPT-303 (-26.8%).

Inbreeding depression for seed yield per plant was ranged from -18.6% to 44.1%. Highest inbreeding depression was observed in cross GPM-O-5XT-42 (44.1%) while it was lowest in cross PL-58XPT-303 (-18.6%). Average value of ID was 2.6%, table 3.

Discussion

A lot of studies have been made in intraspecific heterosis in oilseed *Brassica*. Studies on interspecific heterosis in rapeseed-mustard are few probably due to difficulty in obtaining fertile F1 hybrids. U (1935) and Mackay (1973) [16] observed significantly lower crossability in cross combination with *B. rapa* as female parent. Heterosis in hybrids of *B. napus* x *B. rapa* has been reported by Shiga (1970) [24] and Mackay (1973) [16]. Poor growth in hybrids against both parents was also reported by Kamala, 1976.

- The experimental results revealed that the hybrids expressed significant heterosis for various characters studied. Highly significant variability was found in the source materials as well as in F_1 hybrids. Similar findings were also observed by Sharma *et al*. (2003) [23] and Arifullah *et al*. (2012) [2]. Significant differences were also noted among parents vs. F_1s, parents vs. F_2s and F_1s vs. F_2s for all the characters. A summary of heterosis for highest value in the desired direction with respect to each character studied is presented in table 4.

In case of primary branch per plant; crosses NGM-43XT-42 expressed highest heterosis. For secondary branches per plant, crosses NGM-43XBN-10, NGM-17XBN-10 and GPM-O-5XBN-10 exhibited highest heterosis. Heterosis for primary and secondary branches per plant in mustard has also been reported by Sood *et al*. (2000) [28], Singh *et al*. (2009) [23], Sadat *et al*. (2010) [22], Akbar *et al*. (2007) [1]. Our results are further strengthened by Dar *et al*. (2010) [5] and Mahto & Haider (2004) [17] who reported high significant positive heterosis for primary branches and seed yield per plant in different populations of *Brassicas*.

For main shoot length cross NGM-43XT42 recorded highest heterosis. Banga and Labana (1984) [3] also reported heterosis for length of main shoot in mustard.

For siliquae on main shoot, crosses NGM-43XT-42, NGM-43XBN-10 and PL-58XT-42 expressed maximum heterosis. Banga and Labana (1984) [3] also reported heterosis for this trait in mustard.

Table 2: Mean performance of parents, their F1 hybrids and F2 population for yield and yield contributing traits in oilseed *Brassica*.

Parent/F1/F2	Generation	PB	SB	MSL	SOMS	SPP	SL	SPS	TW	SYPP	OC	OYPP
NGM-43	-	4.4	7.0	67.5	45.0	207.4	5.0	15.9	6.1	13.6	38.7	5.2
NGM-17	-	4.8	7.6	76.6	57.9	272.6	5.1	16.4	5.2	14.6	40.8	5.9
PL-58	-	5.3	12.7	73.6	50.7	284.5	5.6	15.4	5.3	15.1	38.2	5.8
GPM-O-5	-	4.7	9.0	74.2	56.4	241.6	4.7	13.9	6.3	14.3	38.9	5.6
PT-303	-	5.8	11.2	59.1	39.0	240.0	5.4	17.0	3.7	10.6	39.1	4.1
T-42	-	3.9	2.6	57.8	43.0	130.6	6.0	38.3	4.0	9.0	41.2	3.7
BN-10	-	4.7	4.3	63.8	45.0	162.6	6.3	20.2	4.1	7.6	39.0	3.0
NGM-43XPT-3-03	F1	5.7	11.0	75.7	52.8	332.0	4.6	14.8	5.0	14.4	39.9	5.7
NGM-43XPT-3-03	F2	5.4	11.8	57.3	46.9	313.0	5.8	15.2	4.8	15.1	40.7	6.1
NGM-17XPT-303	F1	5.0	8.0	71.9	50.7	288.6	5.4	14.3	4.9	13.8	41.1	5.6
NGM-17XPT-303	F2	4.1	7.7	67.0	37.0	270.0	5.0	14.3	4.5	11.8	40.5	4.8
PL-58XPT-303	F1	5.7	11.8	65.8	59.5	326.5	3.8	13.6	5.7	11.1	37.8	4.2
PL-58XPT-303	F2	5.6	12.8	69.2	59.9	347.0	4.7	14.9	6.2	13.1	37.6	4.9
GPM-O-5XPT-303	F1	6.2	9.0	64.1	48.8	277.0	5.4	17.2	4.9	19.7	39.8	7.8
GPM-O-5XPT-303	F2	4.0	8.0	63.7	37.0	251.0	5.3	14.2	4.9	14.9	41.8	6.2
NGM-43XT-42	F1	5.7	7.6	81.5	64	306.0	4.7	14.9	5.1	12.6	40.4	5.1
NGM-43XT-42	F2	5.9	7.1	77.6	67.1	360.0	4.6	16.7	5.2	14.8	40.7	6.0
NGM-17XT-42	F1	4.7	8.2	64.8	42.1	240.3	4.6	12.9	6.6	20.7	39.4	8.1
NGM-17XT-42	F2	4.4	7.2	63.0	40.7	200.0	4.5	12.9	7.5	15.3	37.8	5.8
PL-58XT-42	F1	5.6	12.4	75.8	62.9	274.0	4.6	15.4	4.7	8.4	41.9	3.5
PL-58XT-42	F2	5.7	12.2	71.4	61.1	302.0	4.4	17.9	4.6	9.3	42.8	4.0

GPM-O-5XT-42	F1	5.3	3.9	60.3	44.4	112.2	6.2	38.0	5.6	14.0	43.6	6.1
GPM-O-5XT-42	F2	5.3	3.5	64.4	41.6	105.0	6.1	37.3	5.8	7.8	43.3	3.4
NGM-43XBN-10	F1	5.5	13.1	76.3	60.2	502.3	4.4	14.3	6.4	20.1	37.8	7.6
NGM-43XBN-10	F2	6.0	14.4	72.8	61.8	514.0	5.2	15.8	6.5	22.8	36.6	8.3
NGM-17XBN-10	F1	5.0	11.8	65.4	54.7	379.0	4.4	12.3	6.3	15.9	38.0	6.0
NGM-17XBN-10	F2	5.3	12.9	69.1	51.8	370.0	5.1	14.2	6.1	16.9	38.7	6.5
PL-58XBN-10	F1	6.2	13.7	68.8	58.5	308.0	6.9	17.0	5.2	19.0	37.7	7.1
PL-58XBN-10	F2	6.0	14.3	70.9	61.7	321.0	7.0	17.9	4.9	20.9	39.2	8.2
GPM-O-5XBN-10	F1	6.1	12.0	77.3	56.5	340.5	5.8	16.2	5.8	18.1	37.7	6.8
GPM-O-5XBN-10	F2	5.9	12.3	71.1	61.7	361.0	5.8	16.0	5.9	17.1	40.9	7.0

For siliquae per plant; crosses NGM-43XBN-10, NGM-43XT-42, GPM-O-5XBN-10, and NGM-43XPT-303 recorded significantly high values of heterosis. Higher numbers of silique per plant coupled with more seed per siliqua and medium / bold seed size could be an important indicator for high seed yield, Rameeh (2011) [21] also found high positive heterosis for seed per plant.

The crosses PL-58XBN-10 expressed maximum heterosis for siliqua length. While for seeds per siliqua crosses GPM-O-5XT-42 exhibited highest heterosis. In mustard heterosis for siliqua length and seeds per siliqua has been reported by Hirve and Tiwari (1991) [10] and Sood *et al* (2000) [28].

For test weight; crosses NGM-17XT-42 and NGM-17XBN-10 recorded high heterosis. Kumar *et al* (1990) [15] reported significant heterosis for 1000 seed weight.

Significant heterosis of agronomic traits in the F_2 generation has been reported in rapeseed (Engqvist and Becker, 1991) [8], however, the utilization of heterosis in mustard is still limited. Heterosis over environments is variable and environment dependent, climatic changes from year to year could modify the response for various agronomic traits in Indian mustard (Lionneton *et al*., 2004) [15].

Extent of inbreeding depression

To assess decline in performance, the extent of inbreeding depression was estimated and studied for nine yield & its component characters. In interspecific hybrids the F_2 and subsequent generations could provide a good opportunity to select desirable genotypes. Kumari *et al* (2009) [13] reported that the results in F_2 generation provide good ground for further study in segregating generations in cotton. It was suggested that yield of F_1 did not predict the yield of bulk in advanced generations and combined performance of hybrids in F_1 and F_2 generation could be a good indicator to identify most promising populations to be utilized either as F_2 hybrids or as a source population for further selection in advanced generations.

As it could be visualised from the table 3 that characters like secondary branches (-9.9 to 12.8%), main shoot length (-6.6 to 24.3%), siliquae on main shoot (-9.2 to 27.0%), siliquae per plant (-17.6 to 16.6%), siliquae length (-25.4 to 6.6%), seeds per siliqua (-16.5 to 17.5%) and test weight (-14.4 to 8.8%) showed moderate inbreeding depression, which suggest that these characters could be basically controlled by additive gene action. Similar results have been reported by Doloi and Rai (1981) [6]. While seed yield per plant (-18.6 to 44.1%) and primary branches (-9.1 to 35.5%) revealed high inbreeding depression. Significant inbreeding depression for seed yield in Indian mustard has also been reported by Thakur and Bhateria (1993) [29].

Inbreeding depression in F_2 can give an idea about the genetic control of characters and this could help in isolating high yielding pure lines from the promising crosses. An examination of data on inbreeding depression for seed yield per plant and other characters indicated that in general lower mean expression of F_2 against respective F_1 may be due to dominance and epistatic interaction. Banga and Labana (1984) [3] suggested the importance of non-additive gene action for controlling the characters. Similarly, Singh *et al*. (2003) [23] reported that most of the high heterotic cross combinations for different characters showed low inbreeding depression in F_2 generation.

Table 3: Estimates of heterosis and inbreeding depression for nine yield and yield contributing traits.

Cross	PB		SB		MSL		SOMS		SPP		SL		SPS		TW		SYPP	
	H	ID	H	ID	H	ID	H	ID	H	ID	H	ID	H	ID	H	ID	H	ID
NGM-43XPT-303	-1.7	5.3	-1.3	-7.3	12.1	24.3	17.3	11.2	38.3*	5.7	-14.4	-25.4	-12.5	-2.4	-18.0*	4.2	6.3	-4.9
NGM-17XPT-303	-13.8	18	-28.3*	3.8	-6.1	6.8	-12.4	27	5.9	6.4	-0.3	6.6	-15.7	0	-4.4	8.8	-5.8	14.2
PL-58XPT-303	-1.7	1.8	-7.5	-8.9	-10.6	-5.2	17.4	-0.7	14.8	-6.2	-32.5*	-23.9	-19.9	-9.7	9.4	-8.3	-26.8*	-18.6
GPM-O-5XPT-303	6.9	35.5	-19.3	11.1	-13.6	0.6	-13.5	24.2	14.7	9.5	-0.4	1.1	1.5	17.5	-21.1*	0.9	37.4*	24.2
NGM-43XT-42	29.5	-3.5	7.9	6	20.7	4.8	42.2*	-4.8	47.5*	-17.6	-20.6*	2.2	-61.1*	-12.1	-15.8*	-1.5	-7.4	-17.9
NGM-17XT-42	-2.1	5.9	8.6	12.8	-15.4	2.7	-27.3*	3.4	-11.8	16.6	-22.2*	1.8	-66.3*	0	28.1*	-14.4	41.4*	25.9
PL-58XT-42	4.7	-2.7	-2.8	1.2	3	5.8	24.1*	2.9	-3.7	-10.2	-22.7*	4.1	-59.9*	-16.5	-10.5	2	-44.7*	-11.4
GPM-O-5XT-42	12.8	0	-56.4*	10.3	-18.7	-6.6	-21.3*	6.3	-53.6*	6.1	3.5	1.6	-0.9	1.7	-11.2	-5	-2.4	44.1
NGM-43XBN-10	17	-9.1	87.1*	-9.9	13	4.5	33.8*	-2.7	142.2*	-2.3	-30.6*	-18.9	-28.8*	-10.2	4.4	-1.7	48.3*	-13.4
NGM-17XBN-10	3.1	-7.1	56.3*	-9.3	-14.6	-5.7	-5.5	5.3	39.0*	2.4	-29.9*	-15.5	-39.0*	-15.4	22.3*	3.9	8.9	-6.3
PL-58XBN-10	17	3.2	7.9	-4.4	-6.5	-3	15.4	-5.5	8.3	-4.2	9.8	-1.2	-15.6*	-5.3	-1	5.8	25.8*	-10
GPM-O-5XBN-10	29.8	3.3	34.1*	-2.5	4.2	8.1	0.2	-9.2	40.9*	-5.9	-7.9	0.1	-19.7*	1.1	-6.7	-1.7	26.2*	5.3
Average	8.5	4.2	-0.9	0.2	-2.7	3.1	2.7	4.8	4.7	0	-1.6	-5.6	-9.5	-4.3	-2.9	-0.6	-0.1	2.6

MPH= Mid Parent Heterosis, BPH= Better Parent Heterosis, ID = Inbreeding Depression, * significant heterosis at 5% level of probability.

Table 4: List of crosses appearing as promising based on high mid and better parent heterosis & low inbreeding depression for various characters

S N	Characters	Promising crosses
1	Nos of primary branches	NGM-43XT-42
2	Nos of secondary branches	NGM-43XBN-10, NGM-17XBN-10, GPM-O-5XBN-10
3	Main Shoot Length	NGM-43XT-42
4	Siliqua on main shoot	NGM-43XT-42, NGM-43XBN-10, PL-58XT-42
5	Siliquae per plant	NGM-43XBN-10, NGM-43XT-42, GPM-O-5XBN-10, NGM-43XPT-303
6	Siliqua length	PL-58XBN-10
7	Sees per siliqua	GPM-O-5XT-42
8	Test weight	NGM-17XT-42, NGM-17XBN-10
9	Seed Yield per plant	NGM-43XBN-10, NGM-17XT-42, PL-58XBN-10, GPM-O-5XBN-10, GPM-O-5XPT-303
10	Oil content	GPM-O-5XT-42, PL-58XT-42
11	Oil yield per plant	NGM-43XBN-10, NGM-17XT-42, GPM-O-5XPT-303, GPM-O-5XBN-10, PL-58XBN-10

Conclusion

As an overview of all the results suggested that among parents, BN-10 proved to be superior when used as male parents in most of the hybrid combinations. Hybrids PL-58 x BN-10, GPM-O-5 x BN-10, NGM-17 x BN-10, NGM-43 x BN-10 and NGM-43 x T-42 were emerged as best for yield and its component traits. Most of the crosses exhibiting high heterosis in desired direction involved at least one good general combiner for most of the characters but not necessarily high per se performance of the parents. In most of the crosses high heterosis did not involve parents with high mean this indicates the genetic diversity among the parents.

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References

1. Akbar M, Tahira Hussain M. Heterosis for seed yield and its components in rapeseed. J Agri. Res. 2007; 45(2):95-104.
2. Arifullah, Mohammad, Munir Mohammad, Mahmood, Abid, Ajamal SK *et al*. Combining ability analysis of some yield attributes in Indian mustard [Brassica juncea (L.) Czern Coss]. Pakistan Journal of Agriculture research. 2012; 25(2):104-109.
3. Banga SS, Labana KS. Heterosis in Indian Mustard [Brassica juncea (L.) Coss], Z Pflanzenzucht. 1984; 92:61-70.
4. Chauhan JS, Meena ML, Kumar Arvind. Estimation of heterosis and inbreeding deepression for seed yield and its components Indian mustard [*Brassica juncea* (L.) Czern Coss]. Journal of Maharashtra Agricultural Universities. 2011; 36(1):57-62.
5. Dar ZA, Wani SA, Zaffar G, Habib M, Wani MA, Ishfaqq A, Khan MH, Razvi SM. Variability studies in Brown Sarson (*Brassica rapa* L.). Res. J Agr. Sci. 2010; 1(3):273-274.
6. Doloi PC, Rai B. Inbreeding depression in Rapeseed. Indian Journal of Genetics and Plant Breeding. 1981; 41(3):368-373.
7. Dutta A. Combining ability and heterosis for seed yield and its component characters yellow sarson (Brassica rapa L. var. yellow sarson). State Agricultural Technologists' Service Association, West Bengal, India, SATSA Mukhaptra Annual Technicaled. Springer Verlag Berlin. 2014; 18:132-137.
8. Engquist GM, Becker HC. Heterosis and epistasis in rapeseed estimated from generation means. Euphytica. Vol. 1991; 58(1):31-35.
9. Hassan G, Mohammad F, Khalil IH. Heterosis and heterobeltiosis studies for morphological traits in bread wheat. Sarhad J Agri. 2006; 22(1):51-54.
10. Hirve CD, Tiwari AS. Heterosis and inbreeding depression in Indian mustard. Indian J Genet. 1991; 51(2):190-193.
11. Kamala T. Interspecific hybrids in Brassica. Cytologia. 1976; 41:407-415.
12. Kumar PR, Arora RK, Singh NP, Yadav RC, Kumar P. A study of heterosis in Indian mustard (Brassica juncea L. Czern & Coss). Act. Agron. Tuengarica. 1990; 39(1-22):137-143.
13. Kumari Basamma, Kajjidoni ST, Salimath PM, Patil Malgouda. Heterosis and inbreeding depression for economic traits in desi cotton. Electronic Journals of Pant Breeding. 2009; 1:47-51.
14. Lal Kanhaiya, Krishna Ram, Ranjeet, Ali Hasmat. Heterosis for yield and its components Indian mustard [Brassica juncea (L.) Czern Coss]. Trends in Biosciences. 2013; 6(3):259-263.
15. Lionneton E, Aubert G, Ochatt S, Merah O. Genetic analysis of agronomic and quality traits in mustard (B. juncea). Theor Appl Genet. 2004; 109:792-799. doi:10.1007/s00122- 004-1682-0
16. Mackay GR. Interspecific hybrids between forage rape (*Brassica napus* L.) and turnip (*Brassica campestris* L. ssp. Rapifera) as alternative to forage rape. An exploratory study with single pair crosses. Euphytica. 1973; 22:495-499.
17. Mahto JL, Haider ZA. Heterosisin Indian Mustard (*Brassica juncea* L. and cosson). J Trop. Agric. 2004; 42(102):39-41.
18. Matzingar DF, Mann TJ, Cockerham CC. Diallel crosses in Nicotiana tabacum. Crop Sci. 1962; 2:383-386.
19. McNaughton IH. Brassica nanocampestris (2n-58) I. Synthesis, cyrtology, fertility and general consideration. Euphytica. 1973; 22:301-309.
20. Prajapati KK, Verma OP, Kumar K, Prakash Singh, Tiwari R. Estimates of some quantitative genetic characters in Brassica rapa var. yellow sarson under different environments. Journal of Oil seeds Research. 2013; 27(1):49-51.
21. Rameeh V. Line x Tester analysis for seed yield and yield components in spring and winter type varieties of ilseed rape. J Cereal Oilseeds. 2011; 2(5):66-70.

22. Sadat HA, Nematzadeh GA, Jelodar NB, Chapi OG. Genetic evaluation of yield and yield components at advanced generations in rapeseed (*Brassica napus* L.) African J Agric. Res. 2010; 5(15):1958-1964.
23. Sharma, Ritesh, Sharma, Pankaj, Singh PP, Kumar A. Study on genetic parameters for seed yield and yield components in India mustard. National Seminar on Advances in Genetics and P1. Breed. Impact of DNA Revolution. Oct. 30-31-2003. UAS, Dharwad, 2003, 87.
24. Shiga T. Rape breeding by interspecific crossing between Brassica napus and Brassica campestris in Japan. Jap. Agr. Res. Quart. 1970; 5:5-10.
25. Shweta, Ranjeet, Singh P, Dixit RK. Combining ability and heterosis for seed yield, its components and oil content in Indian mustard. Farm Sci. J. 2005; 14:44-48.
26. Singh M, Swarnkar GB, Prasad L, Dixit RK. Heterobeltiosis and inbreeding depression in Indian mustard [B. juncea (L.) Czern and Coss]. Crop Res. Hissar. 2003; 26(2):318-325.
27. Singh Mahak, Ranjeet, Srivastava SBL. Heterosis and combining ability estimates in Indian mustard (Brassica juncea (Czern & Coss.) J Oilseeds Res. 2009; 26:61-63.
28. Sood OP, Sood VK, Thakur HL. Combining ability and heterosis for seed yield traits involving natural and synthetic Indian mustard (Brassica juncea L. Czern. & Coss.). Indian J of Plant Breeding and Genetics. 2000; 60(4):561-563.
29. Thakur HL, Bhateria S. Heterosis and inbreeding depression in Indian mustard. Indian J of Genetics and Plant Breeding. 1993; 1(9):60-65.
30. Turi NA, Raziuddin S, Shah SS, Ali S. Estimation of heterosis for some important traits in mustard (B. juncea). J Agril Bio Sci. 2006; 1:6-10.
31. Genome-analysis in Brassica with special reference to the experimental formation of B. napus and peculiar mode of fertilization. Jap. J Bot. 1935; 7:389-452.