Estimation of heterosis for plant growth, oil content and yield related traits in Indian mustard [*Brassica juncea* (L.) Czern&Coss] using half diallel

ABSTRACT

Geneticinvestigation was carried out diallel design for heterosis analysis studies the experimental material comprised with eight parents with two checks was carried out to identify high heterotic crosses and their relationship in Indian mustard. Several hybrids exhibited heterobeltiosis and standard heterosis for seed yield per plant and other characters. The heterosis analysis revealed substantial hybrid vigor across 28 hybrid crosses, with noteworthy improvements in traits such as earlier flowering, earlier maturity, and increased seed weight. The seed yield per plant exhibited better parent heterosis ranging from -20.71% to 16.28%, with five crosses yielding more seeds than their better parents. P3 (PM-22) X P8 (RH-749) was the best cross, with a 16.28% increase. Standard heterosis ranged from -38.72% to 35.14%, with ten crosses showing significant positive heterosis. The findings from this investigation provide crucial insights into the genetic performance and breeding potential of Indian mustard genotypes. The identified parental lines and cross combinations with desirable heterosis effects offer valuable resources for breeding programs aimed at developing high-yielding and resilient mustard varieties, contributing to the advancement of agricultural practices and crop improvement. The above best parent and best crosses can be used in hybridization and heterosis breeding respectively.

KEYWORDS:*Brassica juncea***,**Diallel analysis, heterobeltiosis, standard heterosis.

1. INTRODUCTION

Oilseeds hold significant importance both in India and globally, as evidenced by the impact of the Yellow Revolution. Key rapeseed-mustard producing nations include Canada, China, Germany, and France. This group of crops ranks as the third most crucial oilseed crop, following soybean and groundnut, contributing approximately 20-25% of India's total oilseed production (Kapadia et al., 2020). Despite substantial growth in oilseed brassica production in India, productivity remains low due to extensive rainfed farming, various biotic and abiotic stresses, and resource constraints (Kumar et al., 2023; Kumar et al., 2024). Brassica crops are highly diverse and second most important source of edible oil in India. Indian mustard [*Brassica juncea* (L.) Czern. &Coss.] is predominantly cultivated and accounts more than 70% of the area under the rapeseed-mustard crops. The area, production and productivity of rapeseed-mustard in India are 6.0 million hectares and 7.98 million tonnes and 1324.0 kg/ha, respectively (Anonymous, 2018). India holds third position in area and production after Canada and China (Kumar et al. 2024). In India, Rajasthan is the largest producer of rapeseed-mustard followed by Uttar Pradesh, Haryana, Madhya Pradesh, West Bengal, Gujarat and Assam. It is mostly grown in Alwar, Bharatpur, Sri Ganganagar, Kota, Bikaner and Jaipur districts of Rajasthan. Indian mustard is a natural amphidiploid, derived from cross of *B. rapa* and *B. nigra* (Kumar et al., 2024). Seed oil ranges from 38–40% which is a cooking and frying medium throughout the north India (Shekhawat *et al.,* 2022). They are next to cereals in production of agricultural commodities in India. Seed quality, Seed yield and other yield related parameters of Brassica oil seed crop has been tried to improve by several Researchers (Rakow, 1995, Singh, 2003, Saini, 2015 and Kumar, 2017). Heterosis is a highly effective method for enhancing crop varieties, characterized by increased vigor, size, fruitfulness, growth rate, and resistance to diseases, pests, and climatic challenges in cross-bred organisms compared to their inbred counterparts (Shull, 1952; Kumar et al., 2018). The development of hybrid cultivars has seen success across many Brassica species (Miller, 1999). To study the inheritance of quantitative traits and evaluate various breeding strategies, a thorough understanding of combining ability is crucial (Allard, 1960). Heterosis has been extensively utilized in rapeseed breeding (Wang et al., 2017; Xie et al., 2018), with reliable prediction techniques significantly accelerating crossbreeding efforts and reducing the costs of large-scale field evaluations. The goal of hybrid seed production is to boost yield and enhance oil quality in oilseed crops. In light of the current status of rapeseed in India, this study aims to evaluate a) the mean performance of parental genotypes and their F1 hybrids, and b) heterosis in F1 hybrids.

2. MATERIAL AND METHODS

Breeding material was procured from SVPUA&T, Meerut, (UP) consisted of eight varieties of Indian mustard namely, Rohini, Vardan, PM-22, Pusa Tarak, PM-26, RLM-619, CS-54, and RH-749 along with two checks viz., GM-2 and Vardan. These varieties of Indian mustard were subjected to diallel fashion mating design (excluding reciprocals) during Rabi 2021-22.

The experimental material comprising of 38 treatments viz., (8 parents + 28 F1's and 2 checks) was evaluated in RBD with three replications during Rabi 2022-2. Each parent and F1's planted in one row of 5m long 45cm apart; plant to plant distance was maintained 15cm by thinning. All the recommended agronomic practices were adopted for raising a healthy crop. Uniform cultural practices, as recommended, were applied throughout the growing season to all genotypes to minimize field variations and environmental influences.

2.1 Traits Measurement and Statistical Analysis

Data were collected on 10 randomly selected plants from the central two rows on a single plant basis for plant height and yield traits, including main raceme length, 1000-seed weight, and seed yield per plant. All recorded data were subjected to analysis of variance (ANOVA) to test the null hypothesis of no differences between parental means and their F1 populations (Kirti et al 2022). Upon finding significant differences among the parental genotypes and their F1 hybrids for various traits, the data were further analysed for Heterosis expressed as per cent increase or decrease in F1 over its (mid-parent, better-parent, and commercial) value in the desirable direction was estimated for various traits. Data were subjected to combining ability analysis as per Griffing (1956) and according to Matzinger *et al.* (1962).

3. RESULT AND DISCUSSION

The estimation of heterosis using different diallel crosses reveals various significant interactions across multiple traits, including days to flowering (DF), days to maturity (DM), and thousand seed weight (TSW). For Days to 50 per cent flowering (DF), Better parent heterosis or heterobeltiosis ranged from -12.52 percent (P6 X P7) to -2.91 percent (P6 X P8). Out of twenty-eight crosses, nineteen crosses showed negative and significant desirable heterosis for days to 50% flowering. The best five crosses were P6 X P7 (-12.52), P2 X P7 (-11.46), P1 X P7 (-10.34), P4 X P6 (-9.74) and P2 X P4 (-9.10). Similarly for days to maturity (DM), heterobeltiosis ranged from -17.52 percent (P4 X P6) to 3.52 percent (P1 X P7). Out of twenty-eight crosses, twenty-two crosses showed negative and significant desirable heterosis for days to maturity. Standard heterosis ranged from -25.37 percent (P3 X P4) to 6.91 percent (P1 X P6). Out of twenty-eight crosses, twenty-one crosses showed negative and significant heterosis. The best five crosses were P3 X P4 (-25.37), P3 X P5 (-22.79), P3 X P7 (-21.60), P4 X P5 (-21.28) and P4 X P7 (-20.60). However, four crosses showed positive significant heterosis for days to maturity. For 1000 seed weight Standard heterosis ranged from -18.64 percent (P2 X P7) to 31.04 percent (P4 X P7). Out of twenty-eight crosses, eight crosses showed positive and significant heterosis. The best five crosses were P4 X P7 (31.04), P2 X P4 (23.76), P1 X P4 (18.48), P3 X P5 (17.44) and P4 X P8 (17.44). Heterobeltiosis ranged from -19.57 percent (P3 X P7) to 22.21 percent (P3 X P4). Out of twenty-eight crosses, seven crosses showed positive and significant desirable heterosis for 1000 seed weight.These results are in accordance with the findings of Singh *et al.* (2010), Tele *et al.* (2014), Vaghela *et al.* (2014) and Kumar *et al.* (2015).

For biological yield (g) heterobeltiosis ranged from -17.30 percent (P4 X P6) to 17.86 percent (P4 X P5). Out of twenty-eight crosses, six crosses showed positive and significant desirable heterosis for biological yield. Out of twenty-eight crosses, only three crosses showed positive and significant heterosis. The best crosses were P3 X P4 (22.75), P2 X P4 (19.13) and P1 X P4 (12.03). However, all the crosses showed either negative significance or non-significance for biological yield (Kumar et al., 2022).

For harvest index, heterobeltiosis ranged from -16.98 percent (P2 X P6) to 13.44 percent (P2 X P7). Out of twenty-eight crosses, eight crosses showed positive and significant desirable heterosis for harvest index. The best five crosses were P2 X P7 (13.44), P2 X P5 (11.95), P2 X P3 (11.13), P5 X P6 (9.84) and P3 X P8 (8.75). While, standard heterosis ranged from -29.37 percent (P4 X P6) to 29.50 percent (P1 X P6). The best five crosses were P1 X P6 (29.50), P6 X P7 (27.77), P1 X P4 (26.19), P3 X P6 (25.91) and P4 X P5 (23.20).

Oil content heterobeltiosis ranged from -3.66 percent (P3 X P7) to 3.99 percent (P1 X P3). Eleven crosses showed positive and significant desirable heterosis for oil content. The best five crosses were P1 X P3 (3.99), P4 X P8 (3.53) P4 X P5 (3.52), P3 X P5 (3.19) and P2 X P6 (2.54). Out of twenty-eight crosses, seven crosses showed positive and significant heterosis.However, twenty crosses showed negative significant heterosis for oil content.Twelve crosses showed positive and significant desirable heterosis for primary branches per plant. The best five crosses were P6 X P7 (18.58), P3 X P4 (16.05), P4 X P8 (15.18), P3 X P8 (12.54) and P2 X P6 (12.27). while, standard heterosis, twenty-two crosses showed positive and significant heterosis (Kirti et al., 2022).

For plant height, seven crosses showed negative and significant desirable heterosis, best five crosses were P6 X P7 (-5.56), P2 X P7 (-5.00), P3 X P6 (-4.48), P1 X P7 (-3.64) and P2 X P4 (-3.58). While, none crosses exhibited positive and significant desirable heterosis for plant height. Standard heterosis ranged from -7.67 percent (P3 X P7) to 4.06 percent (P1 X P8), best five crosses were P3 X P7 (-7.67), P4 X P7 (-7.28), P5 X P7 (-4.96), P3 X P5 (-4.68) and P3 X P4 (-4.44). However, four crosses showed positive significant heterosis for plant height.

Seventeen crosses showed positive and significant desirable heterosis for number of secondary branches per plant, five crosses were significant, P1 X P6 (29.68), P3 X P6 (-17.41), P5 X P6 (-14.79), P6 X P7 (-12.66) and P1 X P3 (-12.15). Standard heterosis ranged from -26.45 percent (P2 X P6) to 35.89 percent (P6 X P7). The best five crosses were P6 X P7 (35.89), P4 X P6 (28.87), P4 X P7 (23.55), P2 X P7 (22.10) and P6 X P8 (20.24).

The similar results were also obtained by Dholu et al. (2014), Surin et al. (2018) for heterobeltiosis and standard heterosis. Whereas Kumbhalkar et al. (2000), Nasrin et al. (2011) for heterobeltiosis. While, Chaurasiya et al. (2022) for standard heterosis. For seeds per siliqua heterobeltiosis ranged from -13.27 percent (P6 X P7) to 16.51 percent (P6 X P8). Out of twenty-eight crosses, nine crosses showed positive and significant desirable heterosis for number of seeds per siliqua, whereas, standard heterosis ranged from -26.82 percent (P1 X P6) to 37.39 percent (P5 X P6).

Out of twenty-eight crosses, fourteen crosses showed positive and significant desirable heterosis for total number of siliquae per plant. The best five crosses were P4 X P6 (20.10), P1 X P4 (17.28), P3 X P4 (15.32), P4 X P7 (15.30) and P4 X P8 (13.20). While for standard heterosis, the best five crosses were P2 X P4 (21.08), P4 X P5 (20.96), P4 X P8 (20.81), P4 X P7 (17.88) and P3 X P4 (17.86).

For siliqua on main raceme out of twenty-eight crosses, fourteen crosses showed positive and significant desirable heterosis for siliqua on main raceme. For seed yield per plant, five crosses showed positive and significant desirable heterosis for seed yield per plant. The best five crosses were P3 X P8 (16.28), P2 X P3 (14.10), P1 X P4 (13.85), P2 X P6 (10.73) and P5 X P7 (7.46). While, twenty-one crosses exhibited negative and significant heterosis for seed yield per plant. Standard heterosis ranged from -38.72 percent (P3 X P4) to 35.14 percent (P4 X P7). Earlier studies by Narsin et al. (2011), Lal et al. (2012), Niranjana et al. (2014) and Chaurasiya et al. (2022) also revealed heterosis in desirable direction for various characters in Indian mustard.

Table 1: Estimation of heterosis with difference diallel

Cross	DF			DM			TSW		
	MID.HET	BET.BET	STD.HET	MID.HET	BET.BET	STD.HET	MID.HET	BET.BET	STD.HET
P1XP2	-0.15 ns	-1.73 ns	3.39 *	2.19 NS	1.05 NS	0.66 NS	-1.74 NS	-5.81 **	6.40 **
P1XP3	0.81 NS	-7.25 **	-5.51 **	-0.67 NS	-12.15 **	-12.49 **	-0.13 NS	-13.20 **	-10.08 **
P1XP4	0.65 NS	-8.32 **	-6.60 **	3.11 *	-10.52 **	-10.87 **	-1.46 NS	-13.44 **	18.48 **
P1XP5	-0.13 NS	-6.42 **	-4.66 **	2.08 NS	-7.86 **	-8.22 **	-0.71 NS	-8.42 **	-5.12 **
P1XP6	-0.38 NS	-3.04 *	4.36 **	1.23 NS	-4.21 **	6.91 **	-0.34 NS	-9.19 **	-5.92 **
P1XP7	-0.53 NS	-10.34 **	-8.66 **	12.14 **	3.52 *	3.12 *	-1.21 NS	-10.48 **	14.16 **
P1XP8	0.09 NS	-0.83 NS	1.03 NS	1.51 NS	1.31 NS	1.31 NS	-0.83 NS	-2.55 NS	0.96 NS
P2XP3	0.76 NS	-8.64 **	-3.88 **	1.32 NS	-9.50 **	-11.87 **	-1.10 NS	-17.07 **	-6.32 **
P2XP4	1.25 NS	-9.10 **	-4.36 **	1.64 NS	-10.94 **	-13.26 **	-0.93 NS	-9.59 **	23.76 **
P2XP5	0.72 NS	-7.02 **	-2.18 NS	2.00 NS	-7.00 **	-9.42 **	-0.16 NS	-11.40 **	0.08 NS
P2XP6	0.23 NS	-0.90 NS	6.66 **	0.24 NS	-6.15 **	4.75 **	-0.93 NS	-13.10 **	-1.84 NS
P2XP7	-0.36 NS	-11.46 **	-6.84 **	1.44 NS	-5.37 **	-7.84 **	-1.33 NS	-6.96 **	18.64 **

P2XP8	0.53 NS	-1.96 NS	3.15 *	1.52 NS	0.20 NS	0.20 NS	-2.10 NS	-7.72 **	4.24 *
P3XP4	2.56 NS	1.44 NS	-13.19 **	-0.40 NS	-2.54 NS	-25.37 **	-0.19 NS	-22.21 **	6.48 **
P3XP5	1.03 NS	-0.93 NS	-11.79 **	-1.51 NS	-3.74 *	-22.79 **	0.68 NS	-5.67 *	-17.44 **
P3XP6	2.21 NS	-8.26 **	-1.26 NS	-2.04 NS	-17.41 **	-7.82 **	-0.15 NS	-5.26 *	-19.28 **
P3XP7	1.50 NS	-0.76 NS	-15.07 **	-2.54 NS	-7.01 **	-21.60 **	0.55 NS	-19.57 **	2.56 NS
P3XP8	2.43 NS	-4.95 **	-4.95 **	-0.07 NS	-11.77 **	-11.77 **	1.00 NS	-10.88 **	-10.88 **
P4XP5	0.36 NS	-2.65 NS	-13.32 **	2.57 NS	-1.85 NS	-21.28 **	-0.11 NS	-18.12 **	12.08 **
P4XP6	1.55 NS	-9.74 **	-2.85 *	-0.42 NS	-17.52 **	-7.94 **	-0.43 NS	-19.23 **	10.56 **
P4XP7	0.53 NS	-0.63 NS	-16.82 **	0.76 NS	-5.82 **	-20.60 **	-0.88 NS	-4.27 **	31.04 **
P4XP8	1.68 NS	-6.60 **	-6.60 **	2.07 NS	-11.56 **	-11.56 **	-0.84 NS	-14.20 **	17.44 **
P5XP6	-0.18 NS	-8.81 **	-1.85 NS	-0.84 NS	-14.79 **	-4.89 **	0.60 NS	-0.73 NS	-13.12 **
P5XP7	-0.28 NS	-4.35 **	-14.84 **	-1.92 NS	-4.30 **	-19.33 **	-1.26 NS	-16.75 **	6.16 **
P5XP8	0.63 NS	-4.89 **	-4.89 **	1.53 NS	-8.52 **	-8.52 **	-0.26 NS	-6.48 **	-6.48 **
P6XP7	-0.57 NS	-12.52 **	-5.84 **	-0.49 NS	-12.66 **	-2.52 NS	-2.37 NS	-18.57 **	3.84 *
P6XP8	0.66 NS	-2.91 *	4.50 **	-0.47 NS	-5.65 **	5.31 **	-1.51 NS	-8.80 **	-8.80 **
P7XP8	0.17 NS	-8.96 **	-8.96 **	-0.02 NS	-7.87 **	-7.87 **	-1.41 NS	-12.05 **	12.16 **

Cross	**BY**			**HI**			**OC**		
	mid.het	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**
P1XP2	0.25 NS	-7.72 **	-5.07 **	-0.28 NS	-14.94 **	-11.83 **	1.67 NS	-0.75 NS	0.94 NS
P1XP3	0.02 NS	-10.62 **	-8.05 **	-0.16 NS	-5.54 **	-22.53 **	-0.25 NS	-3.99 *	-2.35 NS
P1XP4	-0.39 NS	-14.48 **	-12.03 **	0.22 NS	-0.43 NS	-26.19 **	-0.72 NS	-3.67 *	-2.03 NS
P1XP5	-1.76 NS	-3.18 *	2.56 NS	0.04 NS	-4.93 **	-22.76 **	-0.52 NS	-1.78 NS	-0.11 NS
P1XP6	-0.87 NS	-1.41 NS	2.55 NS	0.32 NS	-3.65 *	-29.50 **	2.38 NS	0.15 NS	1.86 NS
P1XP7	0.51 NS	-2.67 NS	0.13 NS	-1.04 NS	-4.19 **	-25.12 **	0.39 NS	0.18 NS	1.89 NS
P1XP8	0.54 NS	-0.87 NS	1.98 NS	0.64 NS	-12.86 **	-12.86 **	-1.54 NS	-2.37 NS	-0.70 NS
P2XP3	1.58 NS	-1.67 NS	-14.91 **	-0.77 NS	-11.13 **	-7.88 **	1.34 NS	-0.11 NS	-3.25 NS
P2XP4	0.90 NS	-6.54 **	-19.13 **	-0.21 NS	-14.42 **	-11.29 **	0.53 NS	-0.09 NS	-3.23 NS
P2XP5	-0.43 NS	-9.55 **	-4.19 **	-1.28 NS	-11.95 **	-8.73 **	-0.62 NS	-1.76 NS	-2.62 NS
P2XP6	-0.27	-8.65 **	-4.98 **	0.62 NS	-16.98	-13.95	2.76 NS	2.54	-0.26

	NS				**	**		NS	NS
P2XP7	1.09 NS	-4.07 **	-7.56 **	-1.30 NS	-13.44 **	-10.28 **	1.89 NS	-0.34 NS	0.94 NS
P2XP8	-0.52 NS	-7.22 **	-7.22 **	-0.59 NS	-2.35 *	1.22 NS	1.26 NS	-0.33 NS	-0.33 NS
P3XP4	-0.17 NS	-4.63 *	-22.75 **	-1.23 NS	-5.98 **	-22.89 **	-0.18 NS	-1.00 NS	-5.30 **
P3XP5	-2.82 *	-14.25 **	-9.17 **	-2.16 NS	-2.62 NS	-20.13 **	-0.66 NS	-3.19 NS	-4.04 *
P3XP6	-2.42 NS	-13.22 **	-9.73 **	-0.83 NS	-9.67 **	-25.91 **	1.23 NS	-0.44 NS	-3.15 NS
P3XP7	0.19 NS	-7.80 **	-11.15 **	-1.07 NS	-3.40 *	-20.78 **	-0.10 NS	-3.66 *	-2.42 NS
P3XP8	-0.73 NS	-10.16 **	-10.16 **	0.27 NS	-8.75 **	-8.75 **	0.17 NS	-2.80 NS	-2.80 NS
P4XP5	-3.16 *	-17.86 **	-12.99 **	-1.14 NS	-5.46 **	-23.20 **	-1.81 NS	-3.52 *	-4.37 *
P4XP6	-3.23 *	-17.30 **	-13.98 **	-0.19 NS	-4.73 **	-29.37 **	0.47 NS	-0.37 NS	-3.08 NS
P4XP7	0.79 NS	-11.03 **	-14.26 **	-0.92 NS	-3.46 *	-24.56 **	-0.64 NS	-3.40 *	-2.16 NS
P4XP8	-1.64 NS	-14.54 **	-14.54 **	-0.41 NS	-13.29 **	-13.29 **	-1.38 NS	-3.53 *	-3.53 *
P5XP6	-2.69 *	-3.57 *	2.15 NS	-1.44 NS	-9.84 **	-26.75 **	2.13 NS	1.17 NS	0.28 NS
P5XP7	-0.97 NS	-5.44 **	0.17 NS	-2.98 *	-4.82 **	-22.68 **	0.12 NS	-0.95 NS	0.33 NS
P5XP8	-3.68 **	-6.37 **	-0.82 NS	-1.93 NS	-11.13 **	-11.13 **	-0.31 NS	-0.75 NS	-0.75 NS
P6XP7	-1.01 NS	-4.65 **	-0.82 NS	-0.74 NS	-7.57 **	-27.77 **	2.61 NS	0.58 NS	1.87 NS
P6XP8	-1.94 NS	-3.84 **	0.03 NS	0.28 NS	-16.07 **	-16.07 **	0.53 NS	-0.84 NS	-0.84 NS
P7XP8	-0.43 NS	-2.24 NS	-2.24 NS	0.15 NS	-10.80 **	-10.80 **	0.45 NS	-0.19 NS	1.09 NS

Cross	**PB**			**PH**			**SB**		
	mid.het	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**
P1XP2	0.23 NS	-1.91 NS	16.31 **	2.11 NS	0.23 NS	0.23 NS	0.15 NS	-3.70 *	7.02 **
P1XP3	-0.90 NS	-5.78 **	19.93 **	0.93 NS	-0.90 NS	-0.90 NS	-0.43 NS	-8.57 **	-6.21 **
P1XP4	0.86 NS	-9.35 **	28.54 **	1.43 NS	0.86 NS	0.86 NS	-0.81 NS	-6.90 **	8.87 **
P1XP5	0.99 NS	-7.30 **	22.31 **	2.09 NS	0.99 NS	0.99 NS	-1.45 NS	-6.76 **	-4.35 *
P1XP6	-0.35 NS	-14.85 **	34.43 **	1.42 NS	-0.35 NS	-0.35 NS	-19.45 **	-29.68 **	-3.31 NS
P1XP7	1.85 NS	-5.42 **	6.80 **	0.55 NS	1.85 NS	1.85 NS	0.14 NS	-9.62 **	15.16 **
P1XP8	-0.03 NS	-7.02 **	4.98 *	3.60 *	-0.03 NS	-0.03 NS	1.04 NS	-0.24 NS	2.34 NS
P2XP3	-0.32 NS	-3.56 *	22.76 **	-0.39 NS	-0.32 NS	-0.32 NS	1.06 NS	-10.45 **	-0.48 NS
P2XP4	1.08 NS	-6.31 **	32.84 **	-1.44 NS	1.08 NS	1.08 NS	0.64 NS	-1.86 NS	14.76 **
P2XP5	0.99 NS	-3.43 *	27.41	1.42 NS	0.99	0.99	-2.11	-10.74	-0.81

			**		NS	NS	NS	**	NS
P2XP6	-0.24 NS	-12.27 **	38.51 **	1.55 NS	-0.24 NS	-0.24 NS	1.72 NS	-8.04 **	26.45 **
P2XP7	0.52 NS	-6.11 **	11.33 **	-0.68 NS	0.52 NS	0.52 NS	2.37 NS	-4.18 **	22.10 **
P2XP8	-0.29 NS	-7.74 **	9.40 **	2.48 NS	-0.29 NS	-0.29 NS	-0.15 NS	-5.15 **	5.40 **
P3XP4	0.21 NS	-16.05 **	19.03 **	0.16 NS	0.21 NS	0.21 NS	0.08 NS	-13.24 **	1.45 NS
P3XP5	2.12 NS	0.69 NS	32.84 **	0.97 NS	2.12 NS	2.12 NS	-1.59 NS	-4.67 *	-12.74 **
P3XP6	-0.11 NS	-10.40 **	41.45 **	-0.06 NS	-0.11 NS	-0.11 NS	2.06 NS	-17.13 **	13.95 **
P3XP7	0.71 NS	-9.70 **	14.95 **	-0.92 NS	0.71 NS	0.71 NS	0.15 NS	-16.20 **	6.77 **
P3XP8	-0.31 NS	-12.54 **	11.33 **	2.23 NS	-0.31 NS	-0.31 NS	-0.35 NS	-7.42 **	-7.42 **
P4XP5	1.78 NS	-0.72 NS	40.77 **	0.89 NS	1.78 NS	1.78 NS	-0.97 NS	-11.72 **	3.23 NS
P4XP6	1.01 NS	-4.23 **	51.19 **	-0.15 NS	1.01 NS	1.01 NS	1.30 NS	-6.28 **	28.87 **
P4XP7	2.40 *	-12.86 **	23.56 **	-2.09 NS	2.40 *	2.40 *	1.12 NS	-3.04 *	23.55 **
P4XP8	1.02 NS	-15.18 **	20.27 **	2.26 NS	1.02 NS	1.02 NS	0.45 NS	-6.83 **	8.95 **
P5XP6	2.12 NS	-7.39 **	46.21 **	1.16 NS	2.12 NS	2.12 NS	0.99 NS	-15.89 **	15.65 **
P5XP7	1.96 NS	-9.87 **	18.91 **	1.44 NS	1.96 NS	1.96 NS	-0.18 NS	-14.24 **	9.27 **
P5XP8	1.85 NS	-11.16 **	17.21 **	2.94 *	1.85 NS	1.85 NS	-0.46 NS	-4.68 **	-4.68 **
P6XP7	0.56 NS	-18.58 **	28.54 **	-0.47 NS	0.56 NS	0.56 NS	2.59 *	-1.17 NS	35.89 **
P6XP8	0.13 NS	-19.23 **	27.52 **	1.53 NS	0.13 NS	0.13 NS	1.26 NS	-12.55 **	20.24 **
P7XP8	0.13 NS	-1.77 NS	0.68 NS	1.45 NS	0.13 NS	0.13 NS	0.28 NS	-10.51 **	14.03 **

Cross	**SPS**			**TSPP**			**SMR**		
	mid.het	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**	**mid.het**	**bet.bet**	**std.het**
P1XP2	3.49 *	2.34 NS	6.26 **	0.23 NS	-5.39 **	-5.01 **	-0.98 NS	-6.57 **	-24.25 **
P1XP3	3.01 *	-4.84 **	13.97 **	-0.90 NS	-4.47 **	-8.24 **	0.23 NS	-1.35 NS	-17.42 **
P1XP4	0.79 NS	-3.76 *	7.40 **	0.86 NS	-17.28 **	15.13 **	0.09 NS	-1.39 NS	-20.05 **
P1XP5	1.59 NS	-9.25 **	17.11 **	0.99 NS	-3.81 **	-5.25 **	0.29 NS	-4.17 **	-22.30 **
P1XP6	0.91 NS	-15.36 **	26.82 **	-0.35 NS	-4.88 **	-15.22 **	-0.43 NS	-3.15 *	-21.47 **
P1XP7	2.07 NS	-2.36 NS	8.54 **	1.85 NS	0.78 NS	-8.24 **	1.39 NS	-4.72 **	-12.16 **
P1XP8	1.77 NS	1.01 NS	2.54 NS	-0.03 NS	-5.46 **	-5.46 **	0.41 NS	-9.08 **	-9.08 **
P2XP3	0.92 NS	-5.80 **	12.82 **	-0.32 NS	-2.48 NS	-2.09 NS	0.14 NS	-6.91 **	-22.07 **
P2XP4	-0.03	-3.51 *	7.68 **	1.08 NS	-13.00	21.08 **	-0.40	-4.68 **	-25.00

	NS				**		NS		**
P2XP5	-0.90 NS	-10.58 **	15.40 **	0.99 NS	0.04 NS	0.44 NS	0.00 NS	-1.32 NS	-27.10 **
P2XP6	-0.46 NS	-15.75 **	26.25 **	-0.24 NS	-9.87 **	-9.51 **	-0.45 NS	-3.53 *	-26.05 **
P2XP7	-1.16 NS	-4.42 **	6.26 **	0.52 NS	-4.16 **	-3.78 **	0.00 NS	-10.99 **	-17.94 **
P2XP8	0.06 NS	-1.79 NS	1.97 NS	-0.29 NS	-0.49 NS	-0.10 NS	-0.96 NS	-14.86 **	-14.86 **
P3XP4	0.00 NS	-3.41 *	15.68 **	0.21 NS	-15.32 **	17.86 **	0.05 NS	-2.96 NS	-18.77 **
P3XP5	0.33 NS	-3.28 *	24.82 **	2.12 NS	0.85 NS	-0.67 NS	1.19 NS	-4.75 **	-20.27 **
P3XP6	-0.63 NS	-10.60 **	33.96 **	-0.11 NS	-7.92 **	-11.56 **	0.09 NS	-4.13 **	-19.74 **
P3XP7	-0.56 NS	-4.13 **	14.82 **	0.71 NS	-1.90 NS	-5.78 **	0.64 NS	-3.99 **	-11.49 **
P3XP8	2.68 *	-5.80 **	12.82 **	-0.31 NS	-2.28 NS	-2.28 NS	0.53 NS	-7.66 **	-7.66 **
P4XP5	-1.48 NS	-8.15 **	18.54 **	1.78 NS	-13.09 **	20.96 **	2.07 NS	-1.05 NS	-22.15 **
P4XP6	-1.02 NS	-13.65 **	29.39 **	1.01 NS	-20.10 **	11.21 **	0.53 NS	-0.76 NS	-21.92 **
P4XP7	-0.76 NS	-0.95 NS	10.54 **	2.40 *	-15.30 **	17.88 **	0.88 NS	-6.51 **	-13.81 **
P4XP8	-0.11 NS	-5.30 **	5.68 **	1.02 NS	-13.20 **	20.81 **	-0.59 NS	-11.19 **	-11.19 **
P5XP6	-1.47 NS	-8.31 **	37.39 **	2.12 NS	-6.94 **	-8.33 **	0.95 NS	-0.88 NS	-24.02 **
P5XP7	0.59 NS	-6.37 **	20.82 **	1.96 NS	-1.90 NS	-3.37 *	1.36 NS	-8.71 **	-15.84 **
P5XP8	-0.49 NS	-11.69 **	13.97 **	1.85 NS	1.08 NS	1.08 NS	1.81 NS	-11.49 **	-11.49 **
P6XP7	-0.42 NS	-13.27 **	29.96 **	0.56 NS	-4.98 **	-13.49 **	0.22 NS	-8.22 **	-15.39 **
P6XP8	0.15 NS	-16.51 **	25.11 **	0.13 NS	-9.37 **	-9.37 **	0.04 NS	-11.64 **	-11.64 **
P7XP8	0.37 NS	-4.68 **	5.97 **	0.13 NS	-4.35 **	-4.35 **	0.55 NS	-3.38 **	-3.38 **

Table 2: Estimation of heterosis

Cross	**SY**		
	mid.het	**bet.bet**	**std.het**
P1XP2	-0.70 NS	-9.16 **	-17.49 **
P1XP3	-1.04 NS	-6.92 **	-29.87 **
P1XP4	-0.16 NS	-13.85 **	-35.09 **
P1XP5	-0.42 NS	-7.03 **	-19.23 **
P1XP6	0.14 NS	-3.36 *	-27.19 **
P1XP7	0.03 NS	-0.35 NS	-24.34 **
P1XP8	1.50 NS	-11.01 **	-11.01 **
P2XP3	-0.74 NS	-14.10 **	-21.97 **
P2XP4	-1.01 NS	-20.71 **	-27.98 **
P2XP5	-0.86 NS	-3.02 *	-11.91 **
P2XP6	0.79 NS	-10.73 **	-18.91 **
P2XP7	-1.99 NS	-10.03 **	-18.28 **
P2XP8	-0.50 NS	-5.06 **	-5.06 **
P3XP4	1.22 NS	-7.70 **	-38.72 **
P3XP5	-0.24 NS	-12.01 **	-23.55 **
P3XP6	-0.54 NS	-3.16 NS	-32.14 **

P3XP7	-0.78 NS	-7.01 **	-29.40 **
P3XP8	0.63 NS	-16.28 **	-16.28 **
P4XP5	-1.38 NS	-19.65 **	-30.19 **
P4XP6	-0.17 NS	-11.13 **	-37.72 **
P4XP7	-0.69 NS	-14.57 **	-35.14 **
P4XP8	0.95 NS	-21.92 **	-21.92 **
P5XP6	-0.57 NS	-10.19 **	-21.97 **
P5XP7	-1.23 NS	-7.46 **	-19.60 **
P5XP8	0.20 NS	-6.38 **	-6.38 **
P6XP7	-0.11 NS	-3.96 **	-27.08 **
P6XP8	0.87 NS	-14.23 **	-14.23 **
P7XP8	0.75 NS	-11.38 **	-11.38 **

DF- Days to 50% flowering, DM- Days to maturity, TSW- 1000 seeds weight (g), BY- Biological yield plant^{-1} (g), HI- Harvest index (%),OC- Oil content (%),PB- Primary branches/plant, PH-Plant height (cm), SB-Secondary branches/plant, SPS- Seeds/ silique, TSPP- Total number of silique per plant, SMR- Siliquae on main raceme, SY- Seed yield/plant(g)

4. CONCLUSION

Overall, the analysis of heterosis in these diallel crosses indicates varying levels of heterosis across different traits, with several crosses demonstrating highly significant heterosis, which could be advantageous for breeding programs aiming to improve these traits.Considerable amount of heterobeltiosis and standard heterosis were observed for plant growth parameters, yield, and oil content related traits studied, however the degree of heterosis varied from cross to cross.

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