International Journal of Bio-resource and Stress Management https://ojs.pphouse.org/index.php/IJBSM

Crossref

IJBSM March 2026, 17(3): 01-07

Article AR6820

Research Article

Natural Resource Management

DOI: HTTPS://DOI.ORG/10.23910/1.2026.6820

Heterosis and Inbreeding Depression for Seed Yield and its Contributing Characters in Indian Mustard [*Brassica juncea* (L.) Czern & Coss.]

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ABSTRACT

The experiment was conducted in compact family block design with three replications during *rabi* (October, 2022–March, 2023) 2022–23 at Centre for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India to study heterosis and inbreeding depression for seed yield and its contributing characters in Indian mustard [*Brassica juncea* (L.) Czern & Coss.]. The expression of heterosis and heterobeltiosis was maximum for seed yield plant^{-1} followed by number of siliquae plant^{-1}, number of secondary branches plant^{-1} and 1000 seed weight. For seed yield plant^{-1}, cross III (GDM 4×PM 30), cross IV (GM 6×PDZM 31) and cross VI (RB 50×NUDHYJ 4) depicted significant and positive relative heterosis and heterobeltiosis. The cross III also showed significant and desirable estimates of relative heterosis and/or heterobeltiosis for days to flowering, days to maturity, number of primary and secondary branches plant^{-1}, number of siliquae on main branch, number of siliquae plant^{-1} and 1000 seed weight, while cross IV exhibited significant and desirable relative heterosis and/or heterobeltiosis for days to flowering, days to maturity, number of secondary branches plant^{-1}, number of siliquae plant^{-1}, length of siliqua and oil content. The magnitude of inbreeding depression was found positive and significant for days to maturity, plant height and erucic acid in cross VI. While significant negative inbreeding depression was observed for 1000 seed weight (cross V); oil content (cross VI); oleic acid (cross II and V) and linoleic acid (cross VI), hence these crosses would likely to yield transgressive segregants for the characters under consideration.

KEYWORDS: Heterosis, inbreeding depression, seed yield, Indian mustard

Citation* (VANCOUVER)*: Patel et al., Heterosis and Inbreeding Depression for Seed Yield and its Contributing Characters in Indian Mustard [*Brassica juncea* (L.) Czern & Coss.]. *International Journal of Bio-resource and Stress Management,* 2026; 17(3), 01-07. HTTPS://DOI.ORG/10.23910/1.2026.6820.

Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

Conflict of interests: The authors have declared that no conflict of interest exists.

RECEIVED on 14th November 2025 RECEIVED in revised form on 16th February 2026 ACCEPTED in final form on 29th February 2026 PUBLISHED on 06th March 2026

1. INTRODUCTION

Brassica crops are highly diverse and second most important source of edible oil in India. The genus *Brassica*, belongs to *Brassicaceae* family and includes six cultivated species. Among which Indian mustard is a natural amphidiploid (2n=36) of *Brassica nigra* (2n=16) and *Brassica campestris* (2n=20). It originated in Asia with its major center of diversity in China (Vaughan, 1977). It is popularly known as *rai*, *raya* or *laha* in India. Mustard contributes more than 13% to the global production of edible oil. It was introduced in India from China and from where it spread to Afghanistan and other countries. It is largely self-pollinated crop. However, owing to insects, especially the honeybees, the extent of cross-pollination varies from 4.0 to 16.6% (Rambhajan et al., 1991). Its seed is a key ingredient of traditional mustards, including Brown and Indian mustard, which are noted for their unique flavor profiles and culinary versatility (Szollosi, 2020; Gain et al., 2024). In addition to its use as edible oil, mustard oil has a spectrum of industrial utilities such as paint and printing ink additives, greases and lubricants, resins and polymers, plastics, cosmetics and also in the pharmaceutical industries (Gupta, 2016). Indian mustard is predominantly cultivated and accounts more than 70% of the area under the rapeseed-mustard crops. The major rapeseed-mustard producing countries are Canada, China, Germany and France. With global production of over 27 mmt in recent years, *B. juncea* plays a significant role in not only meeting domestic oil demands but also supporting agricultural economics (Rai et al., 2022). In India, rapeseed-mustard was cultivated in an area of 9.18 mha with the production of 13.25 mt and productivity of 1444 kg ha^{-1} (Anonymous, 2023). Rajasthan is the largest producer of rapeseed-mustard followed by Uttar Pradesh, Haryana, Madhya Pradesh, West Bengal, Gujarat and Assam. In Gujarat, area, production and productivity of mustard during 2023–24 was 2.77 lakh ha, 5.25 lakh t and 1896 kg ha^{-1}, respectively (Anonymous, 2023). In Gujarat, it is mostly grown in the districts of Banaskantha, Mehsana, Patan, Sabarkantha, Aravalli, Kheda, Ahmedabad, Kutch and Gandhinagar after harvest of short duration *kharif* cereals and/or pulses. Exploitation of hybrid vigour for increasing the yield of agricultural crops has become one of the most important techniques in plant breeding. Generally, heterosis results from the interplay of additive, dominance, and epistatic genetic effects that enhance heterozygosity and hybrid vigor in relation to many yield-attributing and stress-related traits (Sang et al., 2022; Liu et al., 2024). The magnitude of heterosis helps in the identification of potential combinations of the crosses to be used in conventional breeding programme for the generation of a wide array of variability in segregating generations. Subsequently many studies have reported the extent of heterosis for seed yield. Significant level of heterosis was reported in *B. juncea* (13 to 91%) by Yadava et al. (2012), Meena et al. (2015) and Patel et al. (2021). Understanding of inbreeding depression in *B. juncea* is crucial for developing high-yielding and stress-resilient cultivars by enhancing breeding efficiency, enabling early-generation selection and preserving superior genotypes (Akanksha et al., 2021). For genetic improvement, selection of superior parents is one of the important steps for development of better hybrids. Higher yield of hybrid is results due to the presence of hybrid vigour (heterosis) for yield and yield components. On the other hand, inbreeding depression reflects through reduction or loss in vigour and fertility ultimately decreases the seed yield. Consequently proportion of inbreeding depression becomes helpful to plant breeders. With this fact, the present experiment was conducted using generation mean analysis including six generations of five crosses in order to identify the most promising heterotic cross combinations.

2. MATERIALS AND METHODS

The experiment was conducted in compact family block design with three replications during *rabi* (October 2022 to March, 2023) 2022–23 at Centre for Oilseeds Research, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar. The material consist of six crosses viz., SKM 1746×SKM 1620 (cross I), ANDM 14-9×GM 3 (cross II), GDM 4×PM 30 (cross III), GM 6×PDZM 31 (cross IV), DRMR 150-35×LES 44 (cross V) and RB 50×NUDHYJ 4 (cross VI) involving twelve diverse parents of mustard. The entire experimental material comprised of parents (P_1 and P_2), F_1, F_2, B_1 (F_1×P_1) and B_2 (F_1×P_2) generations of all twelve crosses. Each replication was divided into six compact blocks each consists of single cross and blocks were consisted of six plots comprised of six basic generations of each cross. The plots of various generations contained different number of rows i.e., parents and F_1 in single row; B_1 and B_2 in two rows and F_2 in four rows. Total 50 plants were accommodated in each row. The inter and intra row spacing was 45 cm and 10 cm, respectively. All the recommended agronomical practices and necessary plant protection measures were followed timely to raise a good crop. Observations were recorded on individual plant basis in each replication on randomly selected five plants from P_1, P_2 and F_1; ten plants from backcross (B_1 and B_2) and twenty plants from F_2 generations for seventeen traits. The heterotic effects in term of superiority of F_1 over better parent (heterobeltiosis) was worked out as per Fonseca and Patterson (1968); over mid parent value (relative heterosis) as per Turner (1953) and inbreeding depression as loss in vigour due to inbreeding.

3. RESULTS AND DISCUSSION

For a successful heterosis breeding programme in any crop, there were two important pre-requisites (1) there must be an ample evidence of the presence of significant heterotic effect in the hybrids that could really be of practical utility and (2) the production of hybrid seed at commercial scale must be economically feasible (Singh and Narayanan, 2009). Inbreeding depression refered to decrease in fitness and vigour due to continuous selfing. It decreased heterozygosity and caused fixation of unfavourable/ lethal recessive alleles in F_2, while in case of heterosis, undesirable recessive genes of one parent werem asked by favourable dominant alleles of other parent. The estimates of heterosis expressed as percentage over mid parent (RH) and heterobeltiosis expressed as percentage over better parent (HB) in F_1 hybrids and inbreeding depression in F_2 population for various characters calculated in six crosses of Indian mustard were presented in Table 1. While graphical

Table 1: Relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) for various characters in six crosses of Indian mustard

Characters	I. SKM 1746×SKM 1620			II. ANDM 14-9×GM 3			III. GDM 4×PM 30		
	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)
Days to flowering	-5.60** (0.37)	1.34 (0.36)	-5.93** (0.43)	-4.68** (0.44)	6.34** (0.50)	-4.09** (0.44)	-4.09** (0.39)	1.06 (0.42)	-2.09 (0.48)
Days to maturity	-0.33 (0.78)	4.12** (0.95)	-1.38 (0.82)	-0.42 (0.65)	5.60** (0.81)	-1.52* (0.70)	-3.92** (0.41)	-2.74** (0.48)	-2.80** (0.47)
Plant height (cm)	-4.00 (3.70)	7.29 (5.22)	-7.61** (3.43)	-1.22 (4.73)	9.41* (5.75)	-1.41 (4.47)	-0.44 (4.64)	3.86 (4.70)	0.92 (5.09)
No. of primary branches plant^{-1}	5.73 (0.26)	1.22 (0.32)	14.16** (0.25)	4.05 (0.24)	2.67 (0.24)	2.60 (0.21)	12.66* (0.29)	1.14 (0.34)	6.18 (0.30)
No. of secondary branches plant^{-1}	9.95 (0.65)	9.34 (0.71)	18.47** (0.73)	10.73 (0.85)	4.81 (1.13)	11.22 (0.76)	24.59** (0.79)	9.62 (1.13)	16.78** (0.72)
Length of main branch (cm)	10.86** (2.90)	5.67 (3.20)	-2.35 (2.82)	3.67 (2.11)	1.14 (2.18)	1.83 (2.12)	3.69 (2.42)	-2.83 (2.66)	2.26 (2.60)
No. of siliquae on main branch	7.86* (1.56)	6.98 (1.45)	3.19 (1.50)	5.02 (1.51)	4.01 (1.72)	7.45 (1.53)	9.99* (2.08)	3.29 (2.63)	4.91 (1.99)
No. of siliquae plant^{-1}	4.82 (12.51)	2.10 (15.32)	12.07* (17.07)	5.56 (19.06)	2.40 (22.43)	5.38 (17.52)	32.67** (29.37)	23.09* (35.83)	16.72* (28.08)
Length of siliqua (cm)	4.47* (0.08)	2.67 (0.11)	6.46** (0.09)	1.82 (0.11)	-3.02 (0.15)	-0.43 (0.09)	1.73 (0.13)	-3.85 (0.15)	2.22 (0.14)
No. of seeds siliqua^{-1}	9.22* (0.52)	7.14 (0.61)	9.67** (0.52)	-2.19 (0.54)	-7.37 (0.55)	0.87 (0.55)	5.91 (0.53)	2.75 (0.65)	0.78 (0.52)
Seed yield plant^{-1} (g)	13.57 (1.76)	11.06 (2.04)	18.70** (1.99)	9.09 (1.87)	3.06 (2.30)	8.22 (1.80)	34.08** (2.29)	28.95** (2.73)	26.62** (2.24)
1000-seed weight (g)	-3.24 (0.19)	-5.48 (0.21)	-0.80 (0.19)	4.31 (0.18)	-11.56** (0.22)	0.87 (0.18)	13.09** (0.14)	12.15** (0.17)	8.61** (0.14)
Oil content (%)	3.19** (0.29)	0.91 (0.34)	4.28** (0.29)	1.92* (0.33)	1.27 (0.41)	1.07 (0.30)	0.03 (0.30)	-1.31 (0.34)	-0.22 (0.32)
Oleic acid (%)	9.72** (0.29)	1.94 (0.35)	2.49 (0.30)	3.18 (0.20)	-1.78 (0.30)	-4.44** (0.17)	-8.41** (0.32)	-39.83** (0.48)	3.53** (0.23)
Linoleic acid (%)	6.96* (0.44)	4.27 (0.47)	-3.71 (0.44)	7.55** (0.32)	3.81 (0.42)	6.74** (0.31)	-9.88** (0.25)	-34.10** (0.32)	5.23 (0.24)
Linolenic acid (%)	0.72 (0.20)	2.39 (0.27)	2.27 (0.18)	9.77** (0.16)	6.56** (0.20)	8.99** (0.16)	6.96** (0.14)	5.00** (0.14)	6.23** (0.14)
Erucic acid (%)	-5.34* (0.97)	-3.09 (0.94)	0.61 (0.98)	-5.96** (0.56)	-2.73 (0.81)	-3.17** (0.53)	16.20** (0.28)	1528.76** (0.23)	-10.12** (0.29)

Table 1: Continue...

Characters	IV. GM 6×PDZM 31			V. DRMR 150-35×LES 44			VI. RB 50×NUDHYJ 4		
	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)	RH (%)	HB (%)	ID (%)
Days to flowering	-6.47** (0.49)	-2.66 (0.66)	-14.47** (0.51)	-13.56** (0.50)	-2.52 (0.55)	-9.78** (0.60)	-6.98** (0.46)	2.56 (0.50)	0.31 (0.55)
Days to maturity	-1.76** (0.51)	-0.60 (0.48)	-4.30** (0.48)	-3.61** (0.61)	-1.35* (0.74)	-3.69** (0.62)	-0.23 (0.53)	2.25** (0.71)	1.06* (0.56)
Plant height (cm)	2.51 (4.17)	5.10 (4.44)	-3.57 (4.27)	-3.77 (3.44)	6.94** (3.90)	-0.21 (2.67)	1.11 (3.69)	8.18* (5.23)	6.54** (3.34)
No. of primary branches plant^{-1}	4.82 (0.27)	2.35 (0.27)	8.62 (0.25)	7.88 (0.23)	5.95 (0.28)	15.73** (0.20)	13.33** (0.21)	8.97 (0.24)	13.53** (0.22)
No. of secondary branches plant^{-1}	28.31** (0.84)	24.12** (0.93)	25.10** (0.86)	17.62** (0.73)	14.21 (0.89)	19.59** (0.73)	27.53** (0.74)	22.04** (0.82)	20.37** (0.75)
Length of main branch (cm)	0.42 (2.32)	-3.37 (3.21)	2.44 (2.02)	-0.61 (2.85)	-9.76* (3.42)	-5.23 (2.67)	6.50* (2.42)	4.95 (3.02)	7.20** (2.49)
No. of siliquae on main branch	4.10 (1.80)	2.84 (2.13)	9.32* (1.81)	7.28 (1.51)	-0.29 (1.84)	-2.95 (1.45)	5.61 (1.49)	4.62 (1.46)	-2.55 (1.52)
No. of siliquae plant^{-1}	24.06** (23.29)	14.05 (26.52)	19.64** (24.42)	18.64* (21.14)	16.52 (25.14)	15.78* (21.82)	37.60** (19.09)	33.19** (19.85)	21.62** (21.82)
Length of siliqua (cm)	5.30** (0.08)	1.20 (0.09)	6.78** (0.09)	12.85** (0.09)	12.00** (0.10)	10.05** (0.10)	6.57** (0.09)	2.66 (0.09)	-2.78 (0.08)
Number of seeds siliqua^{-1}	3.06 (0.47)	0.92 (0.64)	-0.46 (0.41)	16.35** (0.52)	13.61** (0.59)	8.18* (0.50)	5.86 (0.58)	3.20 (0.68)	0.22 (0.57)
Seed yield plant^{-1} (g)	37.98** (1.96)	26.71** (2.18)	26.87** (2.08)	12.94* (1.46)	8.11 (1.66)	18.59** (1.47)	37.44** (2.22)	25.94* (2.73)	23.30** (2.32)
1000-seed weight (g)	-6.91* (0.13)	-17.22** (0.15)	-0.51 (0.14)	-12.94** (0.12)	-17.20** (0.16)	-5.11* (0.11)	0.99 (0.14)	-18.44** (0.16)	13.09** (0.14)
Oil content (%)	4.81** (0.32)	4.37** (0.37)	5.38** (0.33)	0.97 (0.32)	-0.59 (0.42)	0.36 (0.30)	-1.09 (0.29)	-2.66** (0.37)	-1.70* (0.29)
Oleic acid (%)	-8.53** (0.25)	-41.39** (0.31)	5.31** (0.25)	-11.04** (0.26)	-40.72** (0.22)	-3.16** (0.20)	-10.74** (0.18)	-39.73** (0.19)	-1.35 (0.17)
Linoleic acid (%)	-8.79** (0.21)	-33.68** (0.27)	1.18 (0.23)	-9.22** (0.19)	-32.21** (0.18)	-0.74 (0.20)	-10.76** (0.21)	-32.32** (0.28)	-3.38** (0.20)
Linolenic acid (%)	4.64** (0.15)	-8.46** (0.19)	3.38** (0.14)	7.80** (0.17)	3.67* (0.20)	6.08** (0.18)	8.53** (0.16)	2.81 (0.18)	-4.38** (0.17)
Erucic acid (%)	15.05** (0.27)	1873.73** (0.23)	-6.99** (0.27)	18.58** (0.23)	1392.93** (0.16)	0.67 (0.22)	16.51** (0.19)	293.91** (0.15)	4.65** (0.15)

Note :*p<0.05, **p<0.01 and figures in parentheses represent SEm values

representation of relative heterosis, heterobeltiosis and inbreeding depression for days to maturity, seed yield plant^{-1} and 1000 seed weight and oil content, oleic acid and erucic acid were presented in Figure 1 and Figure 2, respectively. The degree of heterosis varied from cross-to-cross for all the seventeen characters studied. For the characters like days to flowering, days to maturity, plant height and erucic acid, the low scoring parent was considered as better parent. Hence, negative heterosis was useful for these traits.

Significant relative heterosis in desired direction was observed for days to flowering in all the six crosses; length of main branch, number of siliquae on main branch, length of siliqua, number of seeds siliqua^{-1}, oil content, oleic acid, linoleic acid and erucic acid in cross I; oil content, linoleic acid and erucic acid in cross II; days to maturity, number of primary branches plant^{-1}, number of secondary branches plant^{-1}, number of siliquae on main branch, number of siliquae plant^{-1}, seed yield plant^{-1} and 1000 seed weight in cross III; days to maturity, number of secondary branches plant^{-1}, number of siliquae plant^{-1}, length of siliqua, seed yield plant^{-1} and oil content in cross IV; days to maturity, number of secondary branches plant^{-1}, number of siliquae

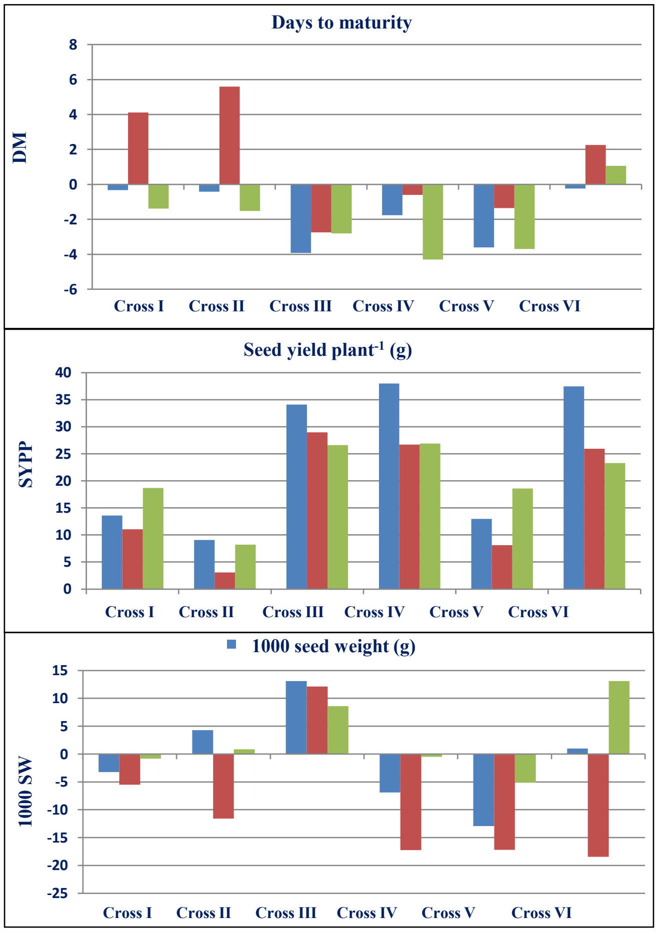

Figure 1: Relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) in six crosses for days to maturity, seed yield plant^{-1} (g) and 1000 seed weight (g) in Indian mustard

plant^{-1}, length of siliqua, number of seeds siliqua^{-1} and seed yield plant^{-1} in cross V and number of primary branches plant^{-1}, number of secondary branches plant^{-1}, length of main branch, number of siliquae plant^{-1}, length of siliqua and seed yield plant^{-1} in cross VI.

Niranjana et al. (2014) had also reported significant negative relative heterosis for days to flowering and days to maturityas observed in the present study. Several research workers has been reported relative heterosis in desire direction for various characters in Indian mustard like number of primary and secondary branches plant^{-1} (Choudhary et al., 2020; Devi and Dutta, 2020 and Mandal and Kar, 2023), length of main branch and number of siliquae on main branch (Choudhary et al., 2020), number of siliquae plant^{-1} and length of siliqua (Devi and Dutta, 2020, Abhinaya et al., 2021 and Kumar et al., 2021), number of seeds siliqua^{-1} (Devi and Dutta, 2020 and Kumar et al., 2021), seed yield plant^{-1} (Patel et al., 2019, Choudhary et al., 2020, Devi and Dutta, 2020, Abhinaya et al., 2021, Kumar et al., 2021 and Mandal and Kar, 2023), 1000 seed weight and oil content (Choudhary et al., 2020 and Abdelsatar et al., 2021) and oleic acid and linoleic acid (Chaudhary et al., 2018).

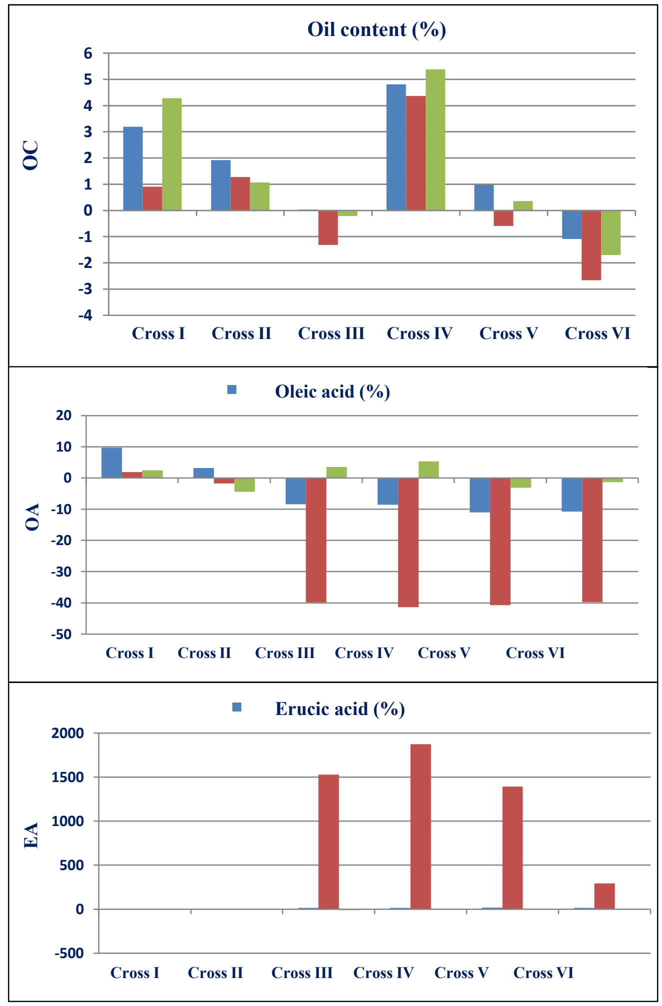

Figure 2: Relative heterosis (RH%), heterobeltiosis (HB%) and inbreeding depression (ID%) in six crosses for oil content (%), oleic acid (%) and erucic acid (%) in Indian mustard

Significant heterobeltiosis in desired direction was found for days to maturity, number of siliquae plant^{-1}, seed yield plant^{-1} and 1000 seed weight in cross III; number of secondary branches plant^{-1}, seed yield plant^{-1}, oil content and linolenic acid in cross IV; days to maturity, length of siliqua and number of seeds siliqua^{-1} in cross V and number of secondary branches plant^{-1}, number of siliquae plant^{-1} and seed yield plant^{-1} in cross VI.

Chaudhary et al. (2018) and Kumar et al. (2021) have also showed significant negative heterobeltiosis for days to maturity as observed in the present investigation. Several researchers had reported significant positive estimates of heterobeltiosis in Indian mustard for various traits i.e., number of secondary branches plant^{-1} (Choudhary et al., 2020, Devi and Dutta, 2020 and Mandal and Kar, 2023), number of siliquae plant^{-1}, length of siliqua and number of seeds siliqua^{-1} (Devi and Dutta, 2020 and Kumar et al., 2021), seed yield plant^{-1} (Patel et al., 2019, Choudhary et al., 2020, Devi and Dutta 2020, Abhinaya et al., 2021 and Mandal and Kar, 2023), 1000 seed weight and oil content (Choudhary et al., 2020 and Abdelsatar et al., 2021).

The crosses exhibited significant negative inbreeding depression for days to flowering (cross I, II, III and IV), days to maturity (cross II, III, IV and V), plant height (cross I), 1000 seed weight (cross V), oil content (cross VI), oleic acid (cross II and V), linoleic acid (cross VI), linolenic acid (cross VI) and erucic acid (cross II, III and IV). Whereas, some of the characters of six crosses showed significant positive inbreeding depression viz., days to maturity (cross VI), plant height (cross VI), number of primary branches plant^{-1} (cross I, V and VI), number of secondary branches plant^{-1} (cross I, III, IV, V and VI), length of main branch (cross VI), number of siliquae on main branch (cross IV), number of siliquae plant^{-1} (cross I, III, IV, V and VI), length of siliqua (cross I, IV and V), number of seeds siliqua^{-1} (cross I and V), seed yield plant^{-1} (cross I, III, IV, V and VI), 1000 seed weight (cross III and VI), oil content (cross I and IV), oleic acid (cross III and IV), linoleic acid (cross II), linolenic acid (cross II, III, IV and V) and erucic acid (cross VI).

The magnitude of inbreeding depression was found positive and significant for days to maturity, plant height and erucic acid in cross VI. Therefore, there would be possibility to get desired segregants for the characters under consideration. While significant negative inbreeding depression was observed for 1000 seed weight (cross V); oil content (cross VI); oleic acid (cross II and V) and linoleic acid (cross VI), hence these crosses would likely to yield transgressive segregants for the characters under consideration.

The main cause of heterosis as of inbreeding depression was the dominance effect and heterosis was absent when traits were influenced only by additive gene action (Pirchner, 1969). If several loci were involved, the unidirectional dominance is required for realizing heterosis, otherwise heterosis might be absent even when the loci show dominance (Falconer, 1977).

The significant positive inbreeding depression was also reported by Ranjeet and Shweta (2007) for days to maturity and plant height. While significant negative inbreeding depression was observed by Abhinaya et al. (2021) for oil content which supported the results obtained in the present study.

4. CONCLUSION

Significant heterosis and/or heterobeltiosis in desired direction was observed for seed yield, number of secondary branches plant^{-1}, number of siliquae plant^{-1}, length of siliqua, 1000 seed weight and oil content suggested the possibility of utilizing hybrid vigour on commercial scale. The parental genotypes GDM 4, PM 30, GM 6, PDZM 31, RB 50 and NUDHYJ 4 due to their presence in high heterotic combinations viz., GDM 4×PM 30, GM 6×PDZM 31 and RB 50×NUDHYJ 4 need to be further exploited in future mustard breeding programme for developing high yielding genotypes.

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