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Assessment of shift in interrelationships, path coefficient analysis and selection indices for the seed yield and its contributing characters in F_2, F_3 and biparental population in mustard

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ABSTRACT

The present study was carried out to assess shift in interrelationship, path coefficient and to formulate selection indices in mustard consist of F_2, F_3 and BIP generations in three crosses (ACN-9 X PC-6, Kranti X PC-6, TAM-108 X PC-6) during rabi 2023-24 and 2024-25 in randomized block design with two replications. Key yield contributing traits were observed including days to first flower, days to maturity, plant height, number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1}. The results on comparative analysis of the mean value indicated that the BIP population consistently outperformed than F_2 and F_3 population for seed yield and it's contributing characters. This indicated that biparental mating may help in releasing more variability than selfing. Medium to high GCV and PCV, high heritability coupled with high genetic advance was observed for number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1} in F_2, F_3 and BIP generations. The correlation study revealed that positive significant association of seed yield plant^{-1} with number of siliquae plant^{-1} and siliquae density on main branch in all the generations. However, intermating in early segregating generations cause shifts in the genetic correlations were observed in few yield contributing traits in BIP generation. Path coefficient analysis indicated that seed yield plant^{-1} was highly influenced directly by number of siliquae plant^{-1}, siliquae density on main branch, days to maturity and days to first flower in all the crosses and their contribution was more in all the crosses except F_3 of C-III cross. Discriminant function analysis exhibited 80.16% to 98.77% increase in relative efficiency over direct selection for seed yield plant^{-1} was observed for direct selection of number of siliquae plant^{-1} in different generations of all the three crosses. This indicates, selection for number of siliquae plant^{-1} in early generation will be more efficient for seed yield plant^{-1} except F_2 of C-II cross in which siliquae density on main branch is more efficient.

Keywords: *Mustard, GCV, PCV, heritability, genetic advance, Path coefficient and selection indices.*

I. Introduction

Indian mustard [*Brassica juncea* L. (Czern and Coss)] is an important oil seed crop belonging to *Brassica* group. Cytologically, *Brassica juncea* is an amphidiploid (2n=36) derived from interspecific cross of *Brassica nigra* (2n=16) and *Brassica campestris* (2n=20). Mustard is the premier oilseed *Brassica* which covers about 85-90% of the total area under cultivation of all these crops. Mustard seed contains about 38 to 43% oil which is yellow fragrant and is considered to be the healthiest and nutritious cooking medium. In India, during 2023-24, mustard production was 13.2 million tonnes and productivity was 1443 kg ha^{-1} (Anonymous, 2024-25).

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India is the third-largest producer of rapeseed-mustard, after Canada and China, contributing approximately 14% to the world's total production. However, it still lags behind in terms of both total production and productivity. There is need to develop new varieties with high yield potential, wider adaptability, disease resistance and high oil content. Availability of variability in the germplasm is the prerequisite for making any improvement. Segregating generation obtained by crossing distant parents is one of the popular sources of increasing variability out of many other sources. Thus, release of variability in segregating generation and its assessment is one of the important programmes. Intermating in early segregating generations of different potential hybrids can release additional variability, as biparental mating is expected to break larger linkage blocks and increase opportunities for recombination. Therefore, it is essential to capture this newly created variability in the segregating generations. Correlation analysis helps determine the strength and direction of associations between traits, while path analysis further breaks these associations into direct and indirect effects, revealing the mechanisms through which traits influence yield. This information is vital for selecting newly developed recombinants from biparental mating that possess desirable traits, thereby enhancing breeding strategies. However, a high genotypic coefficient of variability alone is not a sufficient criterion for selection. Crop improvement also depends on the heritability of traits. By analyzing the magnitude and significance of correlations, breeders can develop selection indices that incorporate multiple desirable traits, enabling simultaneous improvement in yield and related attributes. This multivariate approach improves selection efficiency, genetic gain, and the development of high-performing genotypes across diverse environments.

In this context, a research program was planned to assess the nature and extent of genetic variability in F_2, F_3, and biparental populations; to examine changes in trait interrelationships and path coefficients, if any; and to formulate selection indices for seed yield using discriminant function analysis.

II. Material and Methods

The research work conducted during the year *rabi* 2023-24 and *rabi* 2024-25 at Research field of AICRP on Linseed and Mustard, College of Agriculture, Nagpur. The experimental material consists of four mustard genotypes namely Kranti, ACN-9 and TAM 108-1 as female parents and PC-6 as male parent of the following crosses were grown for obtaining F_2, F_3, and BIP generations and self-seeds. Three crosses designated as C-I (ACN-9 x PC-6), C-II (Kranti x PC-6) and C-III (TAM-108-1 X PC-6) are used in this study. From each of the three crosses, a large F_2 population were raised and plants were selected at random to effect biparental mating during *rabi* 2023-24. The seeds from each of the BIP crosses were harvested separately and the next generation was raised by mixing equal number of seeds from each BIP crosses of C-I, C-II and C-III separately. Simultaneously, selfed seeds (F_3) from each of the F_2 plants involved in the development of BIP's were harvested separately and raised in the next generation. Similarly, F_1 crosses were grown to obtain the F_2 generation seed. The evaluation of F_2, F_3 and the progeny of BIP mating of three crosses was done by growing these generation during *rabi* 2024-25. The observation were recorded for days to first flower, days to maturity, plant height (cm), number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1}(g). The data were analysed by using INDOSTAT services for testing correlation and path analysis.

III. Results and Discussion

Frequency distribution for different traits among F_2, F_3 and BIP generation in C-I, C-II, C-III

Frequency distribution for days to maturity was shown in figure 1. In cross C-I (ACN- 9 X PC-6) the majority of the plants in F_2 and F_3 generation took more than 115 days to maturity while in case of BIP, change in maturity duration was observed *i. e.* 50% plants matured from 111 to 115 and remaining 50% plants were matured after 115 days. In cross C-II (Kranti X PC-6), most of the plants in F_2, F_3 and BIP were matured after 115 days. The most of F_2 plants in C-III (TAM-108-1 X PC-6) cross were matured between 106 to 115 days. However, in F_3 generation 80% plants took more than 115 days to maturity. While in BIP, all the plants matured between 111 to 115 days.

Frequency distribution for plant height was shown in fig. 2. The height of majority of plants in F_2 and F_3 population ranged from 150 to 170 cm in C-I cross whereas in BIP, change in plant height was reported and it ranged from 170 to 190 cm. In C-II cross the majority of plants in F_2 population ranged from 170 to 210 cm whereas F_3 and BIP generation of C-II cross ranged between 150 to 190 cm. While majority of F_2 and F_3 population, plant height was ranged between 150 to 190 cm in C-III cross. However, increased plant height from 170 to 210 cm was recorded in most of BIP as compared to plants of F_2 and F_3 population in C- III. Frequency distribution for number of branches plant^{-1} was observed in figure 3. In C-I, C-II and C-III crosses majority of plants of all generations, number of branches plant^{-1} was ranged between 3-4 class interval.

Number of siliquae plant^{-1} in majority of plants in F_2 population was ranged from 151 to 350 and F_3 and BIP generation of C-I cross were ranged between 201-350 (Fig 4). BIP generations of C-II cross (Kranti X PC-6), number of siliquae plant^{-1} in majority of plants was found to be increased (401 to more than 450) as compared to majority plants of F_2 and F_3 generations (201 to 300). The range of number of siliquae plant^{-1} was 351 to 450 in most of plants of F_2 in C-III cross whereas it was 301 to 400 in F_3 and 301 to 450 in BIP generation.

From the Figure 5, it is observed that the majority of plants in C-I, siliquae density on main branch ranged between 0.31 to 0.90 in F_2, 0.51 to 0.60 in F_3 and 0.31 to 0.60 in BIP. Whereas in C-II cross, range of siliquae density on main branch of the majority of plants was increased from 0.51 to 0.80 in BIP generation when compared with most of the plants of F_2 and F_3 population (0.31 to 0.60. Similarly, in C-III (TAM-108-1 X PC-6) cross, range of siliquae density on main branch of the majority of plants was between 0.31 to 0.70 in F_2, F_3 and BIP population.

Frequency distribution for seed yield plant^{-1} was observed in figure 6. In C-I cross, seed yield plant^{-1} of majority of the plants in F_2 and F_3 population ranged from 12.01g to 18.00g and BIP generations ranged between 15.01 to >21 g. In C-II cross, seed yield plant^{-1} of majority plants of F_2 population ranged from 12.01 to 21.00g and 12.01 to 18.00 g for F_3 generation while range of seed yield plant^{-1} of majority of plants in BIP generations were more than 21g. In C-III cross majority of the plants in F_2 population ranged from 12.01 to 18.00g. Whereas in F_3 and BIP generation, seed yield plant^{-1} of majority plants was ranged between 12.01 to more than 21g. It is indicated that seed yield plant^{-1} was increased in BIP generation of all crosses as compared to F_2 and F_3 population. The superior performance of biparental progenies compared to the F_2 and F_3 populations may be attributed to the higher level of heterozygosity in biparental progenies and the effects of inbreeding depression in the F_3 population (Gardner et al., 1953). The observed enhancement in seed yield per plant could be due to the pooling of favorable alleles or the reshuffling of alleles through recombination, made possible by biparental mating (Deep et al., 2025). The values for traits such as days to maturity, plant height, number of siliquae per plant, siliquae density, and seed yield per plant was higher in biparental populations (BIPs) than in the corresponding F_2 and F_3 populations. Additionally, individual plants with grain yield surpassing that of the parental varieties were identified in all three BIPs. This indicates the presence of transgressive segregants in the BIPs (Deep *et al.*, 2025; Dandade *et al.*, 2015). The broader range of values observed, compared to the corresponding F2 and F3 populations, suggests that biparental mating has been more effective in generating greater variability than selfing. This increase in variability, along with a shift in seed yield and its contributing traits in the desired direction, can be attributed to the breakdown of unfavorable linkages and the expression of rare recombinants.

These recombinants typically remain suppressed due to linkage disequilibrium (Meena *et al*., 2017).

The percentage changes in mean values of various traits in BIP over F_2 and F_3 generations across three crosses (C-I, C-II, and C-III) are presented in Figure 7. The analysis revealed that for days to maturity, BIP showed a percent change over F_2 of -4.69%, 6.74%, and 6.2%, and over F_3 of -6.30%, 0.50%, and -1.00%, respectively. For plant height, BIP recorded a percent increase of 7.47%, -7.19%, and 7.2% over F_2, and 8.76%, 2.49%, and 8.1% over F_3. Regarding the number of branches per plant, the mean values of BIP increased by 29.41%, 24.3%, and 23.24% over F_2, and by 22.22%, 26.06%, and 3% over F_3. For number of siliquae per plant, BIP showed increases of 3.99%, 69.36%, and 9.28% over F_2, while compared to F_3, the values changed by -7.60%, 38.17%, and -2.03%. In case of siliquae density on the main branch, BIP showed -23.43%, 18.5%, and 16.07% over F_2 and -26.86%, 1.5%, and 4.83% over F_3. For seed yield per plant, the percent gain in BIP over F_2 was 12.42%, 24.01%, and 12.24%, while over F_3 it was 12.77%, 31.42%, and 2.7%, respectively. These observations clearly indicate that the BIP populations demonstrated substantial improvements in most of the yield-contributing traits, affirming the effectiveness of biparental mating in enhancing genetic variability and improving trait performance in mustard. The mean values of biparental populations (BIPs) were higher than the corresponding mean values of parents, F_2 and F_3 generations for most of the characters were reported in mustard by Deep *et al*. 2025, Meena *et al*. 2017 and Dandade *et al.* 2015.

Genetic variability parameters

Creation of variability is the pre-requisite either for development of varieties or inbred lines. Variability parameters like genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), Heritability and genetic advance were estimated in F_2, F_3 and BIP in C-I (ACN-9 x PC-6), C-II (Kranti x PC-6) and C-III (TAM-108-1 X PC-6) are presented in Table 1. Low GCV and PCV, medium to high heritability coupled with low to medium genetic advance was recorded for the characters for days to first flower, days to maturity and plant height in F_2, F_3 and BIP generations of C-I, C-II and C-III. Whereas medium to high GCV and PCV, high heritability coupled with high genetic advance was observed for the characters for number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1} in F_2, F_3 and BIP generations of C-I, C-II and C-III. Medium to high GCV and PCV indicated the existence of substantial variability for seed yield and its contributing characters. It also indicated greater scope for selection to improve upon above mentioned characters. Low differences between GCV and PCV were observed for number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1} indicated the lower influence of environment and reflect on reliability of selection based on phenotypic performance. Similar results such as high GCV and PCV and low differences between GCV and PCV for seed yield and its contributing characters were also noted by Kumar *et al.* (2024), Sapkal *et al.* (2013) and Pawar *et al.* (2024) in mustard.

High heritability coupled with high genetic advance was observed for number of branches plant^{-1}, number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1} indicated that variation due to environment played a relatively limited role in influencing the inheritance of these characters. This suggested that selection would be effective in improving these traits.

High heritability coupled with high genetic advance has also been reported by Deep *et al*. (2025), Guguloth *et al.* (2024), Sowmya *et al.* (2024) and Gupta *et al.* (2025) in mustard and Kumar *et al.* (2024) in lentil.

Estimation of correlation coefficient

Seed yield plant^{-1} exhibited several notable correlations with other traits presented in Table 2.

In ACN-9 X PC-6 (C-I) the genotypic correlation between days to maturity, plant height, number of branches plant^{-1}, number of siliquae plant^{-1} and siliquae density on main branch with seed yield plant^{-1} was found positive and highly significant in F_2 generation. In F_3 generation, days to first flower, days to maturity, plant height and siliquae density on main branch had a positive significant genotypic correlation with seed yield plant^{-1}. In case of BIP, significant positive genotypic correlation of seed yield plant^{-1} was observed with number of siliquae plant^{-1}, siliquae density on main branch, days to first flower and days to maturity. Similar results were also reported for plant height, number of siliquae plant^{-1} and siliquae density on main by Gupta *et al.* (2025) and Kumar *et al.* (2024). Whereas in BIP plant height and number of branches plant^{-1} was negatively correlated with seed yield plant^{-1} which was positive in F_2 and F_3 generations. Indicated that in BIP population linkage was broke interrelationship among these characters. The superior performance of biparental progenies over $F_{2:3}$ could be the result of considerable heterozygosity in biparental progenies (Deep *et al.*2025). In Kranti X PC-6 (C-II) for F_2 generation, significant positive genotypic correlation was observed for seed yield plant^{-1} with plant height and siliquae density on main branch whereas days to maturity and number of siliquae plant^{-1} was positive but had a non-significant correlation with seed yield plant^{-1}. In case of F_3 generation siliquae density on main branch showed positive significant genotypic correlation with seed yield plant^{-1}. Whereas days to maturity, days to first flower and number of siliquae plant^{-1} was positive but had a nonsignificant correlation with seed yield plant^{-1}. In case of BIP, plant height, number of siliquae plant^{-1} and siliquae density on main branch was positive but had a non significant correlation with seed yield plant^{-1}. Similar results were also reported for seed yield and its contributing traits by Srivastava *et al.* (2024) and Chaudhary *et al.* (2023). However, days to maturity was exhibited negative significant correlation with seed yield plant^{-1} in BIP which was positive in F_2 and F_3 generations. Such change is desirable for developing variety with early maturity. This might be occurred due to recombination of gene indicated that linkage was break interrelationship among these characters.

In TAM-108-1 X PC-6 (C-III), significant positive genotypic correlation was observed between seed yield plant^{-1} with plant height, number of siliquae plant^{-1} and siliquae density on main branch, in F_2 generation. In case of F_3 generation, positive and significant correlation was observed for seed yield plant^{-1} with number of siliquae plant^{-1} and siliquae density on main branch. In BIP, positive significant genotypic correlation was observed for seed yield plant^{-1} with plant height and number of siliquae plant^{-1}. Similar results were found Patel *et al.* (2020), Patel *et al*. (2000), Badsra and Choudhary (2001), Mahla *et al*. (2003) and Kardam and Singh (2005) in mustard. However, days to maturity and siliquae density on main branch exhibited negative correlation with seed yield plant^{-1} in BIP which was positive in F_2 and F_3 generations. It is well established that, intermating in early segregating generations cause shifts in the genetic correlations in self-pollinated crops (Yunus and Paroda, 1982).

Hence, correlation co-efficient has been the most frequently used statistical tool to identify these changes due to biparental mating. Further, in a breeding programme, selection based on the knowledge and the direction of association between yield and its attributes is very useful in identifying key characters, which can be exploited to achieve maximum improvement in yield (Gowthami *et al*. 2014).

The correlation studies revealed positive significant association of seed yield plant^{-1} with siliquae density on main branch in all the generations and all the crosses studied. Number of siliquae plant^{-1} was also associated with seed yield plant^{-1}. Plant height and days to maturity were also associated with seed yield plant^{-1} in some cases. This indicates that an increase in any one of these four characters especially siliquae density on main branch and number of siliquae plant^{-1} can result in increase in the seed yield of mustard. Hence, it is stressed that more emphasis should be given for siliquae density on main branch and number of siliquae plant^{-1} as they showed very high degree of positive association with seed yield plant^{-1}.

Path co-efficient analysis

The results on the estimates of direct and indirect effect of different characters on seed yield plant^{-1} are presented table 3,4 and 5.

Path analysis studies carried out in F_2, F_3 and BIP of three crosses revealed that seed yield plant^{-1} was highly influenced directly by number of siliquae plant^{-1}, siliquae density on main branch, days to maturity and days to first flower in all the crosses and their contribution was more in all the crosses except F_3 of C-III cross. Plant height also directly influenced on seed yield plant^{-1} in case of F_2 and BIP of C-II and C-III cross. Similar to these results direct effect of number of siliquae plant^{-1} and siliquae density on main branch, days to maturity and days to first flower for seed yield plant^{-1} were also reported by Kumar *et al*. (2024). Number of branches plant^{-1} was found to be the next significant character contributing towards seed yield plant^{-1} which had changed its direction from positive to negative direct effect from one generation to another i.e. it was positive in case of F_2 of C-I and C-III, F_3 of C-III, BIP of all the three crosses and has become negative in F_2 of C-II and F_3 of C-I, C-II crosses. The varying magnitude of direct and indirect effect of characters towards seed yield plant^{-1} were observed in this study. When any character recorded negative direct effect on seed yield plant^{-1} but character exhibited positive indirect significant correlation with seed yield plant^{-1}, then the indirect casual factors are to be considered simultaneously for selection. Based on findings of present investigation it could be enforced that the most promising plant type in mustard should possess characters number of siliquae plant^{-1}, siliquae density on main branch, days to maturity and days to first flower to increase on seed yield plant^{-1} through directly or either indirectly. Such varying magnitude of direct and indirect effect was also recorded by Gupta *et al.* (2025), Kumar *et al.* (2024), Srivastava *et al.* (2024), Chaudhary *et al.* (2023), Patel *et al.* (2000), Badsra and Choudhary (2001), Singh (2004), Kardam and Singh (2005) in mustard.

Selection indices and relative efficiency

Selection for seed yield plant^{-1} in mustard based on single character may not be effective. Selection indices provide the means for making use of correlated traits for higher efficiency in selection for yield. Hence, utilization of appropriate multiple selection criteria based on the selection indices would be more desirable. An application of discriminant function developed by Fisher (1936) and first applied by Smith (1936) helps to identify important combination of yield components useful for selection by formulating suitable selection indices. Different selection indices have been constructed and the results on the formulation of selection indices of different characters, the genetic advance (GA) and relative efficiency (RE) over straight selection for seed yield plant^{-1} for different generations in three crosses of mustard are presented below. Multiple regression equation was constructed with the help of partial regression coefficients of seed yield plant^{-1} on independent characters. Forty-one different selection indices were constructed in F_2, F_3 and BIP of C-I, C-II and C-III crosses in mustard. The efficiencies of different indices were determined by calculating genetic advance and comparing it with that for straight selection for seed yield plant^{-1} taken as 100%. Therefore, the object of the present study was to construct and assesses the efficiency of selection indices in mustard presented in Tables 6, 7 and 8 for C-I, C-II and C-III crosses, respectively.

In the present study, straight selection for seed yield plant^{-1} in F_2 of C-I, C-III and F_3, BIP generations of C-II, C-III crosses were found to be more efficient as compared to indirect selection for seed yield plant^{-1} based on any single character except number of siliquae plant^{-1} which was more efficient with straight selection. Hussain *et al*. (2004) also reported straight selection of seed yield plant^{-1} in toria. In case of F_3 generation of C-I cross and F_2 generation of C-III cross results showed that the genetic advance and relative efficiency assessed for different indices were higher than straight selection when the selection was based on component characters which further increased considerably with the inclusion of two or more characters. The highest efficiency was noted for two characters X8 + X5 (99.58%) combination and maximum efficiency also noted for three, four, five combination (95.13% to 95.22%) considered. Whereas for C-II cross of F_2 generation highest efficiency was noted for two characters X8 + X6 (91.23%). Thus, selection indices are more reliable and realistic for selecting desirable genotypes since they are constructed by giving proper weightage on the characters associated with seed yield plant^{-1}.

In this study 80.16% to 98.77% increase in relative efficiency over direct selection for seed yield plant^{-1} was observed for direct selection of number of siliquae plant^{-1} in different generations of all the three crosses. This indicates selection for number of siliquae plant^{-1} in early generation will be more efficient for seed yield plant^{-1} except F_2 of C-II cross it is efficient with siliquae density on main branch. When these two characters were combined for selection 68.91 % to 99.62% increase in relative efficiency was observed in F_2 of C-I, C-II, C-III and F_3 of C-I, C-II and BIP of C-I and C-II crosses.

Any other character added to number of siliquae plant^{-1}, siliquae density on main branch and seed yield plant^{-1} either increased the relative efficiency at a high rate or decreased the relative efficiency. Hence, it is observed from this study that selection of plants in early generation should be done either for number of siliquae plant^{-1} alone or seed yield plant^{-1} alone or both in combination. In this study combination of both the characters were considered for the selection of plants. Similar results were also reported by Rathod *et al*. (2013), Sandhu *et al*. (2020) and Nigam *et al*. (2009). The percentage of plants selected in the F2, F3, and BIP generations of crosses C-I, C-II, and C-III is presented in Fig. 8. The highest number of plants was selected in the BIP generation of C-II, followed by the BIP generation of C-I.

Table 1. Estimates of genetic variability parameters for different characters in F_2, F_3 and BIP populations of mustard

Characters	Populations	C-I (ACN-9 X PC-6)				C-II (Kranti X PC-6)				C-III (TAM-108-1X PC-6)			
		GCV %	PCV %	h^2(bs) %	GA (10 %)	GCV %	PCV %	h^2(bs) %	GA (10 %)	GCV %	PCV %	h^2(bs) %	GA (10 %)
Days to first flower	F_2	3.57	4.48	53.57	5.38	8.95	9.49	89.02	17.41	9.1	9.66	88.74	17.66
	F_3	8.56	9.12	88.01	16.54	7.7	8.37	84.61	14.59	8.05	8.64	86.85	15.45
	BIP	4.21	5.41	60.32	6.74	8.62	9.19	87.97	16.66	6.68	7.48	79.8	12.30
Days to maturity	F_2	3.34	3.46	93.2	6.65	4.82	4.91	96.59	9.76	2.62	2.79	88.06	5.07
	F_3	2.39	2.55	87.83	4.61	3.12	3.23	93.05	6.20	2.12	2.31	84.79	4.03
	BIP	1.77	2.01	77.78	3.22	1.93	2.11	83.82	3.64	1.59	1.83	75.29	2.84
Plant height	F_2	4.47	5.01	79.61	8.22	5.3	5.66	87.7	10.22	8.35	8.63	93.54	16.63
	F_3	6.17	6.58	87.88	11.94	7.66	7.97	92.45	15.18	7.63	7.94	92.94	15.09
	BIP	6.13	6.48	89.44	11.94	6.22	6.57	89.44	12.11	5.56	5.93	88.09	10.75
Number of branches plant^{-1}	F_2	20.08	20.9	92.3	39.74	20.73	21.45	93.4	41.27	20.43	21.16	93.19	40.63
	F_3	21.12	21.82	93.7	42.11	22.9	23.57	94.39	45.84	18.16	18.74	93.92	36.26
	BIP	20.61	21.1	95.49	41.49	22.29	22.73	96.2	45.04	20.61	21.1	95.49	41.49
Number of siliquae plant^{-1}	F_2	26.39	26.62	98.34	53.92	21.76	22.01	97.77	44.33	25.78	25.99	98.38	52.68
	F_3	20.11	20.35	97.73	41.49	36.53	36.63	99.46	75.05	18.13	18.37	97.39	36.85
	BIP	26.7	26.91	98.5	54.60	24.3	24.38	99.35	57.06	16.5	16.78	99.2	33.44
Siliquae density on main branch	F_2	29.05	29.48	97.04	58.94	27.63	28.3	95.58	55.73	29.42	29.98	96.33	59.49
	F_3	25.46	25.91	96.55	51.40	28.6	29.06	96.84	57.98	28.59	29.07	96.77	57.94
	BIP	28.21	28.99	94.7	56.55	21.74	22.32	94.86	43.62	22.45	23.01	95.24	45.14
seed yield plant^{-1}	F_2	29.09	29.14	99.66	59.83	29.66	29.7	99.73	61.02	33.55	33.59	99.78	78.57
	F_3	24.82	24.88	99.54	51.01	37.67	37.7	99.82	77.52	33.83	33.86	99.83	69.64
	BIP	38.00	38.03	99.84	78.22	36.83	36.85	99.89	75.83	28.16	28.19	99.75	67.18

Table 2. Genotypic correlation coefficient for different characters with seed yield plant^{-1}

Characters	C-I (ACN-9 X PC-6)			C-II (Kranti X PC-6)			C-III (TAM-108-1X PC-6)		
	F_2	F_3	BIP	F_2	F_3	BIP	F_2	F_3	BIP
Days to first flower	-0.255	0.554**	0.467*	-0.744**	0.128	-0.076	-0.692**	-0.115	0.323
Days to maturity	0.479**	0.440*	0.364*	0.225	0.272	-0.615**	0.211	0.135	-0.506*
Plant height	0.712**	0.491**	-0.004	0.535**	-0.506**	0.268	0.294**	-0.126	0.501*
Number of branches plant^{-1}	0.459**	0.003	-0.188	-0.523**	-0.351*	-0.629**	-0.301	-0.442*	-0.709**
Number of siliquae Plant^{-1}	0.369**	-0.359*	0.530 **	0.251	0.072	0.183	0.745**	0.916**	0.288*
Siliquae density on main branch	0.633**	0.928**	0.874**	0.786**	0.288*	0.156	0.318**	0.729**	-0.333

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

Table 3. Estimate of direct and indirect effect of different traits on seed yield plant^{-1} in F_2, F_3 and BIP of C-I (ACN-9 X PC-6)

C-I	Characters	Genotypic correlation	Direct effect	Direct effect %	Total indirect effect	Total indirect effect%	Major contributing characters
F_2	Days to first flower	-0.255	-1.377	539.15	1.122	-439.15	DM, PH, Bran, SPP, SD
	Days to maturity	0.479**	0.543	113.42	-0.064	-13.42	PH, Bran, SPP
	Plant height	0.712**	-1.328	-186.3	3.040	426.6	SPP, SD
	Number of branches plant^{-1}	0.459**	2.017	439.5	-0.558	-121.59	DM, PH, SPP
	Number of siliquae plant^{-1}	0.369**	0.968	262.2	-1.337	362.2	Bran
	Siliquae density on main branch	0.633**	0.122	19.3	0.755	119.3	SPP
F_3	Days to first flower	0.554**	-1.521	-274.6	2.075	375.58	DM, Bran, SD
	Days to maturity	0.440*	11.427	2595.3	-10.987	-2495.38	DM, Bran, SD
	Plant height	0.491**	-1.509	-307.16	2.001	407.14	DM, Bran, SPP
	Number of branches plant^{-1}	0.003	-1.668	-50551.5	1.671	5065.5	DTFF, PH, SPP, SD
	Number of siliquae plant^{-1}	-0.359*	0.032	-8.79	0.359	91.91	DTFF, PH
	Siliquae density on main branch	0.928**	4.329	466.59	5.257	566.5	DTFF, Bran, SPP
BIP	Days to first flower	0.467*	0.226	48.32	0.441	94.49	SPP
	Days to maturity	0.364*	0.273	75.02	0.091	24.94	SPP, Bran, SD
	Plant height	-0.004	0.007	-208.33	-0.011	308.33	SD, Bran
	Number of branches plant^{-1}	0.188	0.027	11.25	-0.215	88.74	PH, Bran
	Number of siliquae plant^{-1}	0.530**	0.073	13.83	0.457	86.16	SPP
	Siliquae density on main branch	0.874**	0.122	13.97	0.752	86.02	SPP

DTFF=Days to first flower, DM=Days to maturity, PH=Plant height, Bran=Number of branches plant^{-1}, SPP=Number of siliquae plant^{-1}, SD=Siliquae density on main br

Table 4. Estimate of direct and indirect effect of different traits on seed yield plant^{-1} in F_2, F_3 and BIP of C-II (Kranti X PC-6)

C-II	Characters	Genotypic correlation	Direct effect	Direct effect %	Total indirect effect	Total indirect effect%	Major contributing characters
F_2	Days to first flower	-0.744**	-0.047	6.31	-0.697	93.68	Bran, SPP, SD
	Days to maturity	0.225	0.697	309.77	-0.472	-209.77	DTFF, DM, PH
	Plant height	0.535**	1.202	224.74	-0.667	-124.7	DTFF, DM, PH, SD
	Number of branches plant^{-1}	-0.523**	1.953	-373.3	-2.477	473.28	
	Number of siliquae plant^{-1}	0.251	1.034	412.48	1.285	472.5	DTFF, DM, PH, SD
	Siliquae density on main branch	0.786**	0.506	64.36	-1.293	164.36	DTFF, DM, PH, Bran
F_3	Days to first flower	0.128	0.834	650.19	-0.706	-550.11	SPP, SD
	Days to maturity	0.272	1.002	368.5	-0.73	-268.57	PH, Bran, SD
	Plant height	-0.506**	-0.044	8.71	-0.462	91.26	DTFF, Bran
	Number of branches plant^{-1}	-0.351*	0.737	-210.08	-1.088	309.85	DM
	Number of siliquae plant^{-1}	0.072	1.214	1679.5	1.287	1779.52	DM, Bran, DM
	Siliquae density on main branch	0.288	0.007	2.570	0.295	102.5	Bran, SPP
BIP	Days to first flower	-0.076	-0.689	908.95	0.614	-809.09	DM, PH, Bran, SPP, SD
	Days to maturity	-0.615**	-0.957	155.52	0.342	-55.52	DTFF, Bran, SPP, SD
	Plant height	0.268	0.511	190.96	-0.243	-90.92	DM, SPP
	Number of branches plant^{-1}	-0.629**	0.187	-29.79	-0.816	129.79	SPP
	Number of siliquae plant^{-1}	0.183	0.042	23.27	0.225	123.27	PH, Bran
	Siliquae density on main branch	0.156	0.004	2.87	0.161	102.87	DTFF, DM, PH, Bran, SPP

DTFF=Days to first flower, DM=Days to maturity, PH=Plant height, Bran=Number of branches plant^{-1}, SPP=Number of siliquae plant^{-1}, SD=Siliquae density on main branch

Table 5. Estimate of direct and indirect effect of different traits on seed yield plant^{-1} in F_2, F_3 and BIP of C-III (TAM-108-1 X PC-6)

C-III	Characters	Genotypic correlation	Direct effect	Direct effect %	Total indirect effect	Total indirect effect%	Major contributing characters
F_2	Days to first flower	-0.692**	0.253	-36.50	-0.945	136.5	SD
	Days to maturity	0.211	0.402	190.83	-0.191	-90.83	DM, SPP
	Plant height	0.294**	0.965	328.16	-0.671	-228.12	SD
	Number of branches plant^{-1}	-0.301	0.109	-36.09	-0.409	136.08	SD, PH
	Number of siliquae plant^{-1}	0.745**	0.223	29.88	0.968	129.88	SD
	Siliquae density on main branch	0.318**	0.438	137.46	0.881	276.63	DTFF, PH, Bran, SD
F_3	Days to first flower	-0.115	-0.307	-61.45	0.808	161.45	SPP, PH
	Days to maturity	0.135	-0.187	-138.50	0.323	238.50	Bran, SPP, SD
	Plant height	-0.126	0.244	-193.19	-0.371	293.19	Bran, SPP, SD
	Number of branches plant^{-1}	-0.442*	0.202	-45.73	-0.644	145.73	DTFF
	Number of siliquae plant^{-1}	0.916**	-0.045	-4.90	-0.961	104.89	SD
	Siliquae density on main branch	0.729**	-0.181	-24.84	0.911	124.85	DM, PH, Bran
BIP	Days to first flower	0.323	1.356	419.70	-1.033	-319.70	Bran, SPP, SD
	Days to maturity	-0.506*	-0.613	121.05	0.107	-21.09	DTFF, SPP
	Plant height	0.501*	2.130	424.85	-0.629	-125.40	DM, Bran, SPP, SD
	Number of branches plant^{-1}	-0.709**	1.13	-159.33	-1.839	259.34	DTFF, DM, PH
	Number of siliquae plant^{-1}	0.288	1.794	622.40	-0.506	-175.55	DTFF, PH
	Siliquae density on main branch	-0.333	-1.706	512.31	0.373	-111.98	Bran, SPP

DTFF=Days to first flower, DM=Days to maturity, PH=Plant height, Bran=Number of branches plant^{-1}, SPP=Number of siliquae plant^{-1}, SD=Siliquae density on main branch

Table 6. Selection indices and realative efficiency in C-I

Selection indices C-1 (ACN-9 X PC-6)	F_2			F_3			BIP		
	GA	RE	% Increase	GA	RE	% Increase	GA	RE	% Increase
X8	2.8	100.00	-	2.39	100	-	20.15	100	-
X2	7.42	264.79	62.2	-	-	-	3.80	18.87	-
X3	-	-	-	-	-	-	3.81	18.90	-
X4	-	-	-	-	-	-	-	-	-
X5	37.36	1331.93	92.4	-	987.54	-	-	1234.31	91.22
X6	-	-	-	-	-	-	-	-	-
X8+X2	0.9	32.25	-	2.08	87.23	-	22.54	111.87	10.61
X8+X3	12.01	428.31	76.6	24.01	1006.54	90.06	20.11	99.81	-
X8+X4	6.5	231.88	56.8	2.32	97.09	-	24.42	121.19	17.48
X8+X5	2.9	103.49	3.36	566.88	23763.45	99.58	64.80	321.60	68.91
X8+X6	5.13	183.03	45.3	2.30	96.22	-	13.85	68.74	-
X8+X2+X3	6.23	222.29	55.01	9.81	411.09	75.67	20.40	101.22	1.21
X8+X2+X4	3.93	140.36	28.77	2.03	84.92	-	20.84	103.42	3.31
X8+X2+X5	0.46	16.73	-	48.99	2053.60	95.13	24.61	122.13	18.12
X8+X2+X6	3.11	110.96	9.87	2.00	83.99	-	19.73	97.94	-
X8+X3+X2	6.23	222.29	55.01	9.81	411.09	75.67	20.40	101.22	1.21
X8+X3+X4	7.91	282.15	64.55	9.86	413.22	75.80	20.59	102.19	2.14
X8+X3+X5	6.88	245.33	59.23	49.93	2093.04	95.22	24.40	121.09	17.42
X8+X3+X6	3.11	110.96	9.87	2.00	83.99	-	19.73	97.94	-
X8+X4+X2	3.93	140.36	28.7	2.03	84.92	-	20.84	103.42	3.31
X8+X4+X3	7.91	282.15	64.5	9.86	413.22	75.80	20.59	102.19	2.14
X8+X4+X5	4.89	174.57	42.71	49.00	2054.03	95.13	24.77	122.93	18.66
X8+X4+X6	5.78	206.17	51.49	2.24	93.86	-	19.94	98.93	-
X8+X5+X2	0.46	16.73	-	48.99	2053.60	95.13	24.61	122.13	18.12
X8+X5+X3	6.88	245.33	59.2	49.93	2093.04	95.22	24.40	121.09	17.42
X8+X5+X4	4.89	174.57	42.71	49.00	2054.03	95.13	24.77	122.93	18.66
X8+X5+X6	4.26	151.94	34.19	49.00	2053.99	95.13	23.85	118.36	15.51
X8+X6+X2	3.11	110.96	9.88	2.00	83.99	-	19.73	97.94	-
X8+X6+X3	7.54	268.74	62.79	9.85	413.03	75.79	19.47	96.63	-
X8+X6+X4	5.78	206.17	51.50	2.24	93.86	-	19.94	98.93	-
X8+X6+X5	4.26	151.94	34.19	49.00	2053.99	95.13	23.85	118.36	15.51
X8+X2+X3+X4	4.26	263.37	62.03	9.79	410.46	75.64	20.84	103.40	3.29
X8+X2+X3+X5	4.26	223.47	55.25	49.92	2092.49	95.22	24.61	122.12	18.11
X8+X2+X3+X6	4.26	248.95	59.83	9.79	410.27	75.63	19.73	97.92	-
X8+X2+X4+X5	4.26	142.22	29.69	48.99	2053.47	95.13	24.98	123.95	19.32
X8+X2+X4+X6	4.26	179.61	44.32	1.93	80.86	-	20.19	100.19	0.19
X8+X2+X5+X6	4.26	113.31	11.75	48.98	2053.43	95.13	24.06	119.41	16.25
X8+X2+X3+X4+X5	4.26	264.37	62.17	49.91	2092.37	95.22	24.97	123.93	19.31
X8+X2+X3+X4+X6	4.26	286.22	65.06	9.77	409.64	75.59	20.18	100.17	0.17
X8+X2+X3+X5+X6	4.26	250.00	60.00	49.91	2092.33	95.22	24.06	119.39	16.24
X8+X2+X3+X4+X5+X6	4.26	287.14	65.17	49.91	2092.21	95.22	24.43	121.25	17.52

X2- Days to maturity, X3-Plant height, X4-Number of branches plant^{-1}, X5-Number of siliquae plant^{-1}, X6- Siliquae density plant^{-1}, X8-seed yield plant^{-1}
Indicates absence of GA/RE (%)/% increase

Table 7. Selection indices and realative efficiency in C-II

Selection indices C-II (Kranti X PC-6)	F_2			F_3			BIP		
	GA	RE	% Increase	GA	RE	% Increase	GA	RE	% Increase
X8	2.17	100.00	-	6.90	100	-	4.13	100	-
X2	17.14	788.28	87.31	-	-	-	15.60	377.69	73.52
X3	-	-	-	-	-	-	13.44	325.40	69.27
X4	4.00	183.90	45.62	-	--	-	-	-	-
X5	22.67	1042.78	90.41	559.62	8111.02	98.77	20.35	1190.84	91.60
X6	0.54	24.88	-	0.17	2.42	-	1.02	24.69	-
X8+X2	-	-	-	6.88	99.76	-	49.20	492.47	**79.69**
X8+X3	2.73	125.77	20.49	2.72	39.36	-	3.73	90.33	-
X8+X4	13.23	608.32	83.56	7.10	102.90	2.82	7.45	180.27	44.53
X8+X5	-	-	-	315.79	4576.93	97.82	4.15	100.38	0.38
X8+X6	24.78	1139.61	91.23	7.20	104.37	4.18	-	-	-
X8+X2+X3	-	-	-	5.46	79.09	-	14.37	347.92	71.26
X8+X2+X4	4.31	198.43	49.60	6.96	100.81	0.81	14.91	360.95	72.30
X8+X2+X5	-	-	-	36.86	534.17	81.28	14.44	349.40	71.38
X8+X2+X6	8.22	378.23	73.56	6.99	101.26	1.24	12.46	301.46	66.83
X8+X3+X2	-	-	-	5.46	79.09	-	14.37	347.92	71.26
X8+X3+X4	7.35	337.98	70.41	5.54	80.31	-	5.43	131.34	23.86
X8+X3+X5	-	-	-	36.61	530.68	81.16	3.93	95.11	-
X8+X3+X6	8.22	378.23	73.56	6.99	101.26	1.24	12.46	301.46	66.83
X8+X4+X2	4.31	198.43	49.60	6.96	100.81	0.81	14.91	360.95	72.30
X8+X4+X3	7.35	337.98	70.41	5.54	80.31	-	5.43	131.34	23.86

X8+X4+X5	6.15	282.84	64.64	36.87	534.35	81.29	5.59	135.22	26.05
X8+X4+X6	12.15	558.65	82.10	7.05	102.21	2.16	-	-	-
X8+X5+X2	-	-	-	36.86	534.17	81.28	14.44	349.40	71.38
X8+X5+X3	-	-	-	36.61	530.68	81.16	3.93	95.11	
X8+X5+X4	6.15	282.84	64.64	36.87	534.35	81.29	5.59	135.22	26.05
X8+X5+X6	9.32	428.58	76.67	36.87	534.44	81.29	-	-	-
X8+X6+X2	8.22	378.23	73.56	6.99	101.26	1.24	12.46	301.46	66.83
X8+X6+X3	10.15	466.82	78.58	5.58	80.86	-	-	-	-
X8+X6+X4	12.15	558.65	82.10	7.05	102.21	2.16	-	-	-
X8+X6+X5	9.32	428.58	76.67	36.87	534.44	81.29	-	-	-
X8+X2+X3+X4	4.58	210.72	52.54	5.53	80.21	-	14.86	359.57	72.19
X8+X2+X3+X5	-	-	-	36.61	530.67	81.16	14.38	347.98	71.26
X8+X2+X3+X6	8.37	384.82	74.01	5.57	80.77	-	12.39	299.81	66.65
X8+X2+X4+X5	2.19	100.83	0.82	36.87	534.34	81.29	14.92	361.01	72.30
X8+X2+X4+X6	10.70	492.20	79.68	7.05	102.14	2.09	13.01	314.84	68.24
X8+X2+X5+X6	7.34	337.42	70.36	36.87	534.42	81.29	12.46	301.53	66.84
X8+X2+X3+X4+X5	2.68	123.27	18.88	36.63	530.84	81.16	14.86	359.63	72.19
X8+X2+X3+X4+X6	10.81	497.29	79.89	5.65	81.87	-	12.94	313.26	68.08
X8+X2+X3+X5+X6	7.50	344.79	71.00	36.63	530.92	81.16	12.39	299.88	66.65
X8+X2+X3+X4+X5+X6	10.15	467.00	78.59	36.64	531.09	81.17	12.95	313.32	68.08

X2- Days to maturity, X3-Plant height, X4-Number of branches plant^{-1}, X5-Number of siliquae plant^{-1}, X6- Siliquae density plant^{-1}, X8-seed yield plant^{-1}
(Indicates absence of GA/RE (%)/% increase)

Table 8. Selection indices and realative efficiency in C-III

Selection indices C-III (TAM-108-_1XPC6)	F_2			F_3			BIP		
	GA	RE	% Increase	GA	RE	% Increase	GA	RE	% Increase
X8	5.83	100	-	14.49	100		3.05	100	-
X2	4.3	73.80	-	-	-	-	9.09	298.26	66.47
X3	9.61	164.83	39.33	-	-	-	6.37	208.97	52.15
X4	-	-	-	-	-	-	-	-	-
X5	-	-	-	-	-	-	15.37	504.00	80.16
X6	0.14	2.56	-	0.18	1.23	-	1.04	34.11	-
X8+X2	5.25	90.03	-	20.30	140.13	28.64	0.89	29.12	-
X8+X3	-	-	-	16.44	113.45	11.86	5.70	186.86	46.48
X8+X4	5.74	98.60	--	1.26	8.71	-	-	-	-
X8+X5	1543.5	26469.42	99.62	14.08	97.16	-	3.27	107.14	6.67
X8+X6	4.29	73.62	-	13.24	91.40	-	-		-
X8+X2+X3	1.56	26.77	-	15.58	107.56	7.03	3.37	110.56	9.55
X8+X2+X4	5.58	95.77	--	13.36	92.20	-	-	-	-
X8+X2+X5	80.97	1388.58	92.80	15.26	105.32	5.05	1.02	33.58	
X8+X2+X6	5	85.76	-	15.14	104.52	4.32	-	-	-
X8+X3+X2	1.56	26.77	-	15.58	107.56	7.03	3.37	110.56	9.55
X8+X3+X4	2.13	36.61	-	12.73	87.86	-	1.79	58.57	-
X8+X3+X5	80.81	1385.76	92.78	14.71	101.54	1.52	4.63	151.94	34.18
X8+X3+X6	5	85.76	-	15.14	104.52	4.32	-	-	-
X8+X4+X2	5.58	95.77	-	13.36	92.20	-	-	-	-
X8+X4+X3	2.13	36.61	-	12.73	87.86	-	1.79	58.57	
X8+X4+X5	80.99	1388.80	92.80	12.33	85.11	-	-	-	-
X8+X4+X6	5.21	89.32	-	12.19	84.11	-	-	-	-
X8+X5+X2	80.98	1388.58	92.80	15.26	105.32	5.05	1.02	33.58	-
X8+X5+X3	80.81	1385.76	92.78	14.71	101.54	1.52	4.63	151.94	34.18
X8+X5+X4	80.99	1388.80	92.80	12.33	85.11	-	-	-	-
X8+X5+X6	80.95	1388.15	92.80	14.24	98.31	-	-	-	-
X8+X6+X2	5.00	85.76	-	15.14	104.52	4.32	-	-	-
X8+X6+X3	-	--	-	14.59	100.71	0.70	-	-	-
X8+X6+X4	5.21	89.32	-	12.19	84.11	-	-	-	-
X8+X6+X5	80.95	1388.15	92.80	14.24	98.31	-	-	-	-
X8+X2+X3+X4	1.45	24.79	-	13.67	94.32	-	-	-	-
X8+X2+X3+X5	80.80	1385.49	92.78	15.53	107.17	6.69	3.51	114.97	13.02
X8+X2+X3+X6	-	--	-	15.41	106.38	6.00	-	-	-
X8+X2+X4+X5	80.97	1388.54	92.80	13.29	91.75	-	-	-	-
X8+X2+X4+X6	4.97	85.16	-	13.16	90.83	-	-	-	-
X8+X2+X5+X6	80.94	1387.89	92.79	15.09	104.12	3.95	-	-	-
X8+X2+X3+X4+X5	80.79	1385.46	92.78	13.60	93.87	-	-	-	-
X8+X2+X3+X4+X6	-	-	-	13.47	92.97	-	-	-	-
X8+X2+X3+X5+X6	80.76	1384.80	92.78	15.36	105.99	5.65	-	-	-
X8+X2+X3+X4+X5+X6	80.75	1384.77	92.78	13.41	92.52	-	-	-	--

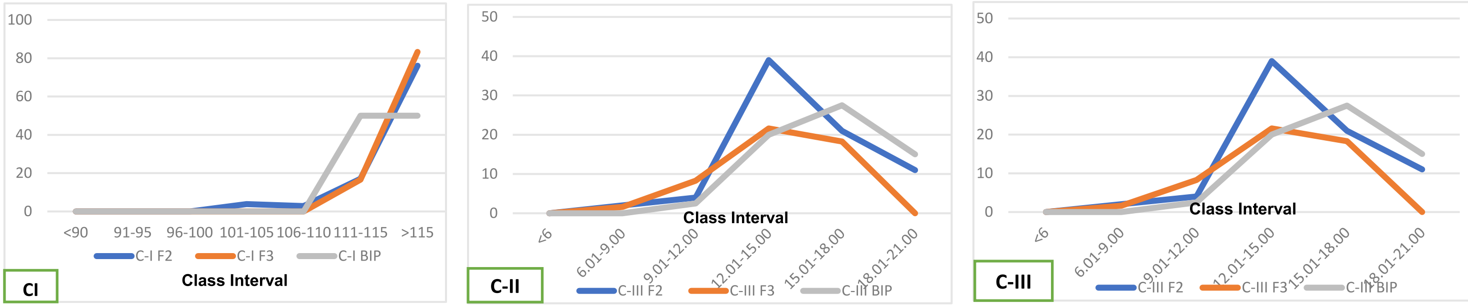

Fig. 1. Frequency distribution of days to maturity among different generation of three crosses in mustard

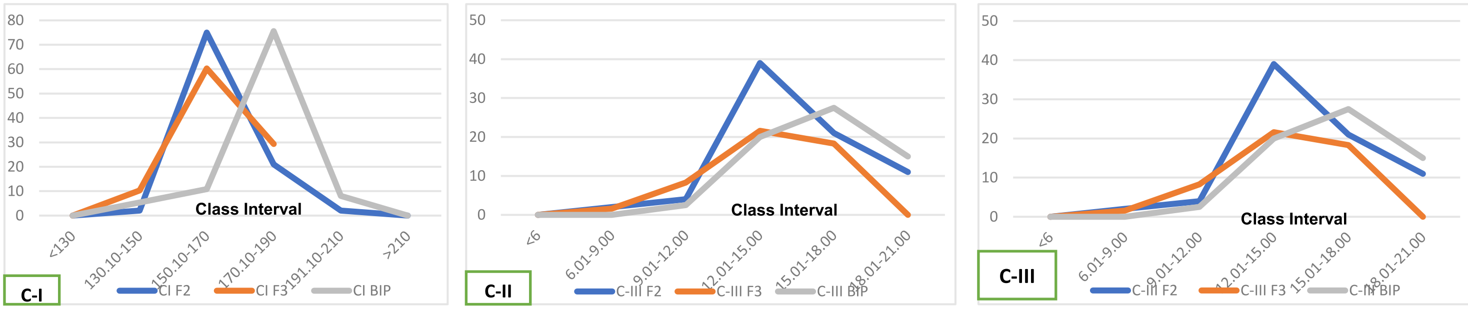

Fig. 2. Frequency distribution of plant height among different generation of three crosses in mustard

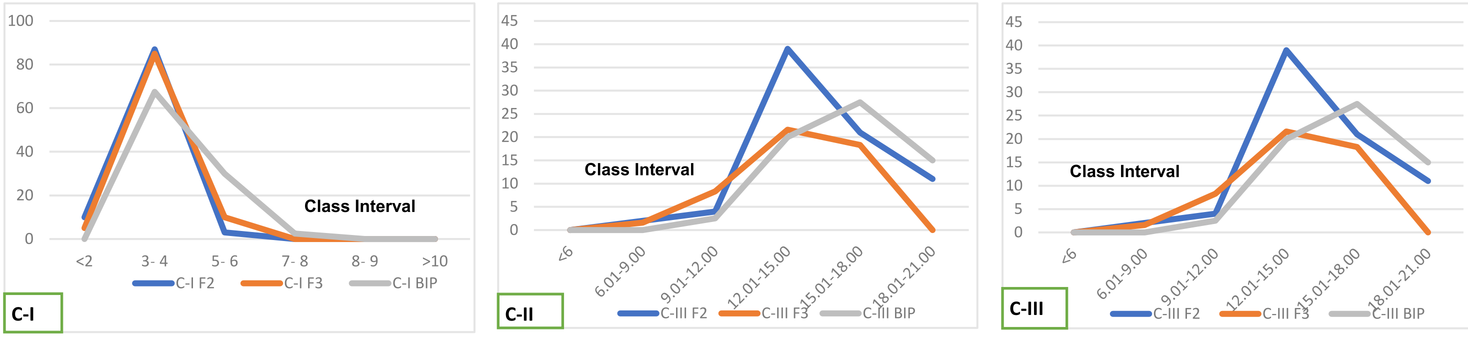

Fig. 3. Frequency distribution of number of branches plant^{-1} among different generation of three crosses in mustard

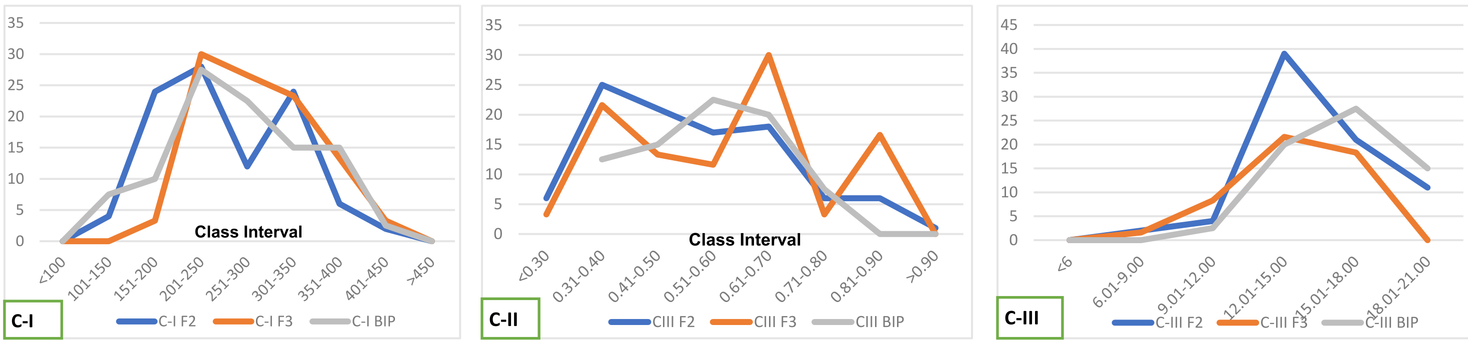

Fig. 4. Frequency distribution of number of silique plant^{-1} among different generation of three crosses in mustard

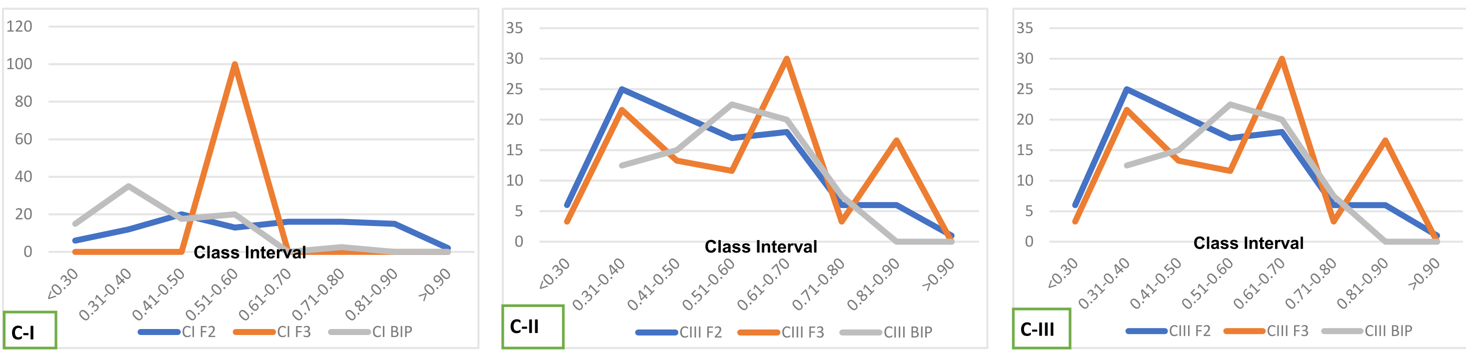

Fig. 5. Frequency distribution of silique density on main branch among different generation of three crosses in mustard

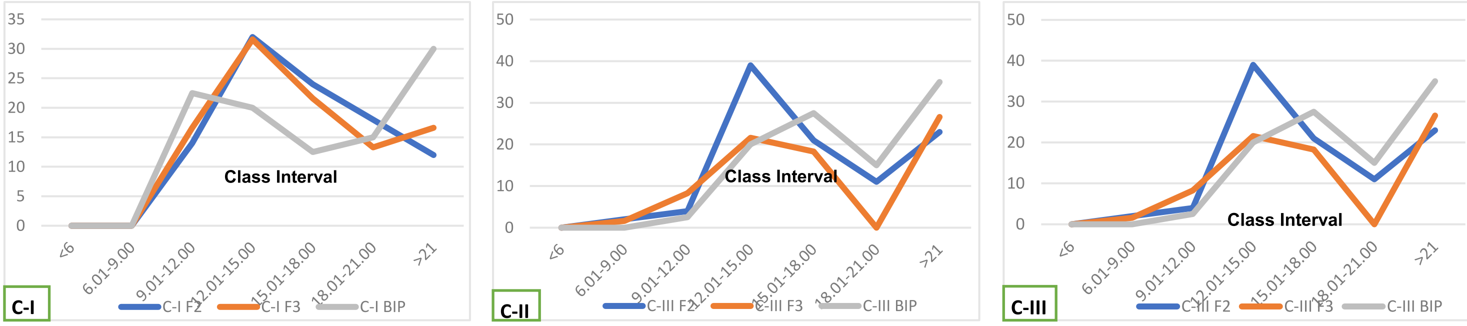

Fig. 6. Frequency distribution of seed yield plant[-1] among different generation of three crosses in mustard

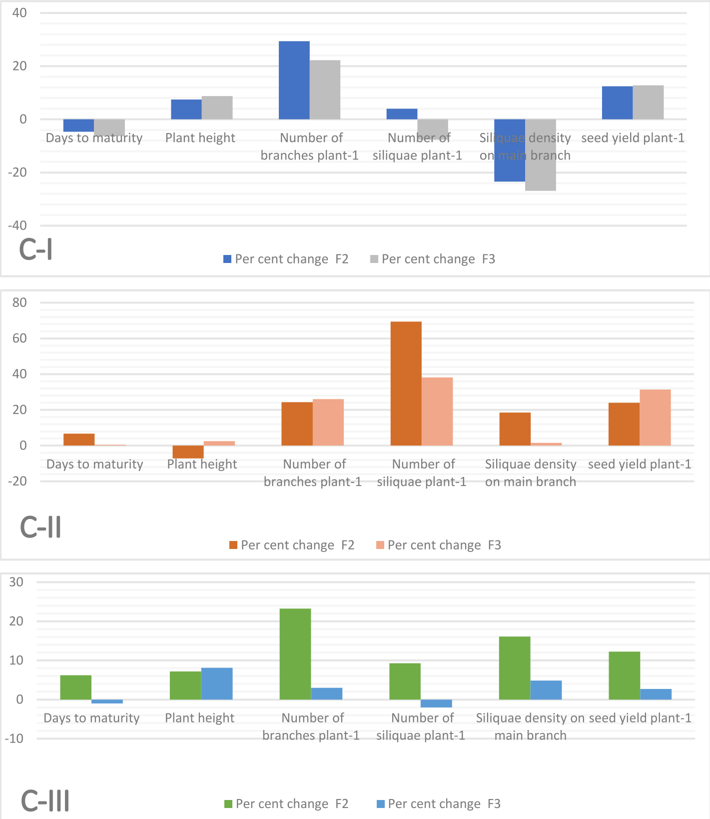

Fig. 7. Per cent change in the mean performance of BIP over F_2 and F_3 in C-I, C-II, C-III

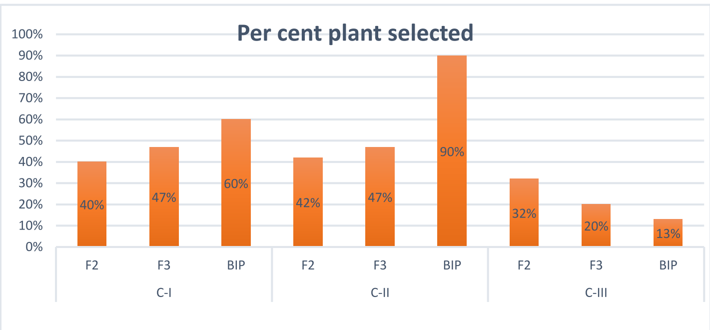

Fig 8. Per cent plants selected in different generations of C-I, C-II, C-III

Conclusions

The study highlighted the superiority of BIP in generating better segregants than F_2 and F_3 generations. A higher percentage of promising plants were selected from BIP, reinforcing its value in mustard improvement programs.

Authors' contributions

AS carried out research and field observations, SR[2] guided and formulated the research programme, SR[2] done statistical analysis to interpret data, SB carried out powdery mildew incidence studies, MP worked on the selection indices for evaluation, DT managed agronomical field standard, SA worked as supporting breeder, PV carried out morphophysiological studies, NS and PI collaborated with AS for taking observations and handling records

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