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Heterotic Component for Yield and Its Attributes in *Eruca sativa* by Using Varietal Diallel Analysis

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ABSTRACT

Ten genetically diverse open pollinated populations of taramira [Eruca sativa (Mill.)] were crossed in a diallel mating design (excluding reciprocals) during Rabi season of 2012-13. The resultant 45 F_1's along with parents were evaluated in RBD with three environments (dates of sowing) with three replications during, Rabi 2013-14.Varieties (v_i) mean squares were significant for all the characters in all the environments except plant height and siliquae per plant in environment-II, while plant height and test weight in environment-III. Overall heterosis ($h_{ii'}$) was highly significant for all the characters in all the environments. Average heterosis ($\bar{h}$) was significant for all the characters in all the environments except siliqua length and number of seeds per siliqua in environment-I, while test weight in the environment-II and environment-III. Varietal heterosis (h_i) was significant for all the characters in all the environments except test weight in the environment-III. Specific heterosis ($S_{ii'}$) was also significant for all characters in all the environments. Specific heterosis ($s_{ii'}$) component accounted for more than 50% to the overall heterosis ($h_{ii'}$) sum of squares. This indicated the presence of additive, dominance and epistatic components in the genetic control of the characters in the present investigation.Among the parents RTM-1415, RTM-314 and RTM-1358 in all the environments, RTM-1351 and RTM-1335 in the environment-II and environment-III were found to be superior based on v_i effects and per se performance not only for seed yield per plant but for some of the other yield traits studied. The other parents worth considering on the basis of h_i values were T-27 and RTM-1415 in environment-I and environment-II, while RTM-1415, RTM-1358 and RTM-1351 in the environment-III. It was therefore recommended to include these parents in hybridization programme to improve seed yield and seed quality. In the present investigation, highly heterotic crosses RTM-1358 x RTM-1415, RTM-314 x RTM-1351 and RTM-1212 x RTM-1358 in all the environments, were desirable as they had high seed yield per plant, high $s_{ii'}$ values, with high heterosis, heterobeltiosis and economic heterosis not only for seed yield per plant but for few other yield traits were studied.

Key words: *Varietal Diallel analysis, Eruca sativa Mill and Heterosis*

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INTRODUCTION

Taramira (*Eruca sativa* Mill.) is important winter season oil seed crop of the family Brassicaceae. It is an introduced crop in India. South Europe and North Africa are believed to be the native place of it[2]. It has diploid number of chromosomes 2n=22 and the chromosomes are very small. Taramira has desirable traits particularly resistance to powdery mildew that can be transferred to *Brassica campestris* and *Brassica juncea* both of which are important crops[23]. It is known by many names such as tera, schwan, seoha, duan, turra, tirwa, merha, merkai, chara, ushan in Uttar Pradash, as sondha in Gwalior (Madhy Pradesh) and tara or simply as taramira in Punjab[24]. In Europe it is known as rocket salad, rocket rouette or arrugula, where it is generally grown for young leaves that are eaten as green salad. The name rocket is well documented in the old literature of the Holy Land. The identity of the plant was a subject of dispute among medieval as well as modern scientists. Most botanists and plant historians agree that the 'gargir' mentioned in the Talmud (5^{th} – 7^{th} centuries) is the garden rocket. Our ancestors cultivated it both as a vegetable and for seed production. It is accepted that rocket corresponds to the Biblical 'oroth'. In the Book of Kings (11 Kings 4: 39-40) in the Bieble; it is said: one of them went out into the field to gather 'oroth'. This plant gathered near Gilgal in the Jordan Valley, where the gargir is very common. The local villaqers or Bedouin collected it as a plot herb of wild salad. Since 'oroth' also appears as 'gargir' in the Talmud it can plausibly be identified with rocket[35]. Taramira is a highly drought tolerant crop, it can be successfully grown as a rainfed crop even on soils with moderate water retaining capacity. The crop is especially suitable for the areas having meager or no irrigation facilities as it has efficient root system to extract moisture from deep soil horizons. During the periods of severe drought coupled with late *Rabi* rains, taramira is the only alternative available for sowing on soils having limited moisture supply. Good yield and economic returns could be obtained by a crop sown as late as December first week. Taramira oil is mainly used in industries. However, the crop has limited improved varieties adapted to wide agroclimatic conditions. This situation demands urgent development of a versatile variety for taramira growing area. For successful implementation of any breeding programme the knowledge of gene action is essential. The diallel mating design provides a systematic approach to study the inheritance of quantitative characters and help in the identification of superior parents and crosses.

MATERIAL AND METHODS

Ten genetically diverse open pollinated populations of taramira (RTM-314, RTM-2002, RTM-1212, T-27, RTM-1351, RTM-1335, RTM-1359, RTM-1355, RTM-1358 and RTM-1415) were crossed in all possible cross combinations (excluding reciprocals) using poly-crossing technique during 2012-13. The resulting 45 F_1s along with parents were evaluated in the ensuing three environments at Agronomy farm, SKN College of Agriculture, Jobner during 2013-14. In each environment the progenies and parents were evaluated in RBD with 3 replications. Each F_1 and parent was sown in a plot having two rows of 5 m length with a row to row distance of 30 cm. with plant to plant spacing of 10 cm maintained by thinning. Non experimental rows were planted all round the experiment to eliminate the border effect. A sample of ten plants was selected randomly and was tagged before commencement of flowering, so as to reduce the biasness in the plant selection. Observations on various morphological traits namely days to flowering, plant height (cm), primary branches per plant, secondary branches per plant, number of siliquae per plant, siliqua length (cm), seeds per siliqua, seed yield per plant (g), test weight (g) and oil content (%), were noted on. Oil content was also estimated using the pooled seed sample using "Nuclear magnetic Resonance spectrometer". The varietal diallel analysis was done as per the analysis II suggested by Gardner and Eberhart[9]. This model assumes that parents used are a set of fixed set of random mating varieties with diploid inheritance, two alleles per locus and no epitasis and have differing gene frequencies. The genetic effects are defined as functions of gene frequencies and additive and dominance effects for individual loci.

Accordingly,

$V_i = \mu + a_i + d_i$

Where,

V_i = Variety mean

a_i = additive effect of i^{th} variety

d_i = dominance effect of i^{th} variety; and

μ = Mean of all the varieties.

$C_{ii'} = \mu + ½ (a_i + a_j^1) + ½ (d_i + d_i^1) + h_{ii'}$

Where,

$C_{ii'}$ = mean of cross between i and i'

a_i & $a_{i'}$ = additive effect of i^{th} and i'^{th} parent

d_i & $d_{i'}$ = dominance effect of i^{th} and i'^{th} parent

$h_{ii'}$ = heterosis because of the difference in the gene frequencies and dominance in the i^{th} and i'^{th} parent can be further partitioned

$h_{ii'} = \bar{h} + h_i + h_{i'} + h_{ii'} + S_{ii'}$

Where,

$\bar{h}$ = average heterosis contributed by the particular set of varieties used in the cross.

$h_i + h_{i'}$ = average heterosis contributed by the varieties i and i' in its crosses measured as deviation from average heterosis ($\Sigma_i h_i = 0$) and

$S_{ii'}$ = specific combining ability of the cross ii'.

The restriction are $\Sigma_i S_{ii'} = \Sigma_{i'} S_{ii'} = 0$

RESULTS AND DISCUSSION

Analysis of variance for the environment-I revealed that replication mean sum of squares were non-significant for all the characters. Entries mean sum of squares were significant for all the characters. Entries mean sum of squares were further partitioned into parents, F_1's and parents v/s F_1's. Parents and F_1's mean sum of squares were significant for all the characters, while parents v/s F_1's mean sum of squares were non-significant for siliqua length (cm) and number of seeds per siliqua (Table 1). Analysis of variance for the environment-II indicated that replication mean sum of squares were significant for all the character except plant height (cm), secondary branches per plant, siliquae per plant and siliqua length (cm). Entries mean sum of square were significant for all the characters. Parents mean sum of squares were significant for all the characters except plant height (cm) and siliquae per plant. F_1's mean sum of squares were significant for all the characters except days to flowering, while parents v/s F_1's mean sum of squares were significant for all the characters except test weight (g) (Table 2). Analysis of variance for the environment-III indicated that replication mean sum of squares were significant for all the characters except siliquae per plant. Entries mean sum of squares were significant for all the characters. Parents mean sum of squares were also significant for all the characters except days to maturity. F_1's mean sum of squares was also significant for all the characters and Parents v/s F_1's mean sum of squares were also significant for all the characters except test weight (Table 3). This indicated significant differences among parents and their crosses (F_1's), revealing the existence studied in taramira[11,12,18,19] and in mustard[3,3,15,16,17,24,30].

The entries mean sum of squares was highly significant in all the three environments for all the characters. The entries mean sum of squares was partitioned into varieties (v_i) and heterosis ($h_{ii'}$) component. The varieties (v_i) was highly significant for all the characters in all the three environments except plant height (cm) and siliquae per plant in the environment-II, while days to maturity and plant height (cm) in the environment-III. Supporting studies were done by Nehra[18] , Nehra and Sastry[19], Kumar *et al.*[12] and Sharma *et al.*[25]. The overall heterosis ($h_{ii'}$) was also highly significant for all the characters. The heterosis mean sum of squares was partitioned into three components namely average (Ћ), variety (h_i) and specific ($s_{ii'}$) heterosis. Average heterosis (Ћ) was significant for all the characters in all the environments except siliqua length in the environment-I, while test weight (g) in the environment-II and environment-III. Varietal heterosis (h_i) mean sum of squares were significant for all the characters in all the three environments except test weight in the environment-III. Specific heterosis ($s_{ii'}$) mean sum of squares was also significant for all the characters in all the three environments (Table 4,5,6). Other researchers[8,12,19,25] were reported similar findings in varietal diallel in taramira over the season. Thakur and Sagwal[31] reported heterosis and combining ability in rapeseed (*Brassica napus* L.) over the season and observed highly significant components of heterosis. The proportion of entry sum of squares accounted for by overall heterosis ($h_{ii'}$) showed lowest value (79.05 %) for number of seeds per siliqua and highest value (98.42 %) for seed yield per plant in the environment-I and lowest value (80.44 %) for number of seeds per siliqua and highest value (99.29 %) for siliquae per plant in the environment-II, while lowest value (77.21 %) for secondary branches per plant and highest value (98.80 %) in the environment-III. A higher proportion of heterosis sum of squares indicate that all the characters were controlled by additive, dominance and epistatic components. The heterosis sum of squares accounted by average heterosis (Ћ) which otherwise reflects dominance were very low for most of the characters in the environment-I and environment-III except plant height, primary branches per plant, secondary branches per plant, seed yield per plant, days to flowering, primary branches per plant, secondary branches per plant, siliquae per plant and seed yield per plant in the environment-II, whereas the variety heterosis (h_i) ranged between 4.08 per cent to 23.27 per cent in the environment-I and 4.28 per cent to 22.78 per cent in the environment-II, while 3.12 per cent to 29.96 per cent in the environment-III for various traits. The partition of specific heterosis ($s_{ii'}$) ranged from 18.29 per cent to 95.64 per cent in the environment-I and 37.00 per cent to 92.99 per cent in the environment-II, while 42.46 per cent to 95.17 per cent in the environment-III. Partitioning of the overall heterosis sum of squares indicate that contribution of specific combining ability was the highest (above 50%) in general among the three components.

Components of heterosis

The critical analysis of the data with regard to variety (v_i) effects and mean performance of each parent for different characters has indicated high correlation (r = 1.00) (simple correlation were worked out between v_i and *per se* performance) between v_i and *per se* performance of parents. This is expected as the v_i values represent the deviation of variety (parents in the present study) mean from the overall mean of the varieties. Among the varieties (parents) RTM-1415 was top seed yielder overall the environments, RTM-314 RTM-1358 and RTM-1351 in the environment-I, RTM-1415, RTM-1351, RTM-314, RTM-1335 in the environment-II, while in the environment-III, RTM-314, RTM-1415, RTM-1335 and RTM-1358 were top seed yielder with high v_i effects (Table 7). The variety RTM-1415 was top ranking for most of the characters except days to flowering, days to maturity, test weight and oil content in all the environments. It had mean ranks of 2.91, 3.09 and 3.55 in all the environments, this is desirable. The second best was RTM-1358 with a mean rank of 4.73, 4.55 and 4.27 in all the environments. The variety RTM-1359 had the lowest v_i effects among all the parents in all the environments.

Total heterosis was divided into three components namely average heterosis (Ћ), varietal heterosis (h_i) and specific heterosis ($s_{ii'}$). The positive with desirable significant average heterosis (Ћ) in the present investigation was observed for most of the characters in all the environments except siliqua length (cm) and number of seeds per siliqua in the environment-I and test weight (g) in environment-II and environment-III which indicate the absence or minimum differences in the gene frequencies among the parents for these characters[12,19,25]. Comparison of h_i values with *per se* performance indicated the existence of an inverse relationship between the two, i.e. varieties with high mean values were having very low and/ or undesirable h_i effects and vice versa. In quantitative term the relationship was negative found between h_i and *per se* performance of parents. Such relationship was earlier reported in Corn[6], Nehra and Sastry[19] in *Eruca sativa,* Sharma[26] in bajra, Dashora[5] in fennel, Kumar *et al.*[12] and Sharma *et al.*[25], in taramira. Among the parents desirable significant positive h_i effects for seed yield per plant with T-27 in the environment-I and environment-II and with RTM-1415 and RTM-1358 in the environment-III thus from heterosis point of view T-27, RTM-1415 and RTM-1358 is desirable. The parent with significant negative thus undesirable h_i effects were RTM-1359 in all the environments and RTM-1355 in the environment-III. The sign of h_i effects is generally dependent upon Ћ *i.e.,* average heterosis and the distribution of genes in the parents and the differences between heterozygote's and the mid parental value at any given locus.

Among the parents desirable significant positive h_i effects for plant height were observed with RTM-1415 in the environment-II; for secondary branches per plant were with RTM-1358 and RTM-1415 in the environment-II and RTM-1351 in the environment-III; for siliquae per plant were with RTM-2002 and RTM-1415 in the environment-I, RTM-1351 in the environment-II and RTM-1415 in the environment-III; for siliqua length were with T-27 in the environment-II and RTM-1415, RTM-1351 and T-27 in the environment-III; for number of seeds per siliqua were with T-27 in the environment-I, RTM-2002 and RTM-1351 in the environments-II and T-27, RTM-1351, RTM-1358 and RTM-1415 in the environment-III; for seed yield per plant were with T-27 in the environment-I, T-27 in the environment-II and RTM-1358 and RTM-1415 in the environment-III; for test weight were with RTM-314 and RTM-1358 in the environment-II and RTM-314, RTM-1212 and RTM-1358 in the environment-III and for oil content was with RTM-1355 in the environment-I, thus from heterosis point of view these parents are desirable.

Among the parents desirable significant positive h_i effects for plant height were observed with RTM-1415 in the environment-I; for secondary branches per plant were with RTM-1358 and RTM-1415 in the environment-II and RTM-1351 in the environment-III; for siliquae per plant were with RTM-2002 and RTM-1415 in the environment-I, RTM-1351 in the environment-II and RTM-1415 in the environment-III; for siliqua length were with T-27 in the environment-II and RTM-1415, RTM-1351 and T-27 in the environment-III; for number of seeds per siliqua were with T-27 in the environment-I, RTM-2002 and RTM-1351 in the environments-II and T-27, RTM-1351, RTM-1358 and RTM-1415 in the environment-III; for seed yield per plant were with T-27 in the environment-I, T-27 in the environment-II and RTM-1358 and RTM-1415 in the environment-III; for test weight were with RTM-314 and RTM-1358 in the environment-II and RTM-314, RTM-1212 and RTM-1358 in the environment-III and for oil content was with RTM-1355 in the environment-I, thus from heterosis point of view these parents are desirable.

The parental varieties used in the present investigation had diverse origin therefore; the gene frequencies are not expected to be similar among the varieties. Only few h_i effects were found significant among all the characters. Significant desirable h_i effects were observed in T-27 for seed yield per plant, number of seeds per siliqua and siliqua length in among the environments; in RTM-1358 for secondary branches per plant, siliquae per plant and test weight in the environment-II and for seed yield per plant, test weight and siliquae per plant in environment-III; in RTM-314 for seed yield per plant in environment-II and environment-III; in RTM-1415 for days to maturity, plant height and secondary branches per plant in environment-II and for siliqua length and seed yield per plant in environment-III; in RTM-1355 only one for oil content in the environment-I.The earlier studied in taramira[12,18,19,25] and in *Brassica juncea*[13].

Perusal of data for $s_{ii'}$ effects indicated that most significant SCA effects were observed in seed yield per plant, plant height, siliquae per plant and number of seeds per siliqua interestingly in all those crosses which exhibited $s_{ii'}$ effects, either both parents differed in direction and/or magnitude with regard to variety heterosis (h_i) effects. This is expected and commonly reported in Corn[6] Nehra and Sastry[19], Kumar *et al*.[12], Sharma *et al.*[25], in *Eruca sativa*; Sharma[26] in bajra; Dashora[5] in fennel. In all the environments, cross RTM-1358 x RTM-1415 exhibited positive significant SCA effects in the desirable direction for seed yield per plant. This cross also had positive significant SCA effects in the desired direction for days to maturity, number of seeds per siliqua, test weight and oil content. Similarly crosses RTM-2002 x RTM-1359 and RTM-314 x RTM-1351 also had positive significant SCA effects for seed yield per plant besides primary branches per plant, siliquae per plant, number of seeds per siliqua, test weight and oil content and cross RTM-1212 x RTM-1358 for seed yield per plant, number of seeds per siliqua, test weight and oil content. These findings were supported by several workers[1,7,10,12,22,24,27,28,32,33,34]. In the environment-I, cross T-27 x RTM-1358for days to flowering and days to maturity and cross RTM-1335 x RTM-1355 for secondary branches per plant and number of seeds per siliqua. In the environment-II, cross T-27 x RTM-1351 for seed yield per plant, secondary branches per plant, siliquae per plant, siliqua length and test weight, RTM-314 x RTM-1355 for seed yield per plant and secondary branches per plant and cross RTM-1335 x RTM-1355 for primary branches per plant, secondary branches per plant, siliquae per plant, siliqua length and number of seeds per siliqua and also in the environment-III, cross T-27 x RTM-1351 for seed yield per plant, secondary branches per plant, siliquae per plant and test weight, RTM-1351 x RTM-1359 for number of seeds per siliqua and test weight, RTM-2002 x RTM-1212 for secondary branches per plant and siliqua length, T-27 x RTM-1359 for primary branches per plant and oil content.

Among the crosses RTM-1358 x RTM-1415 and RTM-314 x RTM-1351 were found as desirable crosses having significant positive SCA effects for five characters including seed yield per plant and oil content and RTM-1212 x RTM-1358 were found as desirable crosses having positive SCA effects for three characters including seed yield per plant. Based on $s_{ii'}$ values, best cross for each character indicated that parent RTM-1358 was involved in 10 crosses for eleven characters, RTM-2002 in 10 crosses for nine characters, RTM-1212 in eight crosses for six characters, RTM-1351 in 11 crosses for ten characters and RTM-314 in 10 crosses for ten characters in the environment-I and in the environment-II, parent T-27 in 9 crosses for eight characters, RTM-1335 in 8 crosses for eight characters and RTM-314 in 10 crosses for nine characters, whereas in the environment-III, parent RTM-314 was involved in 11 crosses for eight characters, RTM-1335 in 8 crosses for six characters, RTM-2002 in 7 crosses for five characters and RTM-1358 in 11 crosses nine characters. It is therefore suggested that for increased seed yield inclusion of parents RTM-1358, RTM-2002, RTM-1212 and T-27 in the crosses is ideal as the crosses having these parents were found to have high s_{ii}, effects for traits, seed yield per plant, days to maturity, plant height, primary branches per plant, secondary branches per plant, siliquae per plant, number of seeds per siliqua, test weight and oil content. The other parents that may be considered are RTM-314, RTM-1335 and RTM-1351 as they had exhibited high s_{ii}, effect in cross combinations for traits, seed yield per plant, days to flowering, days to maturity, secondary branches per plant, siliqua length and number of seeds per siliqua.

Table 1: Analysis of variance giving mean sum of squares for different characters of taramira (*Eruca sativa* (Mill.) in environment-I

Source of variation	df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Replication	2	0.0048	0.168	0.036	0.025	0.929
Entries	54	0.188**	35.043**	3.156**	0.318**	1.610**
(i) Parents	9	0.0125**	44.053**	0.299**	0.396**	1.516**
(ii) F_1's	44	0.204**	33.926**	2.972**	0.290**	1.412**
(iii) Parents v/s F_1	1	0.0478	3.147	36.974**	0.474**	11.186**
Error	108	0.0195	2.013	0.086	0.062	0.325

* Significant at p=0.05 ** Significant at p=0.01

Table 2: Analysis of variance giving mean sum of squares for different characters of taramira (*Eruca sativa* (Mill.) in environment-II

Source of variation	df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Replication	2	1.3152	5.169	4.694	0.127	1.190	11.0364
Entries	54	6.647**	11.213**	81.546**	1.739**	2.358**	79.735**
(i) Parents	9	8.163**	7.111**	57.179**	2.051**	1.342*	58.357**
(ii) F_1s	44	6.306**	12.024**	66.146**	0.713**	1.325**	81.738**
(iii) Parents v/s F_1	1	7.985*	12.412*	978.452**	44.098**	56.986**	183.829**
Error	108	1.228	1.991	1.787	0.1064	0.654	4.3198

Source of variation	df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Replication	2	5.036	0.461	160.597**	0.249	1.594**	116.684**
Entries	54	10.384**	20.079**	63.312**	1.146**	4.238**	102.625**
(i) Parents	9	11.782**	7.170*	26.009	0.978**	3.415**	4.382
(ii) F_1s	44	9.211	22.478**	69.728**	0.597**	3.732**	106.601**
(iii) Parents v/s F_1	1	49.390**	30.708**	116.765**	26.814**	33.920**	811.848**
Error	108	2.221	3.059	14.259	0.132	0.329	6.411

Source of variation	df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Replication	2	0.127**	0.150	0.020	0.013	1.510
Entries	54	0.255**	25.878**	4.117**	0.161**	1.700**
(i) Parents	9	0.219**	30.372**	0.980**	0.042**	1.084*
(ii) F_1s	44	0.265**	25.187**	4.056**	0.188**	1.726**
(iii) Parents v/s F_1	1	0.129*	15.848**	34.999**	0.0171	6.088**
Error	108	0.011	1.724	0.125	0.0065	0.504

* Significant at p=0.05 ** Significant at p=0.01

Table 3: Analysis of variance giving mean sum of squares for different characters of taramira (*Eruca sativa* (Mill.) in environment-III

Source of variation	df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Replication	2	5.842	5.606	3.137	0.0059	0.491	30.587**
Entries	54	7.764**	10.551**	37.692**	1.342**	2.166**	97.143**
(i) Parents	9	5.718**	4.444	2.700**	1.182**	2.961**	18.114**
(ii) F_1s	44	8.088**	10.969**	28.130**	0.759**	1.477**	112.057**
(iii) Parents v/s F_1	1	11.900*	47.096**	777.313**	28.453**	25.333**	152.139**
Error	108	2.003	2.816	1.893	0.041	0.232	5.31

Source of variation	df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Replication	2	0.0054	1.078	0.0251	0.0104	1.531
Entries	54	0.231**	28.099**	2.731**	0.176**	1.625**
(i) Parents	9	0.261**	25.350**	0.396**	0.031**	1.308*
(ii) F_1s	44	0.224**	24.128**	2.896**	0.209**	1.407**
(iii) Parents v/s F_1	1	0.259**	11.157**	16.521**	0.0025	14.068**
Error	108	0.0139	0.789	0.0418	0.007	0.516

* Significant at p=0.05 ** Significant at p=0.01

Table 4: Analysis of variance of 10 parents and their 45 crosses giving mean squares for different characters in the environment-I (According to Gardner and Eberhart (1966) model, analysis-II)

Source of variation	Df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Entries	54	2.216**	3.169**	27.182**	0.579**	0.786**	26.579**
Varieties (v_i)	9	2.721**	2.370**	19.059**	0.684**	0.447*	19.498**
Heterosis (h_{ii})	45	2.115**	4.011**	28.806**	0.559**	0.854**	28.002**
Average (ħ)	1	2.666**	4.137*	326.151**	14.699**	18.995**	61.276**
Variety (h_i)	9	1.736**	3.333**	28.106**	0.650**	0.493*	17.202**
Specific ($s_{ii'}$)	35	2.196**	4.182**	20.491**	0.131**	0.428**	29.829**
Error	108	0.409	0.663	0.596	0.035	0.218	1.439

Source of variation	Df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Entries	54	0.063**	11.681**	1.052**	0.106**	0.537**
Varieties (v_i)	9	0.042**	14.684**	0.099**	0.132**	0.505**
Heterosis (h_{ii})	45	0.067**	11.080**	1.242**	0.101**	0.543**
Average (ħ)	1	0.016	1.048	12.325**	0.158**	3.729**
Variety (h_i)	9	0.013*	7.937**	0.254**	0.093**	0.517**
Specific ($s_{ii'}$)	35	0.082**	12.175**	0.180**	0.101**	0.459**
Error	108	0.0065	0.671	0.029	0.021	0.108

Subscripts indicate

Overall heterosis (h_{ii}) partitioning into three components namely, Average heterosis(ħ), Variety heterosis (h_i) and Specific heterosis($s_{ii'}$)

* Significant at p=0.05, ** Significant at p=0.01

Table 5: Analysis of variance of 10 parents and their 45 crosses giving mean squares for different characters in the environment-II (According to Gardner and Eberhart (1966) model, analysis-II)

Source of variation	Df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Entries	54	3.461**	6.693**	21.104**	0.382**	1.413**	34.208**
Varieties (v_i)	9	3.927**	2.390*	8.669	0.326**	1.138**	1.461
Heterosis (h_{ii})	45	3.368**	7.553**	23.591**	0.393**	1.468**	40.758**
Average (ħ)	1	16.463**	10.236**	38.922**	8.938**	11.307**	270.616**
Variety (h_i)	9	3.837**	3.787**	12.374**	0.245**	1.246**	11.014**
Specific ($s_{ii'}$)	35	2.873**	8.446**	26.037**	0.187**	1.243**	41.838**
Error	108	0.740	1.0198	4.753	0.044	0.109	2.137

Source of variation	Df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Entries	54	0.085**	8.63**	1.372**	0.054**	0.568**
Varieties (v_i)	9	0.073**	10.123**	0.327**	0.014**	0.361*
Heterosis (h_{ii})	45	0.087**	8.327**	1.581**	0.062**	0.607**
Average (ħ)	1	0.043*	5.283**	11.666**	0.0051	2.029**
Variety (h_i)	9	0.059**	4.477**	0.338**	0.074**	0.709**
Specific ($s_{ii'}$)	35	0.096**	9.403**	1.613**	0.0734**	0.541**
Error	108	0.0072	0.575	0.0418	0.0022	0.168

Subscripts indicate

Overall heterosis (h_{ii}) partitioning into three components namely, Average heterosis(ħ), Varietyheterosis (h_i) and Specific heterosis($s_{ii'}$)

* Significant at p=0.05, ** Significant at p=0.01

Table 6: Analysis of variance of 10 parents and their 45 crosses giving mean squares for different characters in the environment-III (According to Gardner and Eberhart (1966) model, analysis-II)

Source of variation	Df	Days to flowering	Days to maturity	Plant height (cm)	Primary branches per plant	Secondary branches per plant	Siliquae per plant
Entries	54	2.588**	3.517**	12.564**	0.447**	0.722**	32.381**
Varieties (v_i)	9	1.906**	1.481*	0.900	0.394**	0.987**	6.038**
Heterosis (h_{ii})	45	2.724**	3.924**	14.897**	0.458**	0.669**	37.649**
Average (ħ)	1	3.967**	15.699**	257.771**	9.484**	8.444**	50.713**
Variety (h_i)	9	4.082**	1.174	8.999**	0.249**	0.455**	3.464*
Specific ($s_{ii'}$)	35	2.339**	4.295**	9.474**	0.249**	0.455**	46.067**
Error	108	0.667	0.664	0.596	0.035	0.035	1.439

Source of variation	Df	Siliqua length (cm)	Number of seeds per siliqua	Seed yield per plant (g)	Test weight (g)	Oil content (%)
Entries	54	0.077**	8.033**	0.910**	0.059**	0.542**
Varieties (v_i)	9	0.087**	8.450**	0.132**	0.0103	0.436*
Heterosis (h_{ii})	45	0.075**	7.949**	1.066**	0.068**	0.563**
Average (ħ)	1	0.086**	3.856*	5.507**	0.0083	4.689**
Variety (h_i)	9	0.45**	5.242**	0.166**	0.019	0.536**
Specific ($s_{ii'}$)	35	0.083**	8.763**	1.171**	0.083**	0.452**
Error	108	0.0065	0.671	0.029	0.0206	0.172

Subscripts indicate

Overall heterosis (h_{ii}) partitioning into three components namely, Average heterosis(ħ), Varietyheterosis (h_i) and Specific heterosis($s_{ii'}$)

* Significant at p=0.05, ** Significant at p=0.01

Table 7: Top five varieties and crosses with high significant desirable components of heterosis in all the environments

Characters	V_i			h_i		
	I	II	III	I	II	III
Seed yield per plant (g)	**RTM-314* (0.50)**	**RTM-1415* (0.66) RTM-1351* (0.66) RTM-314* (0.59)**	**RTM-314* (0.32) RTM-1415* (0.28) RTM-1335* (0.28)**	**T-27* (0.31)**	**T-27* (0.32)**	**RTM-1415* (0.36) RTM-1358* (0.28)**
Test weight (g)	-	**RTM-1212* (0.18) RTM-1351* (0.11)**	**RTM-314* (0.17)**	-	**RTM-1358* (0.13) RTM-314* (0.09)**	**RTM-314* (0.13) RTM-1358* (0.11)**
Oil content (%)	**RTM-314* (0.71)**	**RTM-314* (0.74) RTM-1335* (0.81)**	-	**RTM-1355* (0.42)**	-	-

Characters	$S_{ii'}$		
	I	**II**	**III**
Seed yield per plant (g)	**RTM-1358 x RTM-1415* (3.24) RTM-314 x RTM-1351* (2.38) T-27 x RTM-1335* (1.36) RTM-2002 x RTM-1359* (1.19) RTM-1212 x RTM-1358* (1.00)**	**RTM-1358 x RTM-1415* (3.22) RTM-314 x RTM-1355* (3.00) RTM-314 x RTM-1351* (2.04) RTM-2002 x RTM-1359* (1.97) T-27 x RTM-1351* (1.44)**	**RTM-1358 x RTM-1415* (3.58) RTM-314 x RTM-1351* (2.09) RTM-314 x RTM-1355* (1.56) T-27 x RTM-1351* (1.28) RTM-1335 x RTM-1359* (0.90)**
Test weight (g)	**RTM-1212 x RTM-1358* (0.74) RTM-314 x RTM-1351* (0.56) RTM-1358 x RTM-1415* (0.34) RTM-1212 x RTM-1355* (0.33) RTM-2002 x RTM-1335* (0.28)**	**RTM-1212 x RTM-1358* (0.50) T-27 x RTM-1351* (0.38) RTM-314 x RTM-1351* (0.32) RTM-1212 x RTM-1355* (0.27) RTM-1351 x RTM-1359* (0.26)**	**RTM-1212 x RTM-1358* (0.56) T-27 x RTM-1351* (0.36) RTM-314 x RTM-1351* (0.35) T-27 x RTM-1415* (0.34) RTM-1351 x RTM-1359* (0.25)**
Oil content (%)	**RTM-314 x RTM1351* (1.25) RTM-2002 x RTM-1359* (1.14) RTM-1358 x RTM-1415* (0.98) RTM-1212 x RTM-1358* (0.90) RTM-2002 x RTM-1355* (0.89)**	**RTM-314 x RTM1351* (1.08) RTM-1335 x RTM-1359* (1.17) RTM-1358 x RTM-1415* (1.06) RTM-1212 x RTM-1358* (0.94) RTM-2002 x RTM-1355* (0.91)**	**RTM-314 x RTM1351* (1.37) T-27 x RTM-1359* (0.94) RTM-1358 x RTM-1415* (0.89) RTM-2002 x RTM-1355* (0.87) RTM-1212 x RTM-1358* (0.81)**

CONCLUSION

In the present investigation, highly heterotic crosses RTM-1358 x RTM-1415, RTM-314 x RTM-1351 and RTM-1212 x RTM-1358 in all the environments, were desirable as they had high seed yield per plant, high $s_{ii'}$ values, with high heterosis, heterobeltiosis and economic heterosis not only for seed yield per plant but for some than the other yield traits studied. Since these are varietal crosses, construction of superior populations from the segregates of these crosses is highly recommended. Based upon the results of present study, it is concluded that as there exist a considerable amount of heterosis for various characters including seed yield, development of hybrid varieties holds promise once inbreds are available. Development of inbreds is at present is not feasible because of self incompatibility. If RTM-1358, RTM-1415, RTM-314, and T-27 are used in the hybrid development programme greater strides in seed yield improvement may be expected.

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