

Assessing the best crosses along with its parents for seed yield and quality traits in Indian mustard based on Combining Ability Analysis

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ABSTRACT

Indian mustard is the most extensively cultivated oilseed crop in India, which has a very significant nutritional and economic value. Understanding the genetic mechanisms is important for developing high yielding varieties, mainly the ones governing traits like seed yield. The material was estimated in a Randomized Block Design (RBD) with three replications, and data were recorded on 14 agronomic and quality traits. RH-0749, LAXMI, RL1359, RAJAT, and MAYA as superior general combiners, while hybrids RL1359 × RAJAT and RGN-73 × MAYA exhibited high specific combining ability based on the Combining Ability Analysis. Lower GCA variance than SCA variance and low predictability ratios implied the predominance of non-additive gene action, supporting the potential for heterosis breeding.

Keywords: Line x Tester, SCA, GCA and *Brassica juncea*. L.

INTRODUCTION

In our country, the leading oilseed crops include mustard, peanut, soybean, castor seed, sunflower, sesame, linseed, Niger seed and Saf flower. According to the Ministry of Agriculture & Farmers Welfare (2024–25), soybean accounts for the largest share of oilseed production at 35%, followed by rapeseed-mustard at 32% and groundnut at 25%, while the remaining oilseed crops together contribute just 8% to the total output. In terms of area of production, soybeans dominate over 44% of the total area, which accounts to oilseed crops, rapeseed-mustard contributes for 24%, and groundnut accounts for 20%. Approximately 67% oilseed production is contributed by *kharif* crops, while the remaining 33% is produced during the *rabi* season.

Cytologically, *Brassica juncea* L. (Indian mustard) is an amphidiploid species with a chromosome number of $2n = 4x = 36$, developed through hybridization between *B. campestris* L. ($2n = 2x = 20$) and *B. nigra* L. ($2n = 2x = 16$), followed by subsequent chromosome doubling. According to the Ministry of Agriculture and Farmers Welfare (DAC and FW 2024-25), third advance estimate, India is expected to reach a record-high oilseed production of 40.9 million metric tonnes (MT) this year, with soybean, mustard, and peanut achieving their highest yields to date. Soybean production is forecasted to reach 14.9 MT, while both rapeseed-mustard and peanut are expected to produce 12.4 MT each, reflecting an increase of 1.9 MT and 0.5 MT, respectively, compared to the previous year.

India is the global leader in the area devoted to oilseed cultivation, though the yields of most oilseed crops in India fall below the global average. Although, the demand for edible oils in India is expected to grow substantially due to population increases, with projections of 28.40 million metric tonnes (MT) by 2030 and 41.6 MT by 2050. To boost yields further, it is crucial to develop improved, high-yielding varieties. Successful hybridization programs depend on identifying superior parent plants and understanding their combining abilities to produce desirable offspring.

Hybridization is a key method for overcoming yield limitations^[21,26]. As such, the first step in developing high-yielding superior varieties are identifying the superior parent plants^[17,28,29].

The study aimed to estimate genetic variance components, specifically general combining ability (GCA) and specific combining ability (SCA) variances and their effects in Indian mustard. The combining ability analysis revealed that GCA had a significant influence on seed yield and quality traits, suggesting the dominance of additive gene action, while notable SCA effects on these traits emphasized the role of non-additive gene action.

MATERIALS AND METHODS

Ten diverse genotypes were used to develop twenty-one hybrids using a line x tester crossing scheme at the Agri Farm of Lovely Professional University, Jalandhar, during the Rabi season 2024-25. The details of diverse genotypes used in the experiment are listed in the Table 1 below, along with their sources and characteristics. During the Rabi season of 2024–25, twenty-one F₁ hybrids along with their parents were grown in a randomized block design with three replications. Each plot consisted of two rows, each 2 meters in length and spaced 45 cm apart, while a plant-to-plant distance of 20 cm was maintained after thinning. Standard agronomic practices, such as fertilizer application, weeding, and pest management, were followed as per recommended guidelines.

Data on morpho-physiological and biochemical traits were recorded from five randomly selected plants in each treatment, including both parents and F₁ hybrids. The traits measured comprised plant height (cm), length of main raceme (cm), leaf area index, number of primary and secondary branches, number of siliques per plant, seed yield per plant, biological yield, 1000-seed weight (g), oil content (%), and protein content (%). Additionally, plot-based data were recorded for days to 50% flowering and days to maturity. Estimation of general and specific combining ability variances and their effects will be done according to the procedure of Arunachalam (1974) with the usage of R software packages.

Table 1: Parental genotypes, their sources, and characteristic features

S.N.	Genotype	Source	Characteristics of Genotype
1	RAJAT	DRMR, Bharatpur	Early maturity and moderate resistance to white rust
2	RGN-48	Agricultural Research Station, Sri Ganganagar	Resistant to frost, suitable for rainfed conditions
3	MAYA	Chandra Shekhar Azad University of Agriculture & Technology, Kanpur	White rust resistant
4	RH-0749	Haryana Agricultural University, Hisar	Thermo tolerant variety
5	RH-30	Haryana Agricultural University, Hisar	Early maturity and tolerance to mustard aphids
6	RL-1359	DRMR, Bharatpur	Drought tolerance and high seed yield
7	CS-60	Central Soil Salinity Research Institute, Haryana	Salt tolerant variety
8	LAXMI	Haryana Agricultural University, Hisar	High yield and early maturity
9	VAIBHAV	Chandra Shekhar Azad University of Agriculture & Technology, Kanpur	Adaptable to late sowing and tolerance to heat stress
10	RGN-73	Agricultural Research Station, Sri Ganganagar	Tolerant to lodging and shattering

RESULT AND DISCUSSION

Based on the analysis of general combining ability (GCA) and specific combining ability (SCA) effects for 14 agronomic and yield-related traits in 10 parents (7 female lines and 3 male testers) in the F_1 generation, several promising parental lines and hybrid combinations were identified. For all the traits studied, SCA variance was consistently higher than GCA variance, and both the predictability ratio and GCA/SCA ratio were below 1. This suggests that non-additive gene action played a major role in the inheritance of these traits in Indian mustard^[4,15,20,30].

For earliness traits like days to 50% flowering and days to maturity, several lines (RH-0749, RH-30, RGN-73, and Vaibhav) and testers (RGN-48 and RAJAT) showed desirable negative GCA effects. In terms of plant architecture, negative GCA for reduced plant height and shorter main raceme was observed in RH-0749, CS-60, and Laxmi among females, with MAYA contributing similarly among testers. Yield-contributing traits like leaf area index, primary and secondary branches per plant were positively influenced by lines such as RH-0749, RL-1359, RH-30, Laxmi, RGN-73, and Vaibhav, while testers like RGN-48 and MAYA also contributed positively^[3,14]. For reproductive traits, RH-30 was a strong combiner for siliquae per plant, while negative effects were noted for seeds per siliquae in CS-60, Vaibhav, and RGN-73, and in RAJAT among testers. Biological yield and 1000-seed weight largely showed negative GCA in several females (RH-30, Vaibhav, RGN-73, CS-60, and Laxmi) and in RAJAT among testers. For quality traits, Vaibhav was superior for oil content, while RL-1359, CS-60, RGN-73, and Vaibhav, along with MAYA, were favourable for protein content. Importantly, for seed yield per plant, RH-0749, RH-30, and RL-1359 were good general combiners, whereas MAYA contributed negatively (Table 2, Fig.1)^[6,7,16,25]. The consistent performance of good combiners reflects stability across generations, possibly due to diversity in parents with significant desirable and high gca effects (Table 4).

Based on the magnitude of Specific Combining Ability (SCA) effects (Table 3), several cross combinations were identified as the most promising for various traits. For earliness traits, crosses like RH-30 $\times$ RAJAT, CS-60 $\times$ MAYA, and LAXMI $\times$ MAYA showed significant negative effects for days to 50% flowering, while VAIBHAV $\times$ RGN-48, RH-30 $\times$ MAYA, and RL1359 $\times$ RAJAT were among the best for reducing days to maturity. In terms of plant architecture, VAIBHAV $\times$ MAYA and RL1359 $\times$ RGN-48 increased plant height, while crosses like RL1359 $\times$ MAYA and RH-30 $\times$ MAYA decreased it^[1,22,24]. For the length of main raceme, crosses such as RH-30 $\times$ RAJAT and RL1359 $\times$ RGN-48 had highly significant positive effects.

Significant improvement in leaf area index was noted in crosses like RL1359 $\times$ RAJAT, CS-60 $\times$ RAJAT, and VAIBHAV $\times$ RAJAT. For branching traits, combinations such as RL1359 $\times$ RGN-48 and RH-0749 $\times$ RGN-48 enhanced the number of primary and secondary branches.

Yield-contributing traits like number of siliquae per plant were improved by crosses like RGN-73 $\times$ MAYA and RL1359 $\times$ RAJAT, while number of seeds per siliqua was highest in combinations including RL1359 $\times$ RGN-48 and CS-60 $\times$ RAJAT. For biological yield, crosses such as RL1359 $\times$ RAJAT and RGN-73 $\times$ MAYA showed highly significant positive effects. In seed quality traits, LAXMI $\times$ RAJAT, RH-30 $\times$ MAYA, and RL1359 $\times$ RAJAT were best for 1000-seed weight, while RGN-73 $\times$ RAJAT and CS-60 $\times$ MAYA excelled in oil and protein content. Finally, for seed yield per plant, RL1359 $\times$ RAJAT was the top-performing cross, followed by RGN-73 $\times$ MAYA, both showing significant positive contributions^[10,13,27,29]. The specific combining ability (SCA) effects, which reflect the non-additive portion of genetic variance, are particularly useful in distinguishing crosses based on their genetic potential as breeding materials. However, in self-pollinated crops, SCA effects generally have limited impact on improvement, except in cases where heterosis can be commercially utilized^[5,9,12,17].

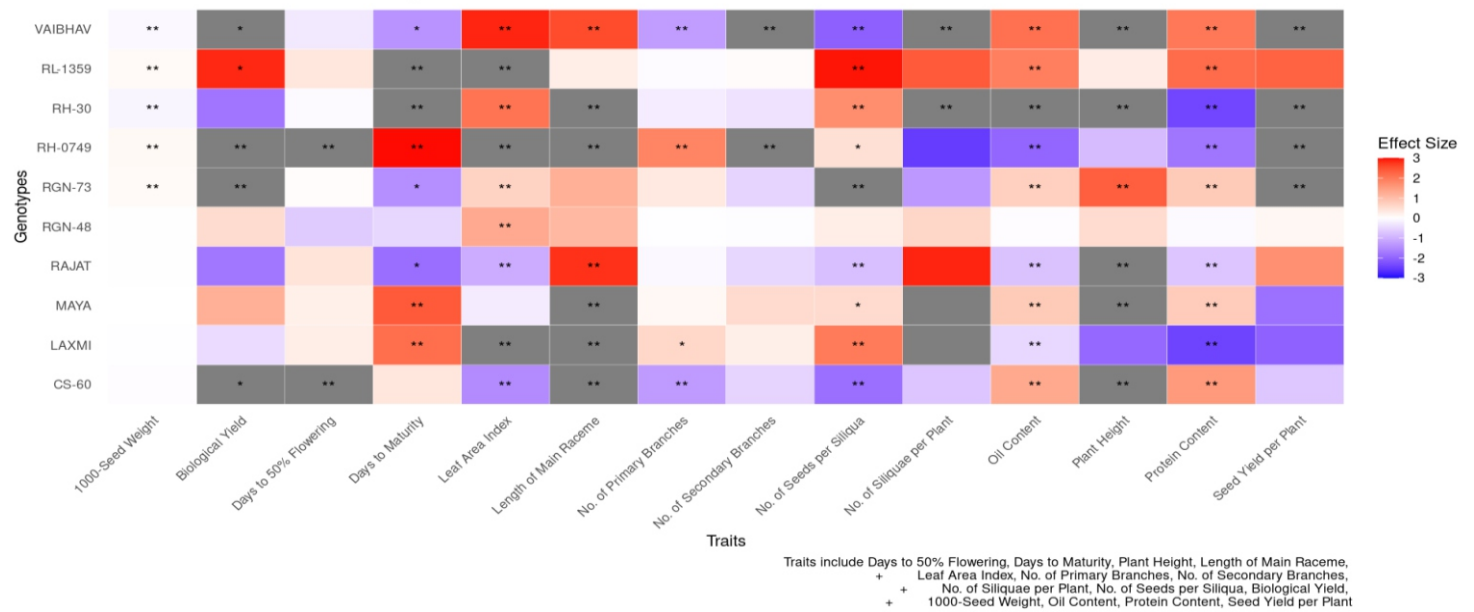
The contribution of lines and testers to genetic variation is reflected by the contribution of lines and testers, while non-fixable effects are shown by the lines $\times$ testers component. The relative contribution of the lines $\times$ testers was also higher than their corresponding contribution of testers for all the characters. The proportional contribution of lines, testers, and their interactions for fourteen traits is represented in Table 5. Lines showed maximum contribution for leaf area index and length of main raceme, while testers contributed most to number of siliquae per plant and main raceme length. Line $\times$ tester interaction contributed substantially, particularly for plant height. Overall, the results indicate the predominance of non-fixable genetic variation, as also supported by the higher SCA variance compared to GCA variance for most traits. These cross combinations are most likely to give transgressive segregants in subsequent generations^[7,17,19,23,25].

Conclusion

The recent experiment highlights the critical role of both general combining ability (GCA) and specific combining ability (SCA) in selecting parent lines for hybrid breeding programs. Parents exhibiting strong GCA, such as RH-0749, RH-30, VAIBHAV, and RL-1359, are valuable for developing superior varieties through selection in segregating populations, as they

Table 2: Estimates of GCA effects for fourteen characters in Indian mustard

Sl No.	Parent	Days to 50% Flowering	Days to Maturity	Plant Height	Length of Main Raceme	Leaf Area Index	No. of Primary Branches	No. of Secondary Branches	No. of Siliquae per Plant	No. of Seeds per Siliqua	Biological Yield	1000-Seed Weight	Oil Content	Protein Content	Seed Yield per Plant
1	RAJAT	0.429	-1.879*	3.686**	2.803**	-1.063**	-0.089	-0.517	2.883	-0.822**	-1.771	-0.014	0.788**	0.738**	1.709
2	RGN-48	-0.667	-0.517	0.552	1.089	1.319**	-0.022	-0.041	0.635	0.263	0.543	0.013	-0.034	-0.058	0.132
3	MAYA	0.238	2.397**	-4.238**	-3.892**	-0.256	0.111	0.559	-3.517	0.559*	1.229	0	0.822**	0.795**	-1.841
4	RH-0749	-5.619**	2.978**	-0.863	-5.613**	4.388**	1.863**	4.835**	-2.511	0.483*	8.546**	0.098**	1.984**	1.778**	4.525**
5	RH-30	-0.063	-7.044**	3.403**	5.876**	2.092**	-0.225	-0.365	6.289**	1.727**	-1.787	0.128**	3.644**	2.389**	4.554**
6	RL-1359	0.381	4.400**	0.292	0.276	6.570**	-0.048	0.057	2.4	2.949**	2.857*	0.094**	1.936**	2.191**	2.311
7	CS-60	5.270**	0.378	7.730**	3.254**	1.505**	-1.292**	-0.543	-0.733	-1.873**	3.924*	-0.033	1.325**	1.551**	-0.715
8	LAXMI	0.27	2.156**	-1.952	-7.590**	6.332**	0.619*	0.257	3.178	1.994**	-0.454	-0.024	0.502**	2.415**	-2.042
9	VAIBHAV	-0.286	-1.400*	4.492**	2.565**	2.875**	-1.270**	-3.698**	-7.289**	-2.051**	-6.143*	0.082**	2.127**	2.022**	-3.859**
10	RGN-73	0.048	-1.467*	2.359**	1.232	0.688**	0.352	-0.543	-1.333	-3.229**	-6.943**	0.075**	0.743**	0.817**	-4.775**

GCA Estimates for Different Genotypes and Traits**Fig. 1. Visual representation of GCA estimates for different genotypes and traits, with significance levels (* at 5% and ** at 1% probability)****Table 3: Estimates of SCA effects for fourteen characters in Indian mustard**

S.N.	Hybrids	Days to 50% Flowering	Days to Maturity	Plant Height	Length of Main Raceme	Leaf Area Index	No. of Primary Branches	No. of Secondary Branches	No. of Siliquae per Plant	No. of Seeds per Siliqua	Biological Yield	1000-Seed Weight	Oil Content	Protein Content	Seed Yield per Plant
1	RH-0749 X RAJAT	-0.095	3.013**	-3.441	-15.092**	0.901**	-0.244	-0.816*	-12.994	-0.311	-2.984	-0.01	1.735**	1.080*	-2.673
2	RH-0749 X RGN-48	0	-4.416**	-3.841	5.822**	-2.154**	0.689**	1.975**	12.054*	-0.197	10.568**	-0.167**	0.04	-0.684	0.858
3	RH-0749 X MAYA	0.095	1.403	7.283	9.270**	1.253**	-0.444	-1.159**	0.94	0.508*	-7.584*	0.177**	-1.775**	-0.396	1.815
4	RH-30 X RAJAT	-2.984**	-1.165	10.292	19.419**	-5.712**	1.311**	3.317**	5.473	3.156**	0.283	-0.192**	0.141	0.241	1.165
5	RH-30 X RGN-48	0.778	6.273**	8.625	-7.600**	3.146**	-1.289**	0.841*	-0.546	1.159*	-1.765	-0.011	0.414*	0.241	1.329
6	RH-30 X MAYA	2.206*	-5.108**	-18.917*	-11.819**	2.567**	-0.022	-4.159**	-4.927	1.997**	1.483	0.203**	-0.555*	-0.482	-2.494
7	RL1359 X RAJAT	0.571	-4.210**	6.137	1.086	8.150**	-0.067	-0.038	18.962**	1.778**	21.371**	0.163**	-4.225**	-3.756**	6.695**
8	RL1359 X RGN-48	-1.667	3.762**	19.070*	6.667**	-2.865**	1.267**	-2.914**	-1.924	3.937**	-11.943**	-0.143**	3.887**	2.718**	-2.754
9	RL1359 X MAYA	1.095	0.448	25.206**	-7.752**	-5.284**	-1.200**	2.952**	17.038**	2.159**	-9.429*	-0.019	0.338*	1.038*	-3.941
10	CS-60 X RAJAT	0.349	-2.187*	-0.975	9.641**	7.439**	-0.356	-3.305**	-11.305*	1.778**	2.171	-0.090**	0.606**	2.061**	-2.633
11	CS-60 X RGN-48	1.444	0.051	-11.975	-7.244**	-3.810**	0.111	1.886**	6.543	2.375**	-5.343	0.104**	-5.509**	-4.752**	1.005
12	CS-60 X MAYA	-1.794*	2.137*	12.949	-2.397*	-3.629**	0.244	1.419**	4.762	0.597*	3.171	-0.014	4.903**	2.692**	1.628
13	LAXMI X RAJAT	0.349	-0.698	-3.819	-9.048**	-4.721**	-0.067	0.495	-0.349	1.244*	-8.384*	0.224**	1.059**	0.7	-1.228
14	LAXMI X RGN-48	1.444	0.273	1.114	1.733	1.143**	0.133	-0.914*	-0.635	-1.175*	4.102	-0.022	-0.675*	0.486	0.009

15	LAXMI X MAYA	-1.794*	0.425	2.705	7.314**	3.578**	-0.067	0.419	0.984	-0.07	4.283	-0.202**	-0.384	-1.186*	1.219
16	VAIBHAV X RAJAT	0.238	3.924**	-4.53	0.33	4.719**	0.089	4.784**	14.651*	0.956*	3.305	-0.019	-3.590**	-4.414**	4.705
17	VAIBHAV X RGN-48	-0.667	-7.771**	-15.130*	5.178**	1.443**	-0.178	-2.159**	-9.368	2.663**	0.39	0.052**	2.763**	2.183**	-0.868
18	VAIBHAV X MAYA	0.429	3.848**	19.660*	-5.508**	-6.162**	0.089	-2.625**	-5.283	1.708**	-3.695	-0.033	0.827**	2.230**	-3.838
19	RGN-73 X RAJAT	1.571	1.324	-3.663	-6.337**	10.775**	-0.667*	-4.438**	-14.438*	1.267**	-15.762**	-0.075**	4.275**	4.088**	-6.033*
20	RGN-73 X RGN-48	-1.333	1.829*	2.137	-4.556**	3.097**	-0.733*	1.286*	-6.124	1.314**	3.99	0.186**	-0.920**	-0.192	0.421
21	RGN-73 X MAYA	-0.238	-3.152**	1.527	10.892**	7.678**	1.400**	3.152**	20.562**	2.581**	11.771**	-0.111**	-3.355**	-3.896**	5.611*
	SE(Sij)±	1.50943	1.31362	12.8677	2.03466	0.62062	0.44439	0.67465	9.681	0.4826	5.01354	0.02668	0.25309	0.51714	2.685
	SE(Sij-Sik)±	2.13466	1.85774	18.1977	2.87745	0.87769	0.62847	0.9541	13.691	0.6825	7.09022	0.03773	0.35792	0.73135	3.79716

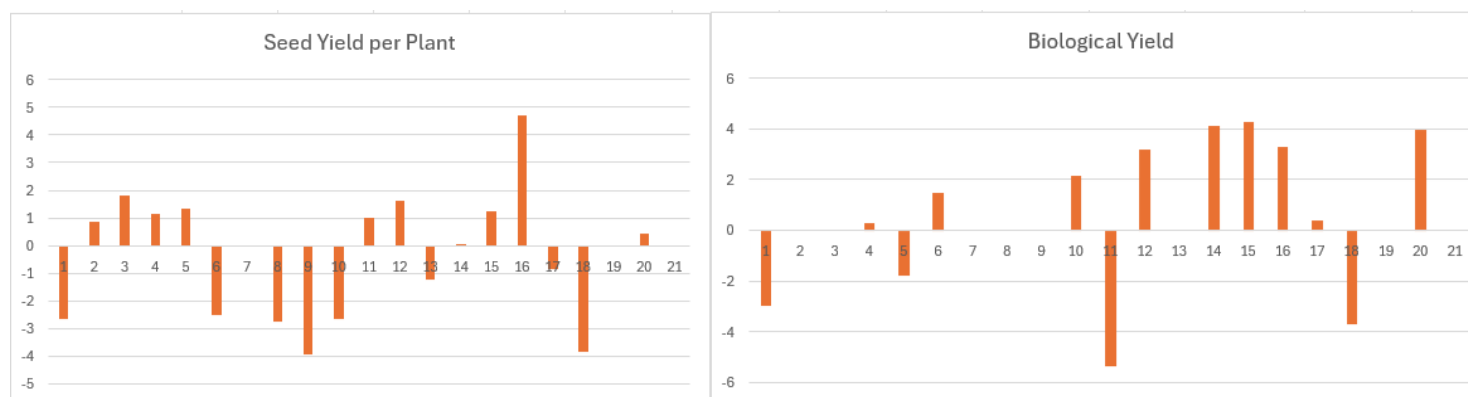


Fig. 2. Visual representation of SCA effects of for key traits
(Note: Extreme values are not represented which are above 6)

Table 4. Estimate of components of genetic variance and related parameter through combining ability for 14 characters in *F₂* generation of 7 x 3-line x tester cross in Indian mustard (*Brassica juncea* L.): mean sum of square

Source of variation	Days to 50% flowering	Days to maturity	Plant height	Length of raceme	Leaf area index	No. of primary branch	No. of secondary branches	No of siliquae per plant	Seed per siliquae	Biological yield per plant	1000 seed weight	Oil content	Protein content	Seed yield per plant
$s^2 2g$	2.66	3.60	27.86	10.30	1.80	0.20	0.13	23.73	0.86	13.16	0.002	0.56	0.30	10.46
$s^2 2s$	0.60	18.60	55	12.5	43.15	0.66	10.60	91	6.22	95.66	0.02	11.23	9.78	10.10
$s^2 2A$	5.32	7.20	55.60	20.60	3.60	0.41	0.26	47.40	1.73	26.20	0.05	1.12	0.60	20.92
$s^2 2D$	0.60	18.60	55	12.5	43.15	0.66	10.60	91	6.22	95.66	0.02	11.23	9.78	10.10
GPR	0.89	0.27	0.50	0.14	0.07	0.38	0.02	0.34	0.21	0.21	0.18	0.091	0.05	0.67
GCA/SCA Ratio	4.43	0.19	0.50	0.08	0.04	0.31	0.01	0.26	0.13	0.13	0.11	0.050	0.03	1.03

$s^2 2g$ =GCA variance, $s^2 2s$ =SCA variance, $s^2 2A$ =additive genetic variance, $s^2 2D$ =Dominance genetic variance, GPR=General predictability ratio

Table 5: Proportional contribution of lines, testers and their interactions to total variance in a set of line x tester crosses in Mustard

Sno	Characters	Contribution (%)		
		Line	Tester	Line * Tester
1	Days to 50% flowering	81.9808	2.19604	15.82315
2	Days to maturity	45.4826	11.67616	42.84124
3	Plant height	9.61430	7.024315	83.36138
4	Length of Main Raceme	19.86379	7.873491	72.26272
5	Leaf Area Index	39.32907	2.284346	58.38658
6	No. of primary branches per plant	67.59276	0.4471852	31.96005
7	No. of secondary branches per plant	44.8396	1.60794	53.55246
8	No. of siliquae per plant	12.9408	5.434192	81.62501
9	No. of seeds per siliqua	56.24541	4.079486	39.67511
10	Biological Yield	27.33503	1.695301	70.96967
11	1000-seed weight	29.23827	0.5265529	70.23517
12	Oil Content	34.91167	3.767081	61.32125
13	Protein content	38.03198	3.925957	58.04207
14	Seed Yield Per Plant	51.42382	8.539328	40.03685

contribute positively to multiple traits. Hybrids like RL1359 × RAJAT, RH-30 × RAJAT, and RGN-73 × MAYA demonstrated high SCA, indicating their potential for enhancing early maturity, yield, and quality traits through heterosis breeding. Further evaluation of hybrids with significant SCA effects across various desirable traits is recommended to improve seed yield and quality for commercial applications.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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