GENETIC ARCHITECTURE AND LINE × TESTER ANALYSIS FOR THERMOTOLERANCE AND YIELD IN INDIAN MUSTARD (BRASSICA JUNCEA L.)

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ABSTRACT
The present study focused on the general combining ability (GCA), specific combining ability (SCA), standard heterosis (SH), and per se performance of mustard genotypes for various physio-morphological-quality traits. The best general combiners identified based on GCA and individual performance were NRC-DR-2 (SLW at 30 DAS, CC at 60 DAS, LAI at 30 DAS), RH-30 (SLW at 60 DAS, PB/Pl), Rajendra Sufalam (SLW at 60 DAS, 1000 SW), NDRE-7 (Early DFFO & DPM), TPM-1 (SS), and RAURD-78 (PB/Pl). Among the studied hybrids, the top yielders were RH-30/RAURD-78, Rajendra Sufalam/NDRE-7, PM-25/RAURD-78, and RH-8814/TPM-1, based on SCA, SH, and per se performance. The RH-30/RAURD-78 cross, which involved two good general combiners, is a promising candidate for heterosis breeding. Additionally, the Rajendra Sufalam/NDRE-7 and PM-25/RAURD-78 crosses, which involved HxL or LxH general combiners, may generate desirable segregants suitable for transgressive breeding programs. The four best economic crosses for seed yield per plant (SY/pl)—RH-30/RAURD-78, Rajendra Sufalam/NDRE-7, PM-25/RAURD-78, and RH-8814/TPM-1—showed superior heterosis for key traits such as SLW (60 DAS), CGR, PH (60 DAS), PB/Pl, and SB/Pl. These superior F_1 hybrids demonstrated significantly higher yield potential along with desirable morpho-physiological and quality traits, making them valuable for future breeding endeavours aimed at enhancing mustard productivity and resilience.

KEYWORDS: General Combining Ability (GCA), Specific Combining Ability (SCA), Heterosis, Seed Yield, Thermotolerance

Introduction

Crop Brassicas, particularly Indian mustard (Brassica juncea L.), play a crucial role in India's edible oil economy and were instrumental in achieving near self-sufficiency during the "Yellow Revolution" of the early 1990s. However, in subsequent decades, fluctuating climatic conditions and yield stagnation have posed significant challenges to mustard production, necessitating the search for thermotolerant genotypes suitable for diverse sowing conditions. Indian mustard experiences temperature sensitivity throughout its growth cycle, from germination and seedling development to flowering and physiological maturity, making heat tolerance a critical breeding objective (**Hall, 1992**). High-temperature stress, particularly during the germination stage in early sown crops and the reproductive stage in late-sown agro-ecologies, limits plant productivity and prevents crops from realizing their full genetic potential. The Intergovernmental Panel on Climate Change (**IPCC, 2007**) has projected a temperature increase of 0.5–1.2°C by 2020, 0.88–3.16°C by 2050, and 1.56–5.44°C by 2080 in India, which could lead to an estimated 10–40% decline in crop production. Given the substantial impact of high temperatures on germination, seedling growth, and post-flowering reproductive stages, breeding for thermotolerant mustard genotypes is imperative.

Since heat tolerance is stage-specific, a genotype that exhibits tolerance at one developmental stage may not necessarily do so at another (**Wahid et al., 2007**). Thus, it is essential to evaluate morpho-physiological traits and yield determinants at multiple growth stages to identify suitable parental lines, hybrids (F_1s), and high-performing combiners (general and specific combiners) for mustard breeding programs.

The selection of an appropriate breeding method depends largely on the nature and magnitude of gene effects, which can be estimated using various biometrical techniques. Among these, combining ability analysis is a powerful tool for identifying superior parents and hybrid combinations. This study aims to contribute valuable insights into thermotolerance breeding in Indian mustard by identifying genotypes, hybrids, and selection strategies that enhance productivity under heat-stressed environments. Studies have shown that early sowing not only improves growth rates but also reduces the impact of pests and diseases, thereby contributing to higher yields and better crop quality (**Sharma & Meena, 2021**).

Line × Tester analysis is a widely used breeding method for evaluating the combining ability of parental lines and understanding the genetic potential of crosses. In crops like Indian mustard (Brassica juncea), this approach has proven particularly beneficial for identifying superior hybrids under specific environmental conditions, such as early sowing. Early sowing of mustard in India is advantageous, as it enables crops to better utilize available soil moisture and sunlight, enhancing growth and yielding potential in comparison to late-sown varieties (**Singh et al., 2019**). Heat stress at both the seedling and terminal stages significantly affects growth and productivity, necessitating the development of temperature-resilient varieties (**Campos et al., 2003**). To enhance yield potential and ensure stability in diverse agro-ecological conditions, breeding efforts must focus on early-sown Indian mustard varieties as an alternative to toria (Brassica rapa L.). Indian mustard, being an amphidiploid (AABB), offers genetic advantages over the diploid toria (AA), making it a more viable choice for early sowing systems. Additionally, its adaptability to diverse cropping systems further strengthens its potential as a superior alternative for sustainable oilseed production in changing climatic conditions.

MATERIALS AND METHODS:

The experimental material comprised of of 21 F1s of Indian mustard (Brassica juncea)involving 7 lines namely RH-8814(RH 765 x R-74-3),RH-30(Selection from P26/3-1),NRC-DR-2(MDOC 43/NBPGR 36),Pusa Mahak(Pusa Bold x Glossy mutant), Rajendra Suflam(Pure line selection) ,Varuna(Pure line selection from Varanasi local) and PM-25(SEJ-8 x Pusa Jagannath)and three testers RAURD-78(Varuna /PBN 9501),NDRE-7(Sekhar/Seeta) and TPM-1(Gamma ray induced mutant of RL 9) were crossed in line × tester mating design. The aim of the present study was to evaluate GCA and SCA of high yielding varieties and breeding lines with early maturing and thermotolerant testers. Therefore, in the present study the three testers were selected on the basis of their thermotolerance ability tested under three different temperatures regimes in the laboratory. The crosses along with their parents were planted in randomized complete block design with three replications during early sown condition at research farm of TCA, Dholi, DRPCAU, Pusa. The treatments were raised in rows of 5m length with a distance of 30cm between rows and 15cm between plants, where each treatment was represented by two rows. Standard agronomic practices were followed to raise the good crop. Recommended doses of fertilizers viz., 80:40:40:40 kg/ha of N:P:K:S, respectively, were applied and irrigated at two critical Phenological stages keeping depth of Irrigation water approximately 3 inch (7.5 cm), first at 30 DAS: Pre -Flowering budding stage and Second: at 60 DAS: Post Flowering siliqua filling stage. Observations were recorded on twenty-one physio-morphological and quality traits, viz., Plant height (**PH**) (30 &60 DAS),Leaf Area Index (**LAI**) (30 & 60 DAS),Chlorophyll content (**CC**)(30 60 DAS),Specific Leaf Weight (**SLW**)(30 &60 DAS),Crop Growth Rate (**CGR**) (30 &60 DAS), Days to first flower open (**DFFO**) ,Days to physiological maturity (**DPM**) ,Length of primary mother axis (**LPMA**), Number of primary branches per plant (**PB/pl**) ,Number of secondary branches per plant , Siliqua on main shoot(**SOMS**), Number of siliqua per plant (**S/S**) ,1000 seed weight (**SW**)(g),Harvest index (**HI**) (%),Dry matter efficiency (**DME**) , Oil Content (**OC**)(%) and Seed yield per plant (**Sy/pl**)(g). Observations for 21 morpho-physiological-quality traits including 4 characters at two phenological stages i.e., 30 & 60 DAS were recorded on five randomly selected competitive plants from each replication except for days to first flower open and days to maturity. Observations on days to flowering and maturity were recorded on per plot basis, seed yield was converted & expressed in kg per hectare and the observations on remaining traits were recorded on randomly selected five competitive plants in each replication. Readings from the five plants were averaged, replication-wise and the mean data was used for statistical analyses. The percentage oil content of rapeseed mustard seeds was analysed using a FT-NIRS at DRMR, Bharatpur, Rajasthan. The combining ability analysis was carried out as per the method of **Kempthorne** (**1957**). The calculations were performed through computer generated programme WINDOSTAT version 9.2 from WINDOSTAT Services, Hyderabad, India.

Determination of physio-morphological characters: For estimation of leaf area index, specific leaf weight, crop growth rate, the plant samples were uprooted above ground level at 30 and 60 days after sowing. Each collected sample were separated to different plant parts and leaf area were measured using graph paper. The collected plant samples were dried separately at 40-45°C in hot air oven for 8-10 days till constant weight was achieved and dry matter of leaves, shoot as well as shoot+ leaves were recorded using electronic weighing machine expressed in g/m. Observations were recorded and the data was subjected to statistical analysis.

RESULTS AND DISCUSSION

Analysis of variance for combining ability

Significant differences were observed among parents and crosses for most traits, justifying their selection for combining ability analysis, except for plant height at 30 DAS, SLW at 30 DAS, LPMA, and DME in early sown conditions. The presence of significant GCA and SCA variance indicated both additive and non-additive gene effects, aligning with previous findings (**Goswami & Behal, 2005; Monalisa et al., 2005; Singh, 2007; Akbar et al., 2008**). Higher SCA variance suggested the predominance of non-additive gene action (Gupta et al., 2010), while GCA variance was higher for LPMA, indicating additive genetic control. Maximum variance contribution from Line × Tester analysis supports heterosis breeding for mustard improvement (**Vaghela et al., 2011; Patel**

et al., 2012; Arifullah, 2013). Maximum contribution for the variance was observed by Line x Tester followed by line than testers indicating that heterosis breeding may be effective using diverse parental lines for the improvement of Indian mustard.

General Combining Ability Effects, Specific Combining Ability Effects and Gene Interaction:

General and specific combining ability estimates help to ascertain the breeding potential of genotypes. While, the former reveals about the ability of various genotypes, when used as parents, to reliably transmit their genetic potential to hybrid progeny, the later highlights the unexpected favourable or unfavourable gene interactions in various genotypes. Thus, based on such information breeder can spot superior donor parents having high gca effect and per se performance and also identifying promising crosses for use in improvement work. In mustard where pedigree breeding is cardinal, crosses with high mean and sca effects are more likely to show transgressive segregation and lead to development of superior pure lines.

General Combining Ability Effects:

The present study focused on general combining ability (GCA) and specific combining ability (SCA) to identify superior parental lines and promising cross combinations in Indian mustard (Brassica juncea). Combining ability analysis plays a crucial role in understanding the genetic basis of yield-contributing traits and their inheritance, which is essential for designing effective breeding strategies (**Sprague & Tatum, 1942; Singh & Dixit, 2007**). The line × tester mating design was used to estimate GCA and SCA effects, helping in the selection of high-yielding, climate-resilient mustard genotypes (**Kempthorne, 1957**).

2. Identification of Superior General Combiners:

General combining ability (GCA) estimates reflect the additive genetic effects of parental lines and their ability to transmit favorable traits to progeny. In this study, significant GCA effects were observed for key morpho-physiological traits, indicating strong additive genetic control over these attributes. Among the evaluated genotypes, NRC-DR-2, NDRE-7, Rajendra Sufalam, RH-30, TPM-1, and RAURD-78 emerged as the best general combiners for multiple agronomic and physiological traits. Specifically, NRC-DR-2 exhibited high GCA effects for leaf area index (LAI) at 60 DAS, chlorophyll content (CC) at 60 DAS, specific leaf weight (SLW) at 30 and 60 DAS, crop growth rate (CGR), leaf per unit mass area (LPMA), and seed yield per plant (**SY/pl**). Similarly, NDRE-7 was identified as a strong general combiner for LAI (60 DAS), SLW (60 DAS), days to first flower open (DFFO), days to physiological maturity (DPM), oil content (OC), and SY/pl. Rajendra Sufalam showed high GCA effects for plant height (PH) at 60 DAS, CC (30 DAS), SLW (60 DAS), CGR, DPM, and 1000-seed weight (1000 SW), while RH-30 exhibited superior GCA for SLW (60 DAS) and primary branches per plant (PB/pl). Additionally, TPM-1 demonstrated high GCA effects for CC (30 and 60 DAS), secondary branches per plant (SB/pl), and seeds per siliqua, and RAURD-78 showed strong potential for PH (30 DAS), CGR, PB/pl, SB/pl, siliqua on main shoot (SOMS), and 1000 SW. The high GCA values in these genotypes indicate their fixable genetic potential, making them ideal candidates for pedigree breeding programs to improve yield and stress tolerance in Indian mustard (**Sprague & Tatum, 1942; Verma et al., 2012**).

3. Role of Specific Combining Ability (SCA) and Heterosis

Specific combining ability (SCA) effects denote non-additive genetic interactions, essential for identifying heterotic crosses in hybrid breeding. Several promising cross combinations exhibited significant SCA effects, indicating strong heterosis expression.

Cross Combination	Key Traits with High SCA Effects
RH-30/RAURD-78	PB/pl, SB/pl, SY/pl
Rajendra Sufalam/NDRE-7	CGR, 1000 SW
PM-25/RAURD-78	SLW (30 & 60 DAS), CC (30 DAS)
RH-8814/TPM-1	Oil content, SY/pl

The RH-30/RAURD-78 cross, which involved two good combiners, demonstrated high heterotic potential, making it suitable for hybrid development (Singh et al., 2005; Patel et al., 2012).

4. Genetic Action in Yield-Contributing Traits

- High GCA effects suggest the predominance of additive gene action, which is favorable for pure-line selection.
- High SCA effects indicate the role of dominance and epistatic interactions, beneficial for heterosis breeding (**Gupta et al., 2011; Verma et al., 2012**).

These findings align with previous studies on heterosis and yield improvement in mustard (Singh et al., 2005; Patel et al., 2012).

Heterosis breeding plays a crucial role in enhancing seed yield, oil content, and heat tolerance in Indian mustard. The study identified RH-30/RAURD-78 and Rajendra Sufalam/NDRE-7 as the most heterotic crosses, demonstrating significant improvements in yield and physiological efficiency, making them suitable for climate-resilient mustard breeding (Singh & Dixit, 2007). Additionally, early sowing is a vital strategy for mitigating heat stress, as it helps in avoiding terminal heat stress during the critical stages of flowering and seed filling, allows better soil moisture utilization and root development, and reduces pest and disease incidence, particularly aphid infestation (**Singh et al., 2013**). Furthermore, marker-assisted selection (MAS) has emerged as a powerful molecular breeding tool for accelerating mustard improvement by enabling the targeted selection of genes associated with heat tolerance (HSP genes) and high oil content (FAD genes). Integrating these breeding strategies can significantly enhance the adaptability and productivity of Indian mustard under climate-stressed environments, ensuring sustainable oilseed production in the face of global temperature fluctuations.

5. Future Prospects and Conclusion

The findings of this study establish NRC-DR-2, RAURD-78, NDRE-7, and Rajendra Sufalam as elite general combiners for mustard breeding programs, while crosses such as RH-30/RAURD-78 and RajendraSufalam/NDRE-7 demonstrated superior heterotic effects, making them valuable for hybrid seed production. The results emphasize the importance of integrating early sowing, hybridization techniques, and selection strategies to develop heat-tolerant and high-yielding mustard varieties. Future research should focus on developing genomic-assisted selection models to enhance breeding efficiency, improving hybrid seed production techniques for large-scale adaptation, and conducting extensive field trials to validate the stability and adaptability of superior genotypes across different environments. This study provides a strong foundation for sustainable mustard breeding and contributes to the development of climate-resilient oilseed production systems (**Singh et al., 2005; Gupta et al., 2010; Verma et al., 2012**).

Figure 1. Differential performance of mustard genotypes under varied temperature regimes (25 ^oC, 30 ^oC, 35 ^oC respectively)

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Table 1. Analysis of variance for combining ability for 21 physio-morphological and quality characters

	df	PH(30 DAS)	PH (60 DAS)	LAI (30 DAS)	LAI (60 DAS)	CC (30 DAS)	CC (60 DAS)	SLW (30 DAS)	SLW (60 DAS)	DFFO	CGR
Replication	2	7.6	77.23	0.01	1.17	0.27	6.15	0.14x10^{-5}	0.09x10^{-6}	32.3	0.04
Treatments	30	12.68*	2632.14**	0.18**	10.41**	22.5**	64.12**	0.14x10^{-5}	0.06x10^{-5}*	40.66**	1.96**
Parents	9	5.83	322.63	0.26**	9.74**	27.88**	65.31**	0.14x10^{-5**}	0.06x10^{-5}*	47.32**	0.06**
Parents (Line)	6	7.69	284.02	0.34**	9.37**	32.35**	68.59**	0.14x10^{-5}	0.09x10^{-5}*	40.71**	0.06**
Parents (Testers)	2	1.34	582.26*	0.06**	10.44**	3.29	23.85*	0.14x10^{-5}	0.01x10^{-5}	74.33**	0.09**
Parents (L Vs T)	1	3.63	35.05	0.18**	10.55**	50.24**	128.57**	0.14x10^{-5}*	0.03x10^{-5}	32.91*	0.04*
Parents Vs Crosses	1	18.83	43912.3**	0	127.23**	34.74**	483.28**	0.14x10^{-5}*	0.02x10^{-5}*	226.24**	25.71**
Crosses	20	15.46**	1607.41**	0.15**	4.87**	19.47**	42.63**	0.14x10^{-5**}	0.05x10^{-5}*	28.39**	1.62**
Line Effect	6	15.26	2414.2	0.13	5.9	4.18	35.11*	0.01x10^{-4}	0.04x10^{-5}	26.44	1.31
Tester Effect	2	26.75	757.09	0.39	2.5	33.3	3.54	0.01x10^{-4}	0.03x10^{-5}	58.78	1.57
Line * Tester Eff.	12	13.68*	1345.74**	0.12**	4.75**	24.81**	52.9**	0.01x10^{-4}	0.06x10^{-5}*	24.3**	1.78**
Error	60	6.77	176.82	0	0.25	1.65	3.95	0.01x10^{-4}	0.04x10^{-5}	6.75	0.01
Total	92	8.72	975.3	0.06	3.58	8.42	23.62	0.01x10^{-4}	0.02x10^{-5}	18.36	0.65

Table 2. General Combining ability effects of parents for 21 physio-morphological quality characters in Indian mustard

	df	PB/PL	SB/PL	SOMS	S/S	LPMA	SY/PL	HI	DPM	DME	1000SW	OC
Replication	2	2.20	17.69	1.86	0.79	321.00	3.29	1.38	0.52	0.00	0.07	0.07
Treatments	30	9.62**	1265.01**	125.86**	6.86**	1102.11**	499.38**	135.87**	37.91**	0.02*	0.36**	1.45**
Parents	9	2.17	181.26**	132.09**	4.7**	1315.57**	298.83**	284.48**	12.81**	0.03*	0.24**	0.99**
Parents (Line)	6	1.59	171.3**	123.79**	2.75*	1287.99**	414.89**	357.48**	14.76**	0.03**	0.29**	0.73*
Parents (Testers)	2	4.97	176.3*	184.83**	11.00**	1976.94**	82.33*	133.41*	5.44	0.01	0.12	2.23**
Parents (L vs T)	1	0.02	250.93*	76.41*	3.78*	158.30	35.47*	148.63*	15.87*	0.01	0.16	0.11
Parents vs Crosses	1	15.81**	6407.81**	108.22**	11.39**	0.00	5142.44**	186.21*	476.32**	0.08**	0.10	2.57**

Crosses	20	12.67**	1495.56**	123.94**	7.6**	1061.15**	357.47**	66.48**	27.29**	0.01	0.43**	1.61**
Line Effect	6	16.83	1619.21	54.02	11.06	3054.84**	439.37	32.50	26.62	0.00	0.50	1.04
Tester Effect	2	19.91	2165.90	11.56	6.97	86.44	859.44	127.91	32.97	0.01	0.67	4.70
Line * Tester Eff.	12	9.37**	1322.01**	177.63**	5.98**	226.76	232.86*	73.24**	26.67**	0.01	0.36**	1.37**
Error	60	1.65	28.43	6.69	0.78	170.85	59.66	20.03	2.79	0.01	0.06	0.28
Total	92	4.26	431.43	45.45	2.76	477.79	201.82	57.40	14.20	0.01	0.16	0.66

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

Parents	PH (30DAS)	PH (60DAS)	LAI (30DAS)	LAI (60DAS)	CC (30DAS)	CC (60DAS)	SLW (30DAS)	SLW (60DAS)	DFFO	CGR
RH-8814	-1.08	-13.79 **	-0.16 **	-0.70 **	-0.17	1.08	0.0002	0.0007**	0.29	-0.27**
RH-30	-1.84 *	-1.65	-0.08 **	0.07	0.33	-0.01	-0.0007 **	0.0002**	1.62	-0.03
NRC-DR-2	0.93	-27.62 **	0.16 **	-1.07 **	0.04	1.93 **	0.0009 **	0.0005 **	-0.83	0.27 **
Pusa Mahak	0.54	16.97 **	-0.03	0.20	-0.53	-1.80 **	0.0000	-0.0006 **	0.06	-0.02
R. Suflam	-0.08	17.26 **	-0.02	-0.18	0.95*	-3.02 **	0.0002	0.0007 **	2.40 **	0.71**
Varuna	-0.51	0.60	0.15**	1.48**	0.49	2.41 **	-0.0006 **	-0.0007 **	-0.71	-0.26**
PM-25	2.05*	8.22	-0.01	0.20	-1.11*	-0.60	0.0000	-0.0009 **	-2.83 **	-0.39 **
TPM1	-0.37	-6.25 *	-0.08 **	0.37**	0.97 **	0.17	-0.0001	-0.0004 **	-0.37	-0.26**
RAURD-78	1.27 *	0.52	-0.08 **	-0.32 **	-1.42 **	-0.47	0.0002	0.0001	1.83 **	0.28 **
NDRE-7	-0.89	5.73	0.16 **	-0.04	0.45	0.30	-0.0001	0.0004 **	-1.46 *	-0.02
CD 95% GCA(Line)	1.75	8.96	0.04	0.34	0.86	1.34	0.0004	0.0001	1.75	0.07
CD 95% GCA(Tester)	1.15	5.86	0.03	0.22	0.57	0.88	0.0003	0.0001	1.15	0.04

Parents	PB/pl	SB/pl	SOMS	SS	LPMA	SY/Pl	HI (%)	DPM	DME	1000 SW	OC (%)
RH-8814	**-0.15**	**-12.00****	**-3.34****	**-0.23**	**2.03**	**-6.29****	**2.44**	**0.05**	**0.02**	**-0.03**	**-0.52 ****
RH-30	**2.77****	**15.89****	**0.80**	**-0.70***	**8.36**	**16.04****	**0.76**	**1.16***	**0.00**	**-0.14**	**0.15**
NRC-DR-2	**0.45**	**19.94****	**-0.40**	**0.42**	**21.05****	**22.13****	**-1.46**	**1.16***	**-0.02**	**0.09**	**0.35**
Pusa Mahak	**0.01**	**-3.02**	**-2.27***	**1.26****	**13.81****	**-22.18****	**-2.67**	**-1.84****	**-0.01**	**-0.33****	**0.24**

R. Suflam	**-1.28****	**-15.17 ** **	**0.09**	**-2.05****	**-7.83**	**3.11**	**2.03**	**-1.51****	**0.03**	**0.43****	**-0.37***
Varuna	**-1.01***	**1.07**	**4.26****	**0.53**	**-1.86**	**7.76****	**-1.31**	**2.60****	**-0.03**	**0.04**	**-0.12**
PM-25	**-0.79**	**-6.71****	**0.86**	**0.77***	**-35.55****	**-7.78****	**0.22**	**-1.62****	**0.01**	**-0.07**	**0.27**
TPM1	**-1.07****	**-11.48****	**0.09**	**0.58****	**-0.90**	**-18.90****	**-2.77****	**-0.65**	**-0.02**	**-0.13***	**-0.24***
RAURD-78	**0.83****	**7.80****	**0.70**	**-0.57****	**2.32**	**6.83****	**1.96**	**1.44****	**0.01**	**0.20****	**-0.31***
NDRE-7	**0.25**	**3.68****	**-0.78**	**-0.01**	**-1.42**	**5.93****	**0.82**	**-0.79***	**0.01**	**-0.08**	**0.54****
CD 95% GCA(Line)	**0.86**	**3.59**	**1.74**	**0.59**	**8.81**	**4.63**	**3.01**	**1.13**	**0.06**	**0.17**	**0.36**
CD 95% GCA(Tester)	**0.57**	**2.35**	**1.14**	**0.39**	**5.76**	**3.03**	**1.97**	**0.74**	**0.04**	**0.11**	**0.23**

Table 3. Specific Combining ability effects of parents for 21 physio-morphological quality characters in Indian mustard

Crosses	**PH (30DAS)**	**PH (60DAS)**	**LAI (30DAS)**	**LAI (60DAS)**	**CC (30DAS)**	**CC (60DAS)**	**SLW (30DAS)**	**SLW (60DAS)**	**DFFO**	**CGR**
RH-8814/TPM1	0.57	1.45	0.17 **	-0.17	-3.05 **	3.99 **	0.00022	0.00044 **	-1.52	0.73 **
RH-8814/RAURD-78	1.73	9.92	-0.01	-0.21	0.18	-2.68 *	-0.00040	-0.00108 **	0.29	-0.42 **
RH-8814/NDRE-7	-2.31	-11.37	-0.16 **	0.38	2.87 **	-1.31	0.00017	0.00063 **	1.24	-0.31 **
RH-30/TPM1	0.60	4.56	0.09 *	2.25 **	1.65 *	-2.76 *	0.00044	-0.00100 **	-2.86	-0.55 **
RH-30/RAURD-78	-1.91	-31.00 **	-0.01	-2.11**	-0.86	-1.02	0.00016	0.00181 **	1.95	0.54 **
RH-30/NDRE-7	1.32	26.45 **	-0.07	-0.15	-0.79	3.78 **	-0.00060	-0.00081 **	0.90	0.01
NRC-DR-2/TPM1	-0.47	22.90 **	-0.09 *	-0.06	-0.56	1.97	-0.00111 **	-0.00033 **	0.92	-0.77 **
NRC-DR-2/RAURD-78	-0.08	-36.37 **	-0.13 **	0.56	0.80	-4.49 **	0.00194 **	-0.00186 **	0.06	0.87 **
NRC-DR-2/NDRE-7	0.55	13.47	0.21 **	-0.49	-0.24	2.51 *	-0.00083 *	0.00219 **	-0.98	-0.10
Pusa Mahak/TPM1	-1.25	-9.84	0.03	-1.77 **	0.10	-0.87	0.00011	-0.00022	-0.30	-0.49 **
Pusa Mahak/RAURD-78	0.38	17.26 *	0.23 **	0.61 *	3.93 **	0.60	0.00049	-0.00075 **	1.17	0.54 **
Pusa Mahak/NDRE-7	0.87	-7.42	-0.25 **	1.16 **	-4.04 **	0.27	-0.00060	0.00097 **	-0.87	-0.05
R. Suflam/TPM1	-3.23 *	-12.66	-0.09 *	0.50	3.79 **	-4.01 **	-0.00011	-0.00056 **	6.03 **	-0.58 **
R. Suflam/RAURD-78	0.67	16.97*	0.17 **	-0.64 *	-3.44 **	2.19	-0.00073	0.00192 **	-4.83 **	-0.27 **
R. Suflam/NDRE-7	2.56	-4.31	-0.08 *	0.14	-0.35	1.82	0.00084 *	-0.00137 **	-1.21	0.85 **
Varuna/TPM1	0.26	-2.78	-0.11**	-0.40	0.52	-2.01	0.00067	0.00056 **	0.81	1.18 **
Varuna/RAURD-78	0.22	6.53	-0.23 **	1.33 **	-2.32 **	7.39**	-0.00062	0.00037 **	-0.38	-0.67 **
Varuna/NDRE-7	-0.48	-3.75	0.34 **	-0.93 **	1.81 *	-5.38 **	-0.00005	-0.00092 **	-0.43	-0.51 **
PM-25/TPM1	3.51 *	-3.63	0.00	-0.35	-2.45 **	3.70 **	-0.00022	0.00111 **	-3.08 *	0.49 **

PM-25/RAURD-78	-1.00	16.69 *	-0.02	0.47	1.71 *	-2.00	-0.00084 *	-0.00041**	1.73	-0.60**
PM-25/NDRE-7	-2.51	-13.06	0.02	-0.12	0.74	-1.70	0.00106**	-0.00070**	1.35	0.10
CD 95% SCA	3.04	15.52	0.08	0.58	1.50	2.32	0.00074	0.00024	3.03	0.12

Crosses	**PB/Pl**	**SB/PL**	**SOMS**	**S/S**	**LPMA**	**SY/pl**	**HI (%)**	**DPM**	**DME**	**1000 SW**	**OC**
RH-8814/TPM1	1.23	9.75**	-0.20	0.49	3.06	18.61**	-0.84	1.43	-0.02	0.10	0.70*
RH-8814/RAURD-78	-1.47	-3.00	-4.27**	-0.63	-5.70	-18.72**	5.47*	-1.33	0.06	0.07	0.05
RH-8814/NDRE-7	0.24	-6.75*	4.47**	0.14	2.64	0.11	-4.63	-0.10	-0.05	-0.16	-0.74*
RH-30/TPM1	-1.73*	-10.27**	-4.26**	-1.65**	-6.07	-19.33**	-7.73**	2.98**	-0.10	0.05	0.74*
RH-30/RAURD-78	3.87**	38.64**	6.73**	-0.30	-4.23	9.32*	1.24	-0.11	0.01	-0.26	-0.89**
RH-30/NDRE-7	-2.15**	-28.37**	-2.46	1.94**	10.31	-30.69**	6.48*	-2.87**	0.08	0.21	0.16
NRC-DR-2/TPM1	-1.04	-12.98**	6.27**	-0.09	-5.36	-16.02**	2.50	-1.35	0.03	-0.17	0.01
NRC-DR-2/RAURD-78	0.86	11.86**	-3.61*	1.33*	9.41	2.55	-1.70	2.22	-0.03	0.00	-0.31
NRC-DR-2/NDRE-7	0.18	1.12	-2.66	-1.23*	-4.05	-27.38**	-0.80	-0.87	0.00	0.17	0.30
PusaMahak/TPM1	0.74	28.37**	2.20	1.40**	2.17	24.96**	4.54	1.32	0.04	0.16	-0.58
PusaMahak/RAURD-78	-1.16	-26.58**	-0.94	0.02	3.64	-27.23**	-4.89	-0.11	-0.05	0.14	1.02**
PusaMahak/NDRE-7	0.42	-1.79	-1.26	-1.41**	-5.81	2.27	0.35	-1.21	0.01	-0.30*	-0.43
R. Suflam/TPM1	0.90	-1.34	-7.55**	-0.29	2.02	-8.11*	2.94	-2.35*	0.05	-0.01	-0.73*
R. Suflam/RAURD-78	-0.74	-1.56	-0.43	1.26*	2.75	-46.16**	3.04	-3.44**	0.05	0.33*	0.30
R. Suflam/NDRE-7	-0.16	2.90	7.98**	-0.97	-4.77	14.43**	-5.98*	5.79**	-0.10	-0.32*	0.43
Varuna/TPM1	-0.10	-6.92*	-4.60**	0.93	14.28	2.14	-2.49	0.87	-0.03	-0.56**	-0.45
Varuna/RAURD-78	0.33	-14.00**	12.59**	-1.98**	-8.01	-7.18	-1.62	-0.89	-0.01	0.05	0.05
Varuna/NDRE-7	-0.22	20.92**	-8.00**	1.05*	-6.27	5.04	4.12	0.02	0.04	0.51**	0.39
PM-25/TPM1	0.01	-6.61*	8.14**	-0.78	-10.10	-2.26	1.08	-2.90**	0.03	0.43**	0.32
PM-25/RAURD-78	-1.69*	-5.36	-10.07**	0.30	2.14	8.55*	-1.54	3.67**	-0.04	-0.33*	-0.22
PM-25/NDRE-7	1.69*	11.97**	1.94	0.48	7.95	-3.62	0.46	-0.76	0.01	-0.10	-0.10
CD 95% SCA	1.50	6.22	3.02	1.03	15.25	8.02	5.22	1.95	0.10	0.29	0.62

Table 4. Mean performance and estimates of heterobeltiosis for seed yield/plant in Indian mustard genotypes

Lines	Testers			Mean Seed Yield of lines (g)
	TPM-1	RAURD78	NDRE7	
RH-8814	55.33*	61.73*	49.80*	37.47*
	33.36*	57.2**	46.85**	
RH-30	39.73	64.77*	41.33*	46.00*
	7.2	59.24**	35.95*	
NRC-DR-2	49.13*	64.00*	50.73*	30.2
	24.95	58.75**	47.82**	
Pusa Mahek	45.80*	37.33	36.07	29.33
	19.5	29.28	26.61	
R. Suflam	36.2	41.87*	59.20*	48.87*

	-1.85	36.95*	55.29**	
Varuna	47.33*	63.73*	58.87*	14
	22.1	58.58**	55.04**	
PM-25	27.6	56.47*	39.20*	29.84
	-33.59	53.25**	32.47	
Mean Seed Yield of lines (g)	36.87	36.87	26.47	

Table 5. Parental genotypes (lines and testers) and their pedigree

SI. No.	Name of Genotypes	Pedigree /description
1	RAURD-78	Varuna /PBN 9501
2	NRC-DR-2	MDOC 43/NBPGR 36
3	TPM-1	Gamma ray induced mutant of RL 9
4	NDRE-7	Sekhar/Seeta
5	RH-8814	RH 765 x R-74-3
6	RH-30	Selection from P26/3-1
7	PusaMahak (JD-6) **NC** (Early Sown)	Pusa Bold x Glossy mutant
8	Pusa Mustard -25 NC (Early Sown)	SEJ-8 x Pusa Jagannath
9	Rajendra Suflam	Pure line selection
10	Varuna	Pure line selection from Varanasi local