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Research Article

Genetic analysis for yield under seedling and terminal heat stress in Indian mustard

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Abstract
Indian mustard is mostly targeted for commercial cultivation as early sown or late sown crop with the expectation of higher yield. With this objective, genetical analysis (13 heat tolerant line × 4 heat susceptible tester) of yield traits were carried out. Per cent genotypic coefficient of variations for all 12 yield contributing traits in all three environments was low to high with variance ratio less than unity indicating non-additive genes action. The lines namely Urvashi in E1, PR 08-5 in E2 & P, and PRL 08-6 in E3 as well as testers namely RH 0304 in E1, E2 & P, and JMWR 08-3 in E3 exhibited highest GCA for seed yield. These genotypes, in series of crosses, showed high GCA effects in desirable direction for at least four yield contributing traits. For seed yield, five top ranking crosses were found entirely different for each environment indicating that heterosis manifestation was cross and environment specific. The most outstanding heterotic crosses for different environments were Urvashi × RH 0304 in E1, PR 08-5×JMWR 08-3 in E2, PRL 08-6×RH 0304 in E3 and across environments for seed yield along with high heterosis for 4-6 component traits.

Key words
Brassica juncea, heat stress, combining ability, heterosis

Introduction

Indian mustard (*Brassica juncea* L.) is the most important *Rabi* season oilseed crop occupying about 80% area under *Brassica* oilseeds with 30% of total oilseed production. It is grown as early, timely and late sown sole or mixed crop under rainfed or/ irrigated conditions. The early sowing implies many advantages including escape from diseases and mustard aphid attack (Singh *et al.*, 2016a; Singh *et al*., 2016b). However, high temperatures at the time of sowing severely influence seed germination pattern, subsequent seedling establishment and, thus, yield. The inter or mixed cropping with wheat as well as late sowing after rice and cotton exposes this crop to high temperature stress during reproductive stage (Chauhan *et al*., 2009). Indian mustard is reported to have efficient photosynthetic response at 15^{O}C-20^{O}C temperature. Constantly rising global air temperature @ 0.2^{O}C per decade is, however, raising apprehension regarding crop productivity and food security (IPCC, 2007).

Among various abiotic stresses (salinity, drought, temperature and heavy metals), high temperature is considered to be the second most important stress after water stress. This can strike crop at any time and impose many limitations on growth and development. Hall (1992) reported that flowering is the most sensitive stage for temperature stress damage probably due to vulnerability during pollen development, anthesis and fertilization leading to reduced crop yield. High temperature in *Brassica* enhances plant development and cause flower abortion with significant loss in seed yield (Rao *et al*., 1992). Nuttall *et al.* (1992) observed that flowering duration has a strong influence on seed yield and a rise in 3^{O}C in maximum daily temperature during flowering caused a decline of 430 kg/ha in canola seed yields.

Genetic variability has been considered to be the basis of plant breeding. The success of any crop improvement program primarily depends on the evaluation, selection of suitable (donor) genotype(s) and understanding their genetic relevance when used as parent in crossing program. Determining combining ability and gene effects under pertinent stress environment using appreciable high sample size is prerequisite to initiate any trait improvement program. Line × tester mating design is comparatively the better approach since it accommodates large number of lines and furnishes information on combining ability (GCA and SCA) variances and effects as well as genetic component of variances (additive and non-additive). Such informations are useful for the selection of suitable parents for hybridization, superior cross combinations and adequate breeding procedure for genetic improvement of temperature stress in Indian mustard. Considering significance of temperature stress in mustard production system in India, it is necessary to generate genetic information on gene action, combining ability and heterosis so that seed yield of Indian mustard could be enhanced and sustained under existing as well emerging temperature stress environments.

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Materials and methods

The present experiments were carried out at Norman E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture & Technology, Pantnagar, Uttarakhand, India during *Rabi* season, 2010-11 and 2011-12. Based on physiological as well as yield related stress parameters (Singh, 2013; Singh *et al.,* 2016a), four heat susceptible testers namely RH 0216, RH 0304, RK 08-2 and JMWR 08-3 and 13 heat tolerant lines namely Vardan, NRCM 803, Rohini, PR 06-1, Urvashi, PRL 08-6, PRL 07-3, EJ 20, PRL 06-37, PR 08-5, RRN 631, HYT 33 and PRL 08-7 were selected and crossed in line × tester mating design during *Rabi* season (February months), 2010-11. Following recommended agronomic practices (Singh, 2013), 52 F_1s along with their 17 parents (four testers and 13 lines) were sown at 3 different sowing dates i.e. early (last week of September, E1), timely (last week of October, E2) and late (last week of November, E3) to expose the concerned genotypes to seedling as well as terminal heat stress; and correspondingly evaluated for seedling as well as terminal stage heat stress during 2011-12.

Weather data on temperature (^oC, maximum and minimum), relative humidity (%, at 07.15 am & 14.15 pm), rainfall (mm), no. of rainy days, sun-shine hours, wind velocity (km/hr) and evaporation were recorded by Dept. of Agro-meteorology, G.B.P.U.A. & T., Pantnagar for years 2010-11 and 2011-12 (averaged over vegetative phase and reproductive phase, Table 1; weekly mean temperature, Figure 1). Weather in both years was as usual as North Indian environment with minor differences between years. Since, experiments were conducted under well irrigated conditions; so only differences in aerial temperature were the major consideration. There were only 1 to 2^oC temperature differences between years while 2.8^oC to 7.0^oC differences between E1 & E2 and 3.5 ^oC to 4.8^oC differences between E3 & E2. This temperature differences among E1, E2 and E3 was ideal for study of heat stress effect on seedling stage and terminal stage in Indian mustard genotypes.

Field experiments were laid out in randomized block design with three replications of three meters row length spaced 30 cm apart. Ten competitive plants were randomly selected from every genotype of each replication. Observations were recorded on 12 morphological traits namely days to flowering, days to maturity, plant height, length of main raceme, primary branches per plant, secondary branches per plant, siliqua length, seeds per siliqua, seed yield per plant, harvest index, 1000 seed weight and oil content. The data were analysed for variance components, combining ability and heterosis separately for each environment (Singh and Chaudhary, 1985) as well as pooled over environments (Gomez and Gomez, 1984) using SPAR 2.0 (IASRI, 2012) and Crop Stat 7.2 (IRRI, 2009) programme.

Results and discussion

Genetic variability: Significant mean squares due to environments in relation to treatments, parents and crosses indicated clearly the differences among all three environments created by sowing dates (Table 2). Significant mean squares for parents *vs.* crosses for all the traits in all the environments as well as over the environments indicated manifestation of heterosis (Kempthorne, 1957). During the three field trials minimum, maximum and mean weekly temperatures were monitored (Fig. 1). In E1, crop experienced 13^0C higher temperature than E2 at seedling stage while in E3, crop experienced 8^0C higher temperature than E2 at terminal stage leading to exposure of early and late sown crops to heat stress at respective stages. The seed yield of seedling stage and terminal stage heat stressed parental genotypes was reduced by ~28% and ~38% and that of F_1s by ~21% and ~38% respectively, in relation to timely sown crop.

Selection parameters: Low (<10%) to high (>20%) genotypic coefficient of variations for different traits suggested explicitly the presence of wide variation in genetic variability (Table 3). All traits exhibited higher estimates of ‘heritability in broad sense’ (h^2_b) i.e. > 60% while low (<10%) to high (>20%) estimates of genetic advance in % of mean (GA %) in different environments (Table 3). Observations on higher estimates of heritability for various traits are in agreement with those of Das et al. (2001). Heritability estimates together with genetic advance are considered useful in predicting the gain through selection (Johnson et al. 1955). In the present study, GA% showed a wide range in its magnitude and in general very clearly and positively associated with genotypic coefficient of variability. Results showed higher GA% in heat stressed environments (E1 and E3) than normal one (E2) for all the traits except days to maturity and plant height suggesting for increased chances of improvement under heat stress. In earlier studies, high to moderate GA% coupled with high heritability has been reported for seed yield per plant (Sheikh et al. 1999), primary branches per plant, seeds per siliqua and 1000 seed weight (Das *et al.,* 2001).

Components of variances and their magnitude: The variance ratio ($\sigma^2 gca$/ $\sigma^2 sca$) was less than unity for all the yield traits in all the environments and pooled over environments (Table 3). This indicates the predominance of non-additive gene action for all the yield traits that favors the idea of opting for maintaining the heterozygosity for achieving higher seed yield and its key components. Under such situations, the appropriate methodologies will be heterosis breeding; alternatively, biparental mating followed by recurrent selection or diallel selective mating might be practiced for improvement of concerned traits (Jensen 1970, Frey 1975).

Per cent contribution of lines, testers and lines × testers interaction to the total variance: The knowledge of per cent contribution of lines, testers and their interactions; towards the expression of yield traits give an idea about relative importance of nature and magnitude of genetic variability. Fixable component of genetic variation is reflected by the contribution of lines and testers while non-fixable effects are shown by line × tester interaction component. For the expression of days to flowering; days to maturity; plant height; main shoot length and primary branches lines made maximum contribution followed by testers and their interactions in all the environments (Table 4). Testers made maximum contribution for secondary branches, siliqua length, seeds per siliqua, 1000 seed weight and oil content (%). For the expression of seed yield, lines and testers contribution was similar, and more than line × tester interactions. Lines made maximum contribution towards harvest index (%) followed by line × tester interaction. Above results are in agreement with those of Singh *et al.* (2002) for days to flowering, days to maturity, plant height, primary branches/plant, 1000 seed weight and oil content in Indian mustard.

Nicking ability and heterosis: Positive GCA effects for seed yield were associated with desirable GCA effects of 4 to 7 yield contributing characters. This suggests that different parents differed in their pathway to build up desirable GCA effects for seed yield. Environment wise, the genotypes exhibiting higher GCA value for seed yield as well as oil content were Urvashi, HYT 33 and JMWR 08-3 in E_1, HYT 33 and RK 08-2 in E_2, Urvashi and RK 08-2 in E_3 and Urvashi across the environments. The genotypes exhibiting desirable GCA effects in one environment also exhibited the same in other stressed or non-stressed environments. It indicated the stable performance of parents in relation to general combining ability. Similar results were also observed earlier by Parmar *et al.* (2011), Rameeh (2011) and Verma *et al.* (2011).

The ranking of hybrids on the basis of *per se* performance was different with ranking based on their SCA values (Table 5) suggesting that the specific cross combinations for different traits should be selected only on the basis of their SCA values. It was also found that all the top ranking crosses based on SCA effects for all the 12 yield traits were the combinations of high × high, high × low and low × low general combiners as also observed in Indian mustard by Mall *et al*. (2010). The promising specific crosses having high × high GCA effects are amenable for improvement following conventional breeding methods like pedigree method while heterosis breeding as well as mass selection with concurrent random mating seems to be pertinent for promising crosses with combination of high × low GCA. The promising crosses with combination of low × low GCA should be intervened using heterosis breeding, biparental mating and diallel selective mating design (Jensen, 1970, Frey 1975).

Environment wise as well as across the environments, heterosis for all the traits except for days to flowering, days to maturity, plant height and oil content were observed to be high. Low heterosis for days to flowering, days to maturity, plant height and oil content observed in the investigation were not unexpected since these traits, particularly in rapeseed and mustard, are quantitatively photosensitive (Banga 1992). The general pattern of low heterosis for oil content is in agreement with earlier reports (Banga and Labana 1984, Singh 2002). Bhatia and Mitra (1992) argued that physiologically, as specific metabolic system of plant species sets an absolute limit to the directional partitioning of available photosynthates into more valuable compound like oil at the cost of carbohydrates. The outstanding heterotic crosses across the environments for seed yield as well as oil content were PRL 08-6×RK 08-2 and PR 08-5×RK 08-2. Relatively higher magnitude of heterosis for seed yield and its component traits were also reported earlier by Parmar *et al.* (2011) and Verma *et al.* (2011).

It is significant to note that manifestation of heterosis for different characters was environment specific. Five promising crosses for seed yield identified on the basis of high heterosis, SCA effects and *per se* performance as well as heterosis for five or more component traits for different environments is given in Table 5. PRL 08-6×RH 0304 was the only cross that emerged as promising in E1 as well as E3. Thus, present findings suggest that identification of outstanding crosses should be done on the basis of their elaborate evaluation under target environments.

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Table 1. Summary of the weather during the vegetative (DF) and reproductive (Dr) phases of the three cropping seasons

Year/ Period	Mean Temp (^{0}C)		Relative humidity (%)		Total Rainfall (mm)	Total No. of Rainy Days	Mean Sun-Shine Hrs.	Mean Wind Velocity (km/hr.)	Total Evap. (mm)
	Max	Min	07.12 am	14.12 pm					
2010-11									
Early DF	30.77	17.22	87.00	53.67	29.80	5.00	7.93	2.93	18.00
Timely DF	26.29	10.91	88.71	43.71	20.60	2.00	6.99	2.60	14.20
Late DF	20.04	7.18	92.67	58.33	3.80	2.00	5.07	3.26	11.50
2011-12									
Early DF	31.55	18.78	86.17	49.00	4.40	1.00	8.83	2.65	18.60
Timely DF	26.54	11.87	88.57	43.57	0.40	1.00	6.93	2.81	15.10
Late DF	20.26	6.61	92.11	54.78	39.20	4.00	5.39	4.01	13.80
2010-11									
Early Dr	22.11	8.36	91.13	53.94	56.60	6.00	5.88	3.47	26.00
Timely Dr	23.81	9.43	90.07	52.27	36.20	5.00	6.55	4.27	35.80
Late Dr	31.34	13.73	80.39	36.23	32.40	3.00	8.44	5.42	68.80
2011-12									
Early Dr	22.41	8.59	90.81	51.44	69.80	9.00	5.89	3.93	28.80
Timely Dr	23.13	8.64	90.13	49.13	85.80	12.00	6.33	4.82	36.10
Late Dr	28.94	12.58	83.00	37.23	52.40	10.00	7.93	5.32	56.70

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Table 2. Combined analysis of variance for different characters in Indian mustard

Source of variation	d.f.	Mean Squares											
		Days to flowering	Days to maturity	Plant height (cm)	Main shoot length (cm)	Primary branches/ plant	Secondary branches/ plant	Siliqua length (cm)	Seeds per siliqua	Seed yield (g/plant)	Harvest index (%)	1000 seed weight (g)	Oil content (%)
Environments in relation to treatments	2	7889.98**	17152.59**	28938.95**	8965.88**	89.79**	394.54**	17.05**	350.66**	877.79**	888.99**	44.12**	160.49**
Rep within environment	6	0.32	0.66	0.16	0.21	0.03	0.02	0.01	0.05	0.03	0.15	0.03	0.07
Treatments	68	331.92**	986.15**	302.94**	91.74**	2.48**	26.47**	0.74**	8.50**	6.22**	23.62**	0.97**	3.28**
Environments.× Treatments	136	6.28**	35.28**	28.92**	17.68**	0.28**	0.67**	0.07**	0.72**	2.26**	19.03**	0.22**	0.84**
Environments in relation to crosses	2	6047.99**	12756.84**	21453.62**	7238.55**	68.58**	312.00**	13.01**	286.05**	680.72**	632.45**	33.61**	120.41**
Rep within environment in relation to crosses	6	0.21	0.61	0.15	0.25	0.02	0.02	0.01	0.05	0.03	0.24	0.03	0.06
Crosses	51	351.60**	1032.06**	284.73**	76.15**	2.66**	25.20**	0.70**	8.00**	5.30**	25.38**	0.96**	3.31**
Environments.× Crosses	102	6.14**	32.87**	30.37**	17.09**	0.22**	0.63**	0.06**	0.68**	2.27**	19.70**	0.19**	1.02**
Environments in relation to Parents	2	1843.78**	4406.84**	7498.66**	1761.15**	21.22**	83.29**	4.10**	66.41**	204.95**	308.20**	10.53**	40.23**
Rep within environment in relation to Parents	6	0.58	0.15	0.25	0.14	0.06	0.03	0.01	0.02	0.05	0.66	0.02	0.13
Parents	16	283.27**	900.89**	301.87**	93.26**	1.72**	14.45**	0.59**	9.59**	5.47**	19.46**	0.99**	2.72**
Environments.× Parents	32	7.02**	44.50**	25.27**	18.55**	0.46**	0.82**	0.11**	0.78**	1.90**	14.88**	0.34**	0.33**
Parents vs. Crosses	1	106.63**	8.99**	1248.58**	862.30**	6.03**	283.65**	5.50**	16.15**	65.45**	0.78	1.06**	10.88**
Environments.× Parents vs. Crosses	2	1.79**	11.09**	13.32**	33.81**	0.02	0.74**	0.06*	1.80**	7.88**	51.66**	0.03	0.15
Pooled Error	408	0.34	0.32	0.25	0.17	0.04	0.04	0.02	0.05	0.06	0.59	0.04	0.09

*, ** Significant at 5 and 1 per cent probability level

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Table 3. Estimates of selection parameters for different characters in Indian mustard

Parameters	Env.	Days to flowering	Days to maturity	Plant height (cm)	Main shoot length (cm)	Primary branches/ plant	Secondary branches/ plant	Siliqua length (cm)	Seeds per siliqua	Seed yield (g/plant)	Harvest index (%)	1000 seed weight (g)	Oil content (%)
Parental mean	E_1	42.10	132.14	174.44	61.71	4.33	6.97	4.29	11.54	7.34	22.30	3.58	40.66
	E_2	48.43	122.06	182.06	67.84	5.04	8.43	4.62	12.66	10.16	26.31	4.19	41.52
	E_3	54.12	113.57	158.31	56.09	3.75	5.88	4.05	10.38	6.28	21.84	3.30	39.74
	P	48.22	122.59	171.60	61.88	4.37	7.09	4.32	11.53	7.93	23.49	3.69	40.64
F_1 mean	E_1	42.86	132.39	177.15	64.33	4.57	8.49	4.55	11.96	8.59	23.70	3.70	40.90
	E_2	49.37	121.81	185.33	71.57	5.28	10.15	4.82	13.22	10.81	25.51	4.29	41.85
	E_3	55.31	114.40	162.20	57.95	3.95	7.34	4.24	10.52	6.64	21.49	3.37	40.09
	P	49.18	122.87	174.89	64.61	4.60	8.66	4.54	11.90	8.68	23.57	3.79	40.95
GCV (%)	E_1	14.55	7.76	3.36	5.03	12.14	21.42	6.62	8.92	14.77	10.70	9.64	1.86
	E_2	13.07	9.11	3.51	6.00	12.59	19.25	6.28	7.70	8.16	7.90	10.42	1.83
	E_3	10.71	9.73	4.06	6.51	12.51	23.56	7.41	10.14	17.19	14.37	9.90	1.58
	P	12.40	8.52	3.33	4.99	11.46	20.71	6.34	8.20	9.75	6.81	8.53	1.46
Heritability	E_1	89.12	89.69	89.29	88.47	79.42	88.45	72.14	85.43	85.72	81.77	66.53	78.40
	E_2	94.20	94.75	94.45	94.13	85.68	93.90	75.97	90.48	87.88	85.88	79.61	78.65
	E_3	89.03	89.73	89.41	88.74	73.88	88.41	71.24	85.67	85.25	82.48	63.25	73.44
	P	89.74	89.91	89.77	89.40	84.98	89.44	83.33	88.04	87.71	83.82	77.57	82.25
Genetic advance	E_1	12.73	21.11	12.18	6.54	1.07	3.55	0.55	2.13	2.47	4.93	0.64	1.47
	E_2	13.18	22.84	13.32	8.69	1.29	3.84	0.56	2.03	1.73	3.99	0.84	1.44
	E_3	12.08	22.85	13.44	7.66	0.92	3.36	0.58	2.14	2.26	6.14	0.59	1.19
	P	12.49	21.55	11.93	6.55	1.05	3.52	0.57	1.98	1.69	3.20	0.62	1.18
GA %	E_1	30.25	15.98	6.98	10.60	24.61	51.00	12.93	18.45	33.59	22.10	17.82	3.63
	E_2	12.08	22.85	13.44	7.66	0.92	3.36	0.58	2.14	2.26	6.14	0.59	1.19
	E_3	22.32	20.12	8.49	13.65	24.57	57.15	14.23	20.63	36.04	28.12	17.72	3.00
	P	25.90	17.58	6.95	10.59	23.91	49.64	13.09	17.14	21.28	13.62	16.76	2.90
σ^2gca/σ^2sca	E_1	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	E_2	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	E_3	0.03	0.03	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	P	0.03	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01

E_1= Early sown, E_2= Normal sown, E_3= Late sown, P = Pooled over environments.

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Table 4. Contribution of lines, testers and their interactions to total variance for different characters in Indian mustard

Characters	Proportional contribution											
	Lines				Testers				Lines × Testers			
	E_1	E_2	E_3	P	E_1	E_2	E_3	P	E_1	E_2	E_3	P
Days to flowering	96.29	97.30	95.46	97.20	3.27	2.22	3.95	2.67	0.44	0.49	0.60	0.13
Days to maturity	98.35	98.91	95.47	99.27	1.19	0.77	2.16	0.28	0.46	0.32	2.37	0.46
Plant height	77.68	80.37	82.26	82.56	17.80	15.66	13.34	14.69	4.52	3.98	4.40	2.75
Main shoot length	44.47	69.27	65.05	56.53	43.63	25.54	23.15	37.86	11.90	5.19	11.79	5.62
Primary branch / plant	43.91	57.64	58.32	55.74	43.59	34.52	33.00	39.08	12.50	7.84	8.67	5.19
Secondary branch / plant	30.38	29.61	44.23	33.88	59.17	57.38	49.92	58.08	10.46	13.01	5.85	8.05
Length of siliqua	35.44	39.75	47.81	41.01	48.86	50.03	37.74	49.71	15.71	10.22	14.44	9.28
Seeds per siliqua	15.03	8.60	29.03	13.48	66.92	71.09	55.51	74.77	18.05	20.32	15.45	11.75
Seed yield	49.16	50.85	47.90	47.75	42.02	40.84	44.66	48.36	8.83	8.31	7.44	3.89
Harvest index	75.00	67.27	43.55	72.83	7.06	15.87	13.62	5.22	17.94	16.86	42.83	21.95
Test weight	32.51	37.30	34.97	34.71	46.61	52.56	48.04	54.26	20.89	10.14	16.99	11.03
Oil content	37.81	34.72	31.36	48.03	42.79	36.59	51.73	38.28	19.40	28.69	16.90	13.69

$E_{1=}$ Early sown, $E_{2=}$ Normal sown, $E_{3=}$ Late sown, P = Pooled over environments.

Table 5. Heterotic crosses for seed yield and its contributing traits in Indian mustard

Cross combinations	Seed yield					Other traits with significant heterosis effects over	
	Heterosis over		SCA effects	*Per se* performance	GCA effects		
	Standard variety	Better parent				Standard variety	Better parent
Early sown (E_1)							
Urvashi×RH 0304	18.01**	49.62**	0.37**	10.57	H×H	1, 4, 6, 7,8	1, 2, 4, 6, 7, 8, 10, 12
PR 06-1×RH 0304	17.26**	48.68**	0.39**	10.51	H×H	3, 4, 5, 6, 7, 8, 10	2, 4, 5, 6, 7, 8, 10
NRCM 803×RH 0304	14.58**	50.46**	0.43**	10.27	H×H	4, 5, 6, 7, 8	1, 2, 4, 5, 6, 7, 8, 11
PRL 08-6×RH 0304	13.95**	44.48**	0.36**	10.21	H×H	4, 6, 8, 11	3, 4, 6, 8, 11, 12
Urvashi×JMWR 08-3	13.50**	45.01**	0.34**	10.17	H×H	4, 5, 6, 7, 8, 10	1, 2, 4, 5, 6, 7, 8, 10, 11, 12
Timely sown (E_2)							
PR 08-5×JMWR 08-3	38.14**	19.10**	0.29**	12.93	H×H	4, 5, 6, 7, 10	2, 4, 5, 6, 7, 11, 12
PR 06-1×JMWR 08-3	36.68**	13.22**	0.49**	12.79	H×H	3, 5, 6, 7, 8	3, 4, 5, 6, 7, 8, 11
PR 08-5×RK 08-2	34.62**	29.99**	0.23*	12.60	H×H	4, 8, 10, 12	2, 4, 6, 11, 12
NRCM 803×JMWR 08-3	29.74**	17.59**	0.25**	12.14	H×H	4, 5, 6, 7, 8	2, 4, 5, 6, 7, 8
PRL 07-3×JMWR 08-3	29.06**	13.64**	0.54**	12.08	L×H	5, 6, 7, 8	1, 2, 4, 5, 6, 7, 8, 11
Late sown (E_3)							
PRL 08-6×RH 0304	47.32**	57.70**	0.54**	9.69	H×H	4, 5, 6, 10, 11, 12	1, 4, 5, 6, 10, 11, 12
PRL 07-3×RH 0304	29.18**	38.29**	0.33**	8.50	H×H	4, 6, 8, 10	2, 4, 6, 8, 10, 11, 12
PR 08-5×RH 0304	27.20**	36.17**	0.42**	8.37	H×H	4, 6, 8, 10, 12	4, 6, 8, 10, 11, 12
PRL 08-6×RK 08-2	26.65**	36.42**	0.28**	8.33	H×H	4, 5, 11, 12	1, 4, 5, 6, 11, 12
PRL 06-37×RH 0304	26.65**	35.58**	0.23	8.33	H×H	4, 5, 6, 7, 10, 11	4, 5, 6, 7, 11, 12
Pooled over environments (P)							
PRL 08-6×RH 0304	21.17**	33.10**	0.29**	10.06	H×H	4, 5, 6, 11	3, 4, 6, 11, 12
PR 08-5×RH 0304	19.97**	31.79**	0.37**	9.99	H×H	3, 4, 6, 8, 10	2, 4, 6, 10, 11, 12
PR 06-1×RH 0304	18.49**	30.16**	0.23*	9.83	H×H	3, 4, 5, 6, 7, 8, 10, 11	4, 5, 6, 7, 8, 10, 11
PR 08-5×JMWR 08-3	16.05**	20.45**	0.22*	9.63	H×H	3, 4, 5, 6, 7, 8	2, 3, 4, 5, 6, 7, 11, 12
PR 08-5×RK 08-2	17.51**	29.08**	0.24**	9.75	H×L	4, 7, 8, 10, 12	2, 4, 6, 7, 8, 11, 12

1, Days to flowering; 2, Days to maturity; 3, Plant height (cm); 4, Main shoot length (cm); 5, Primary branches number; 6, Secondary branches number; 7, Siliqua length (cm); 8, Seed number per siliqua; 9, Seed yield (g/plant); 10, Harvest index (%); 11, 1000s seed weight (g) and 12, Oil content (%);

*, ** Significant at 5 and 1 per cent probability level