Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
JPP 2018; 7(4): 372-379
Received: 01-05-2018
Accepted: 05-06-2018

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Exploitable genetic variability and character association studies under changing climate in mid-hills of north-west Himalayas in Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]

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Abstract
In order to assess the nature and extent of genetic variability and inter-relationships among seed yield and related traits, an experiment was conducted at CSKHPKV, Palampur during *rabi* 2008-09 and 2009-10. The pooled analysis of variance over the environments indicated that the mean squares due to genotypes were significant when tested against mean squares due to g x e interactions for characters CGR (GS_3), RGR (GS_3), NAR (GS_3), LAR (GS_2), SLW (GS_2), days to flower initiation, days to 50 per cent flowering, days to 75 per cent maturity, plant height, siliqua length, 1000-seed weight and harvest index. The g x e interactions were significant for RGR (GS_2), days to flower initiation, number of secondary branches per plant, siliquae per plant, length of main shoot, siliquae on main shoot, seeds per siliqua, seed yield per plant, biological yield per plant and harvest index indicating that genotypic differences recorded in individual environments had vanished for these characters. The mean values of the characters studied showed a wide spectrum of genetic variation and characters such as LAR, LAI, LAD, SLW, days to flower initiation, seeds per siliqua, 1000-seed weight, seed yield per plant, biological yield per plant and harvest index recorded excellent potential. On the basis of mean performance, Geeta and RH-8544 were found to be promising genotypes for seed yield and biological yield per plant. RH-8544 also exhibited resistance to white rust. The phenotypic correlation coefficient revealed significant positive associations of CGR (GS_2), LAI (GS_2), SLW (GS_2), plant height, number of primary branches per plant, number of secondary branches per plant, siliquae per plant, length of main shoot, siliquae on main shoot, biological yield per plant and harvest index with seed yield per plant. The path coefficient analysis revealed that biological yield per plant and harvest index exhibited positive and high direct effects on seed yield per plant. Therefore, these characters could be considered as the best selection parameters for the improvement of seed yield per plant.

Keywords: *Brassica juncea*, genetic variability, correlation, path coefficient analysis, seed yield

Introduction

Oilseeds occupy an important position in Indian agricultural economy and daily diet, being a rich source of fats and vitamins. India is among the major oilseed producing countries with around 7 per cent contribution in the global production. Indian mustard [*Brassica juncea* (L.) Czern. & Coss.] is second largest oilseed crop in India after soybean contributing about 80 per cent of the total rapeseed-mustard. India accounts for 21.7 per cent of the total global acreage and contributes 10.7 per cent to total production (USDA, 2016) [26]. In spite of all the efforts made over past few decades, the productivity has remained almost constant due to lack of high yielding genotypes with stable performance over the environments. The success in any breeding programme depends upon the nature and magnitude of genetic variability which provides better chances of selecting desired types. The knowledge of inter-relationships between different traits is important in breeding for direct and indirect selection of characters that are not easily measured and those with low heritability. Economic characters, such as seed and oil yields are controlled by many genes and have a complex type of inheritance. The progress of breeding for such economic traits is thus, determined by the nature and magnitude of their genotypic and environmental variability. The components which have high heritability and positive correlation with yield can be used in the indirect selection for yield and act as an alternate mode of selection for yield improvement.

When the indirect associations become complex, path coefficient analysis is the most effective mean to find out direct and indirect causes of association among the different variables. Keeping this in view, the present study was conducted to investigate the extent of genetic

Materials and Methods

Variability, association of seed yield with other component characters and estimate the direct and indirect effects of various characters on seed yield in Indian mustard.

Materials and Methods

Plant materials and experimental design

An experiment was conducted with 31 (local, indigenous and exotic) genotypes of Indian mustard (Table 1) at the experimental farm of the Department of Crop Improvement, CSK HPKV, Palampur, during *rabi* 2008-09 and 2009-10. The trials were laid out in randomized complete block design with three replications in the plot sizes of 3.0 x 0.9 m^2 and 2.5 x 0.9 m^2 during *rabi* 2008-09 and 2009-10, respectively. Row to row and plant to plant spacings were kept 30 and 10 cm during both seasons, respectively. The observations were recorded on seven growth parameters and fifteen morphological and yield related characters, *viz.*, Crop Growth Rate (CGR), Relative Growth Rate (RGR), Net Assimilation Rate (NAR), Leaf Area Ratio (LAR), Leaf Area Index (LAI), Leaf Area Duration (LAD), Specific Leaf Weight (SLW), days to flower initiation, days to 50 per cent flowering, days to 75 per cent maturity, plant height, number of primary branches per plant, number of secondary branches per plant, siliquae per plant, length of main shoot, siliquae on main shoot, siliqua length, seeds per siliqua, 1000-seed weight, seed yield per plant, biological yield per plant and harvest index. For growth parameters, observations were recorded on the basis of three randomly competitive plants in each plot while data on morphological and yield related characters were recorded on randomly selected five competitive plants except days to flower initiation, days to 50 per cent flowering and days to 75 per cent maturity which were recorded on plot basis. The recommended cultural practices were followed to raise the crop under irrigated conditions.

The formulae used for the calculation of growth parameters are described below:

1. Crop Growth Rate (CGR): It is the rate of dry matter production per unit time of ground area and expressed as g/day.

$$CGR = \frac{W_2-W_1}{T_2-T_1}$$

2. Relative Growth Rate (RGR): It indicates the rate of increase in dry weight per unit of dry weight already present and expressed as g/g/day.

$$RGR = \frac{Log_e W_2 - Log_e W_1}{T_2-T_1}$$

3. Net Assimilation Rate (NAR): It is the rate of increase of dry weight per unit of leaf area per unit time and as g/dm2/day.

$$NAR = \frac{(W_2-W_1)}{(T_2-T_1)} \times \frac{(Log_e L_2 - Log_e L_1)}{(L_2-L_1)}$$

4. Leaf Area Ratio (LAR): It is the ratio of the assimilatory material (leaf area) per unit of plant material present and calculated as;

$$LAR = \frac{(L_2-L_1)}{(W_2-W_1)} \times \frac{(Log_e W_2 - Log_e W_1)}{(Log_e L_2 - Log_e L_1)}$$

5. Leaf Area Index (LAI): It is defined as the ratio of leaf area per unit land area and calculated as;

$$LAI = \frac{\text{Leaf area } (dm^2/\text{plant})}{\text{Land area } (dm^2/\text{plant})}$$

6. Specific Leaf Weight (SLW): It indicates the thickness of leaf and was calculated by the method given below and expressed as g/dm^2;

$$SLW = \frac{\text{Leaf dry weight (g)}}{\text{Leaf area } (dm^2)}$$

Where

W_1 & W_2 = Total dry weight (g) of plant at GS_1 and GS_2

L_1& L_2 = Total leaf area (dm^2) at GS_1 and GS_2

LW_1& LW_2 = Total leaf dry weight at GS_1& GS_2

$T_2 – T_1$ = Time interval (days) between GS_2 and GS_1

A = Land area (dm^2) covered by plant

The disease reaction studies were conducted at Shivalik Agricultural Research and Extension Centre (SAREC), Kangra during *rabi* 2009-10. All the genotypes were screened for reaction to white rust (*Albugo candida*) disease under natural conditions and observations on disease severity were recorded on the basis of visual observations. Data on disease severity of white rust on leaves was recorded on 100 days after sowing on 10 leaves sampled randomly from each plot.

Per cent Disease Intensity (PDI) was calculated by using the formula of McKinney (1923) [9].

$$PDI = \frac{\text{Total sum of all numerical rating}}{\text{Number of observations taken} \times \text{maximum disease score}} \times 100$$

Table 1: List of *Brassica* genotypes and their source used in the study

Genotype	Source
Vardan	Kanpur
03-218	H.P.
HPMM-03-108	H.P.
03-143	H.P.
RCC-4	H.P.
OMK-2	H.P.
NRC-1	Rajasthan
NRC-2	Rajasthan
NRC-17	Rajasthan
PusaJaikisan	New Delhi
03-456	H.P.

Heera	Exotic
RL-1359	Ludhiana
OMK-5-1	H.P.
OMK-1	H.P.
OMK-2-21	H.P.
OMK-3	H.P.
OMK-3-29	H.P.
IC-355309	NBPGR, New Delhi
IC-355331	NBPGR, New Delhi
IC-355337	NBPGR, New Delhi
Geeta	Haryana
IC-355421	NBPGR, New Delhi
Bawal-151	Haryana
Varuna	Kanpur
OMK-5-2	H.P.
RH-8544	Hisar
Nav Gold	Rajasthan
OMK-5-3	H.P.
OMK-5-4	H.P.
Zem-1	Exotic

Categorization scale for reaction to white rust

S. No.	Category	Area infected (%)
1.	Resistant	0-10 %
2.	Moderately resistant	>10-25 %
3.	Moderately susceptible	>25-50 %
4.	Susceptible	>50-75 %
5.	Highly susceptible	> 75 %

The analysis of variance for different characters was carried out by following Panse and Sukhatme (1985) [12] approach. The combined analysis of variance over the environments was computed as per the procedure given by Verma *et al.* (1987) [28]. Correlation coefficients at phenotypic levels were computed as per the methods suggested by Al-Jibouri *et al.* (1958) [1] and path coefficient analysis was done by using correlation coefficients as suggested by Dewey and Lu (1959) [5].

Results and Discussion

Analysis of variance

The pooled analysis over the environments, exhibited that mean squares due to genotypes were significant when tested against mean squares due to g x e interactions for characters *viz.*, CGR (GS_3), RGR (GS_3), NAR (GS_3), LAR (GS_2), SLW (GS_2), days to flower initiation, days to 50 per cent flowering, days to 75 per cent maturity, plant height, siliqua length, 1000-seed weight and harvest index (Table 2). Significant variation for most of the characters except for growth parameters was also observed by earlier workers (Verma *et al.* 2008 [29]; Singh *et al.* 2010 [19]; Yadava *et al.* 2011 [30]; Bind *et al.* 2014 [3]; Bibi *et al.* 2016 [2]; Devi 2018 [4]; Singh *et al.* 2018 [22]). Shalini *et al.* (2000) [17] and Patel and Patel (2006) [13] also reported highly significant differences for days to 50 per cent flowering and maturity, number of secondary branches per plant, plant height, 1000-seed weight, seed yield per plant and harvest index. The g x e interactions were significant for characters such as RGR (GS_2), days to flower initiation, number of secondary branches per plant, siliquae per plant, length of main shoot, siliquae on main shoot, seeds per siliqua, seed yield per plant, biological yield per plant and harvest index. The presence of g x e interactions indicated that the genotypic differences recorded in individual environments have vanished for these characters. The reason for high magnitude of variability in the present study may be due the fact that the genotypes selected were developed in different breeding programmes representing different agro-climatic conditions of the country.

Table 2: Analysis of variance for different characters (pooled over the environments)

S. No.	Characters	Mean Squares			
		Genotypes	**Environments**	**Genotype x Environment (g x e)**	**Pooled error**
	df	30	1	30	120
1.	GGR (GS_1) g/day	1.15×10^{-3}	0.26**	1.25×10^{-3}	1.04×10^{-3}
2.	GGR (GS_2)	0.08	0.72	0.09	0.08
3.	GGR (GS_3)	0.83**	2.37×10^{-3}	0.06	0.32
4.	RGR (GS_1) g/g/day	4.80×10^{-5}	0.02**	4.37×10^{-5}	3.20×10^{-5}
5.	RGR (GS_2)	1.83×10^{-4}	0.03**	2.41×10^{-4}*	1.35×10^{-4}
6.	RGR (GS_3)	2.69×10^{-4}*	1.11×10^{-4}	7.96×10^{-5}	1.38×10^{-4}
7.	NAR(GS_1) g/dm²/day	1.90×10^{-5}	5.58×10^{-3}**	1.73×10^{-5}	1.72×10^{-5}
8.	NAR (GS_2)	2.83×10^{-4}	5.67×10^{-4}	2.73×10^{-4}	1.97×10^{-4}
9.	NAR (GS_3)	2.23×10^{-3}*	7.72×10^{-3}	5.95×10^{-4}	1.03×10^{-3}
10.	LAR(GS_1)	0.50	42.32	0.45	0.38
11.	LAR (GS_2)	0.51*	34.38**	0.24	0.26
12.	LAR (GS_3)	0.09	2.76**	0.04	0.07
13.	LAI (GS_1)	0.05	4.13**	0.05	0.05
14.	LAI (GS_2)	0.43	3.49	0.30	0.25
15.	LAI (GS_3)	0.19	1.74	0.09	0.15
16.	LAD (GS_1)	62.10	7791.18**	59.26	51.51

17.	LAD (GS_2)	262.07	537.06	160.66	150.89
18.	LAD GS_3)	385.89	9743.59*	267.89	244.57
19.	SLW (GS_1) g/dm^2	8.87 x10^{-4}	0.08**	8.51 x10^{-4}	7.41 x10^{-4}
20.	SLW (GS_2)	7.34 x10^{-3}*	4.00 x10^{-6}	5.13 x10^{-3}	3.45 x10^{-3}
21.	SLW (GS_3)	2.06 x10^{-3}	0.01**	5.34 x10^{-4}	1.54 x10^{-3}
22.	Days to flower initiation	37.67**	5916.13**	12.11*	7.12
23.	Days to 50 % flowering	34.68**	11397.51**	11.74	8.23
24.	Days to 75 % maturity	8.01*	483.87**	4.06	3.43
25.	Plant height (cm)	693.71*	24676.76**	298.62	200.48
26.	Number of primary branches /plant	0.72	81.34**	0.99	0.71
27.	Number of secondary branches /plant	39.72	3493.53*	47.24**	11.03
28.	Siliquae /plant	3465.12	34484.21*	4627.44**	2245.01
29.	Length of main shoot (cm)	83.71	5012.81**	70.78*	42.49
30.	Siliquae on main shoot	36.28	2210.42**	78.25**	29.41
31.	Siliqua length (cm)	0.61**	13.53**	0.20	0.27
32.	Seeds /siliqua	8.56	37.22*	7.81**	2.77
33.	1000-seed weight (g)	1.58**	3.38**	0.33	0.34
34.	Seed yield /plant (g)	12.48	309.90**	16.65**	2.19
35.	Biological yield /plant (g)	668.95	5188.62**	677.12**	102.83
36.	Harvest index (%)	40.42*	183.08**	15.29**	8.03

* Significance at $P \leq 0.05$; ** Significance at $P \leq 0.01$ df: Degrees of freedom

Estimates of mean performance

The mean values of the characters studied showed a wide spectrum of genetic variation and characters such as CGR, NAR, LAR, LAI, LAD, SLW, days to flower initiation, plant height, seeds per siliqua, 1000-seed weight, seed yield per plant, biological yield per plant and harvest index recorded excellent potential on the basis of mean performance. Geeta and RH-8544 were found to be promising genotypes for seed yield and biological yield per plant. Geeta and OMK-1 also exhibited bold seed size (Table 3).

Table 3: Promising genotypes identified on the basis of mean performance for different characters (pooled over the environments)

Genotypes	Characters
OMK- 1 (R)	CGR, NAR, 1000-seed weight
03-456 (R)	LAR, LAI, LAD, SLW
HPMM- 03- 108 (R)	Days to flower initiation, Seeds/siliqua, plant height
Geeta	1000-seed weight, Seed yield/ plant, Biological yield/ plant yield/plant
RH-8544 (R)	Seed yield/ plant, Biological yield/ plant
OMK-5-4, Bawal-151 (R)	LAR
Heera, Nav Gold, OMK-5-1 (R), OMK-5-3	Biological yield/ plant
OMK-3-29	Harvest Index

R: Resistant to White rust

Estimates of correlation coefficient

The effectiveness of any breeding or selection programme depends upon the nature of associations between yield and other component characters, as more directly and positively a character is associated with seed yield, more will be the success of the selection programme. Therefore, besides getting information on the nature and magnitude of variation, it is also imperative to have knowledge of associations of seed yield with other characters and among themselves and their causation to identify characters for defining an ideal plant type as well as for increasing the efficiency of both direct and indirect selection. At phenotypic level, in pooled over the environments seed yield per plant had significant positive association with CGR (GS_2), LAI (GS_2), SLW (GS_2), plant height, number of primary branches per plant, number of secondary branches per plant, siliquae per plant, length of main shoot, siliquae on main shoot, biological yield per plant and harvest index (Table 4). Significant positive correlations among different characters have also been reported earlier by different workers such as for LAI and siliquae per plant (Reddy 1991 [16]; Yoobiangmi *et al.* 2017[31]), CGR, plant height and siliquae per plant (Joshi *et al.* 1992) [6], CGR and LAI (Mondal and Paul 1994) [10], plant height and siliquae per plant (Patel *et al.* 2001 [14]; Kardam and Singh 2005 [7]; Verma and Mahto 2005) [27], secondary branches per plant and length of main shoot (Sharad and Basudeo 2005; Bind *et al.* 2014) [18, 3], biological yield per plant and harvest index Sirohi *et al.* 2004 [24]; Sirohi *et al.* 2008 [23], Singh *et al.* 2011 [20]; Nasim *et al.* 2013 [11]; Bind *et al.* 2014 [3]; Singh *et al.* 2018 [22], biological yield per plant and silliqua on main raceme (Tiwari *et al.* 2017; Devi 2018) [4, 25] and plant height, number of primary branches per plant and number of secondary branches per plant (Verma *et al.* 2008; Singh and Singh 2010; Bind *et al.* 2014; Lodhi *et al.* 2014; Ray *et al.* 2014; Tiwari *et al.* 2017; Singh *et al.* 2018) [8, 3, 29, 21, 15, 25, 22]. Among other characters, CGR (GS_2) showed significant positive association with LAI (GS_2), SLW (GS_2), plant height, number of secondary branches per plant, siliquae per plant and biological yield per plant whereas it had significant negative association with CGR (GS_3), LAI (GS_3), SLW (GS_3) and days to 50 per cent flowering. LAI (GS_2) had significant positive association with SLW (GS_2), plant height, number of secondary branches per plant, siliquae per plant and biological yield per plant while it showed significant negative association with LAI (GS_3), SLW (GS_3) and days to 50 per cent flowering. SLW (GS_2) observed significant positive correlation with plant height, number of secondary branches per plant, siliquae per plant and biological yield per plant while it had significant negative association with SLW (GS_3) and days to 50 per cent flowering. Plant height recorded significant positive association with number of primary branches per plant, number of secondary branches per plant, length of main shoot, siliquae on main shoot and biological yield per plant while it showed significant negative association with harvest index. Number of primary branches per plant showed significant positive association with number of secondary branches per plant, siliquae per plant, siliquae on main shoot and biological yield per plant while it had significant negative association with harvest index. Number of secondary branches per plant showed significant positive association with siliquae per plant and biological yield per plant while it had significant negative association with 1000-

seed weight and harvest index. siliquae per plant showed significant positive association with siliquae on main shoot and biological yield per plant. Length of main shoot revealed significant positive correlation with siliquae on main shoot and biological yield per plant. Siliquae on main shoot had significant positive and negative associations with biological yield per plant and harvest index, respectively. Biological yield per plant showed significant negative correlation with harvest index.

Table 4: Estimates of correlation coefficients at phenotypic (P) level among different characters (pooled over the environments)

Characters	CGR (GS_2)	CGR (GS_3)	LAI (GS_1)	LAI (GS_2)	LAI (GS_3)	SLW (GS_1)	SLW (GS_2)	SLW (GS_3)	Days to flower initiation	Days to 50% flowering	Days to 75% maturity	Plant height	No. of primary branches/ plant	No. of secondary branches/ plant	Siliquae/ plant	Length of main shoot	Siliquae on main shoot	Siliqua length	Seeds/ siliqua	1000-seed weight	Biological yield/ plant	Harvest index	Correlation with seed yield /plant
CGR (GS_1)	-0.027	-0.054	0.624*	-0.027	-0.054	0.530	-0.027	-0.054	0.112	-0.030	0.034	0.181*	0.123	0.153*	0.058	0.204	0.187*	0.061	-0.059	0.009	0.188*	-0.184*	0.036
CGR (GS_2)		-0.351*	0.020	0.900*	-0.351*	-0.021	0.950*	-0.351*	0.060	-0.189*	0.120	0.225**	0.003	0.145*	0.149*	0.101	0.022	0.066	-0.089	0.128	0.214*	-0.043	0.191*
CGR (GS_3)			-0.017	-0.351*	0.980*	0.134	-0.351*	0.970*	-0.122	-0.066	-0.285*	-0.257*	-0.123	-0.071	0.014	0.027	0.049	-0.059	0.208*	0.043	-0.169*	-0.001	-0.138
LAI (GS_1)				0.020	-0.017	0.668*	0.020	-0.017	0.113	0.098	0.124	0.267*	0.198*	0.185*	0.154*	0.172*	0.149	-0.059	-0.044	-0.009	0.228*	-0.204*	0.060
LAI (GS_2)					-0.351*	-0.021	0.870*	-0.351*	0.060	-0.189*	0.120	0.225*	0.003	0.145*	0.149*	0.101	-0.022	0.065	-0.089	0.128	0.214*	-0.043	0.191*
LAI (GS_3)						0.134	-0.351*	0.850*	-0.122	-0.066	-0.285*	-0.257*	-0.123	-0.071	0.014	0.027	0.049	-0.059	0.207*	0.043	-0.169*	-0.001	-0.138
SLW (GS_1)							-0.021	0.134	0.022	0.002	0.073	0.186*	0.115	0.180*	0.085	0.199*	0.195**	-0.073	-0.025	-0.039	0.185*	-0.187*	0.043
SLW (GS_2)								-0.351*	0.060	-0.189*	0.120	0.225*	0.003	0.145*	0.149*	0.101	-0.022	0.065	-0.089	0.128	0.214*	-0.043	0.191*
SLW (GS_3)									-0.122	-0.066	-0.285*	-0.257*	-0.123	-0.071	0.014	0.027	0.049	-0.059	0.207*	0.043	-0.169*	-0.001	-0.138
Days to flower initiation										0.576*	0.327*	0.390*	0.068	0.118	0.107	-0.009	0.051	-0.049	-0.197*	-0.102	0.343*	-0.361*	-0.018
Days to 50% flowering											0.240*	0.195*	0.136	0.132	0.185*	-0.073	0.042	0.019	-0.113	-0.171*	0.292*	-0.291*	-0.029
Days to 75% maturity												0.166*	-0.042	-0.005	0.037	0.046	-0.097	-0.038	-0.218*	-0.001	0.265*	-0.239*	0.054
Plant height													0.226*	0.305*	0.096	0.340*	0.353*	-0.032	-0.132	-0.041	0.532*	-0.309*	0.264*
No. of primary branches / plant														0.559*	0.328*	0.061	0.264*	0.118	0.053	-0.111	0.302*	-0.150*	0.219*
No. of secondary branches / plant															0.337**	0.012	0.101	0.104	0.012	-0.172*	0.538*	-0.215*	0.405*
Siliquae/ plant																-0.032	0.244*	0.113	0.044	-0.057	0.296*	-0.044	0.264*
Length of main shoot																	0.560*	0.108	0.028	0.105	0.208*	-0.051	0.178*
Siliquae on main shoot																		0.057	0.019	-0.022	0.256*	-0.157*	0.159*
Siliqua length																			0.304*	0.120	-0.012	0.077	0.074
Seeds/ siliqua																				-0.109	-0.153*	0.038	-0.118
1000-																					0.038	0.002	0.099

seed weight																							
Biological yield/ plant																						-0.493*	0.625*
Harvest index																							0.323*

* Significance at P ≤ 0.05; ** Significance at P ≤ 0.01

Estimates of direct and indirect effects

The path coefficient analysis revealed that at phenotypic level, the high positive direct effects on seed yield could be contributed by biological yield per plant and harvest index (Table 5). The results are in conformity with earlier findings (Sirohi *et al.* 2004 [24]; Sirohi *et al.* 2008 [23]; Bind *et al.* 2014 [3]). Selection on the basis of biological yield per plant and harvest index will result into higher seed yield per plant. The significant positive correlations of CGR (GS_2), LAI (GS_2), SLW (GS_2), plant height, number of primary branches per plant, number of secondary branches per plant, siliquae per plant, length of main shoot and siliquae on main shoot with seed yield per plant were due to their high positive indirect effect *via* biological yield per plant. The significant positive correlations of biological yield per plant and harvest index with seed yield per plant were mainly due to their high positive direct effects. Residual effect (0.253) recorded in present investigation indicated that the characters studied accounted for much of the variation for seed yield per plant.

Table 5. Estimates of direct and indirect effects at phenotypic level of different characters on seed yield (pooled over the environments)

Characters	CGR (GS_1)	CGR (GS_2)	CGR (GS_3)	LAI (GS_1)	LAI (GS_2)	LAI (GS_3)	SLW (GS_1)	SLW (GS_2)	SLW (GS_3)	Days to flower initiation	Days to 50% flowering	Days to 75% maturity	Plant height	No. of primary branches/ plant	No. of secondary branches/ plant	Siliquae/ plant	Length of main shoot	Siliquae on main shoot	Siliqua length	Seeds/ siliqua	1000-seed weight	Biological yield/ plant	Harvest index
CGR (GS_1)	-0.024	0.001	0.001	-0.015	0.001	0.001	-0.013	0.001	0.001	-0.003	0.001	-0.001	-0.004	-0.003	-0.004	-0.001	-0.005	-0.005	-0.002	0.001	0.000	-0.005	0.004
CGR (GS_2)	0.000	-0.003	0.001	0.000	-0.003	0.001	0.000	-0.003	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000
CGR (GS_3)	-0.002	-0.013	0.038	-0.001	-0.013	0.038	0.005	-0.013	0.038	-0.005	-0.003	-0.011	-0.009	-0.005	-0.003	0.001	0.001	0.002	-0.002	0.008	0.002	-0.007	0.000
LAI (GS_1)	0.005	0.000	0.000	0.009	0.000	0.000	0.006	0.000	0.000	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.002	0.001	-0.001	0.000	0.000	0.002	-0.002
LAI (GS_2)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
LAI (GS_3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SLW (GS_1)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SLW (GS_2)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SLW (GS_3)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Days to flower initiation	-0.003	-0.002	0.003	-0.003	-0.002	0.003	-0.001	-0.002	0.003	-0.028	-0.016	-0.009	-0.011	-0.002	-0.003	-0.003	0.000	-0.001	0.001	0.006	0.003	-0.009	0.010
Days to 50% flowering	0.003	0.016	0.006	-0.008	0.016	0.006	0.000	0.016	0.006	-0.049	-0.085	-0.020	-0.017	-0.012	-0.011	-0.016	0.006	-0.004	-0.002	0.009	0.015	-0.025	0.025
Days to 75% maturity	0.001	0.003	-0.007	0.003	0.003	-0.007	0.002	0.003	-0.007	0.008	0.006	0.023	0.004	-0.001	0.000	0.001	0.001	-0.002	-0.001	-0.005	0.000	0.006	-0.006
Plant height	-0.005	-0.006	0.006	-0.007	-0.006	0.006	-0.005	-0.006	0.006	-0.009	-0.005	-0.004	-0.025	-0.006	-0.008	-0.002	-0.008	-0.009	0.001	0.003	0.001	-0.013	0.008
No. of primary branches/ plant	0.004	0.000	-0.004	0.006	0.000	-0.004	0.004	0.000	-0.004	0.002	0.004	-0.001	0.007	0.033	0.018	0.011	0.002	0.009	0.004	0.002	-0.004	0.009	-0.005
No. of secondary branches/ plant	0.005	0.005	-0.003	0.006	0.005	-0.003	0.006	0.005	-0.003	0.004	0.005	0.000	0.011	0.019	0.034	0.012	0.000	0.004	0.004	0.000	-0.006	0.019	-0.007
Siliquae/ plant	-0.001	-0.004	0.000	-0.004	-0.004	0.000	-0.002	-0.004	0.000	-0.003	-0.005	-0.001	-0.002	-0.008	-0.008	-0.024	0.001	-0.006	-0.003	-0.001	0.001	-0.007	0.001
Length of main shoot	-0.007	-0.001	0.000	-0.006	-0.003	-0.001	-0.007	-0.003	-0.001	0.000	0.002	-0.002	-0.011	0.002	0.000	0.001	-0.033	-0.018	-0.004	-0.001	-0.003	-0.007	0.002
Siliquae	0.00	-	0.00	0.00	-	0.00	0.00	-	0.00	0.002	0.002	-0.005	0.017	0.013	0.005	0.012	0.027	0.048	0.003	0.001	-	0.012	-0.008

on main shoot	9	0.001	2	7	0.001	2	9	0.001	2												0.001		
Siliqua length	0.001	0.002	-0.001	-0.001	0.002	-0.001	-0.002	0.002	-0.001	-0.001	0.001	-0.001	-0.001	0.003	0.003	0.003	0.003	0.001	0.024	0.007	0.003	0.000	0.002
Seeds/ siliqua	0.001	0.001	-0.003	0.001	0.001	-0.003	0.000	0.001	-0.003	0.003	0.002	0.003	0.002	-0.001	0.000	-0.001	-0.004	0.000	-0.005	-0.015	0.002	0.002	-0.001
1000-seed weight	0.000	0.006	0.002	0.000	0.006	0.002	-0.002	0.006	0.002	-0.005	-0.008	0.000	-0.002	-0.005	-0.008	-0.003	0.005	-0.001	0.006	0.005	0.046	0.002	0.000
Biological yield/ plant	0.198	0.224	-0.178	0.239	0.224	-0.178	0.194	0.224	-0.178	0.359	0.307	0.278	0.558	0.317	0.564	0.310	0.219	0.268	-0.012	-0.160	0.040	1.049	-0.517
Harvest index	-0.149	-0.035	-0.001	-0.166	-0.035	-0.001	-0.153	-0.035	-0.001	-0.295	-0.238	-0.196	-0.253	-0.123	-0.175	-0.036	-0.042	-0.128	0.063	0.031	0.002	-0.403	0.817
Correlation with seed yield/ plant	0.036	0.191*	-0.138	0.060	0.191*	-0.138	0.043	0.191*	-0.138	-0.018	-0.029	0.054	0.264*	0.219*	0.405*	0.264*	0.178*	0.159*	0.074	-0.118	0.099	0.625*	0.323*

Residual effects = 0.253 * Significance at P ≤ 0.05; Bold values indicate direct effects

Reaction to white rust

Of the thirty one genotypes screened for per cent disease severity, eleven genotypes *viz*., 03-218, HPMM-03-108, 03-143, NRC-17, 03-456, RL-1359, OMK-5-1, OMK-1, Bawal-151, RH-8544 and OMK-5-4 were found to be resistant (Table 6 and Fig. 1). Fifteen genotypes *viz*., Vardan, RCC-4, NRC-1, Pusa Jaikisan, Heera, OMK-2-21, OMK-3, OMK-3-29, IC-355331, IC-355337, IC-355421, OMK-5-2, Nav Gold, OMK-5-3 and Zem-1 were found to be moderately resistant. Remaining Five genotypes were found to be moderately susceptible. In pooled over the environments, out of two high yielding genotypes *viz*., RH-8544 showed resistant while Geeta was found to be moderately susceptible to white rust on leaves.

Table 6: Disease reaction of *Brassica juncea* genotypes to white rust on leaves

S. No.	Category	% Leaf area covered	Genotypes
1.	Resistant	0-10 %	03-218, HPMM-03-108, 03-143, NRC-17, 03-456, RL-1359, OMK-5-1, OMK-1, Bawal-151, RH-8544 and OMK-5-4
2.	Moderately Resistant	> 10-25 %	Vardan, RCC-4, NRC-1, Pusa Jaikisan, Heera, OMK-2-21, OMK-3, OMK-3-29, IC-355331, IC-355337, IC-355421, OMK-5-2, Nav Gold, OMK-5-3 and Zem-1
3.	Moderately susceptible	> 25-50 %	OMK-2, NRC-2, IC-355309, Geeta and Varuna

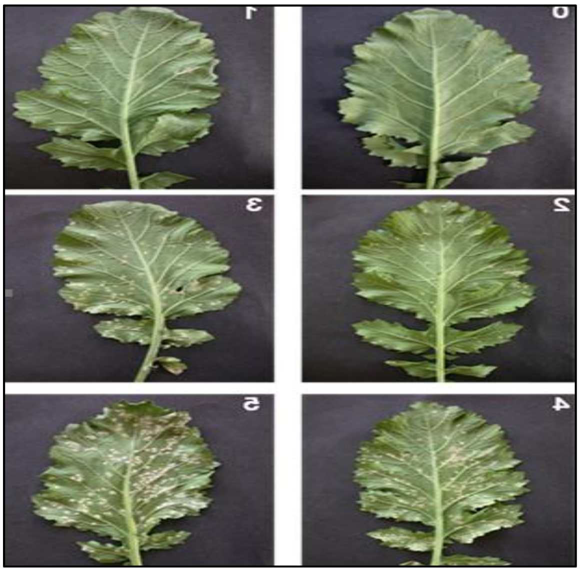

Fig 1: White rust reaction on a scale of 0-6

Conclusion

The study has shown the existence of considerable genetic variation among the genotypes considered which may help in designing the selection methodology to be used further in the breeding programme for seed yield improvement in Indian mustard. In pooled over the environments, two genotypes *viz.*, Geeta and RH-8544 were found superior for seed yield per plant over the best check RL-1359 while RH-8544 also showed resistance to white rust. Based upon correlation and path coefficient analysis, biological yield per plant and harvest index were observed to be the best selection parameter because of its high positive direct and indirect contribution towards seed yield per plant in pooled over the environments.

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