Indian J. Plant Genet. Resour. 28(3): 282-291 (2015)
DOI 10.5958/0976-1926.2015.00036.4

Genetic Variability for Physiological Characters and their Relationships with Seed Yield and its Components in Indian Mustard [*Brassica juncea* (L.) Czern. & Coss.] under Drought

Raju Lal Meena[1], JS Chauhan[2]*, KH Singh[1] and SS Rathore[1]
[1] *ICAR-Directorate of Rapeseed-Mustard Research, Bharatpur-321303, Rajasthan, India*
[2] *Indian Council of Agricultural Research, Krishi Bhawan, Dr. Rajendra Prasad Road, New Delhi-110001, India*

(Received: 19 June 2015; Revised: 02 September 2015; Accepted: 11 September 2015)

Twenty-two genotypes of Indian mustard were grown in a randomized complete block design with three replications. Analysis of variance indicated presence of variability in the experimental genotypes for all the physiological characters investigated except specific leaf weight (SLW) at 35 DAS and seed: husk ratio. Phenotypic (PCV) and genotypic (GCV) variability was substantial for leaf growth rate (LGR), leaf area index (LAI), leaf area ratio (LAR), crop growth rate (CGR), relative growth rate (RGR), net assimilation rate (NAR), transpiration quotient (TQ) and SPAD chlorophyll meter reading (SCMR). All the physiological parameters except LGR between 35 and 75 DAS, TDM at 35 DAS and SCMR at 35 and 75 DAS had high heritability and moderate to high genetic advance implying that additive gene effects were mainly responsible for the expression of these characters. Seed yield/plant was positively and significantly correlated at phenotypic and genotypic levels with LAI, CGR and biological yield/plant. It had negative genotypic correlations of moderate strength (r=-0.599–(-) 0.394) with TQ at 35 and 75 DAS indicating its positive relationship with water use efficiency. Dry matter production, early growth and development of the crop are important under drought stress due to continuous decline in available soil moisture. Since LAI, LGR, CGR, RGR and NAR are the functions of dry matter production and/or leaf area, therefore, selection on the basis of high biological yield and large LAI at 50% flowering should be quite effective in improving seed yield under drought. An increase in LAI might increase radiation load resulting in to high transpiration. Therefore, genotypes having high LAI with erect leaves and low TQ should be accorded priority in the selection programme.

Key Words: ***Brassica juncea* L., Drought, Genetic variability, Genotypes, Physiological parameters, Seed yield**

Introduction

Rapeseed and mustard are important group of oilseed crops contributing 26.1% and 23.9% to the total oilseeds production and acreage, respectively, in India (Anonymous, 2014). Of these, Indian mustard (*Brassica juncea*) is the major crop. Nearly 27% of the total cropped area is rainfed where drought affects growth and development of the crop and consequently, the seed yield, depending upon time of its occurrence, duration and intensity. The yield reduction under drought in Indian mustard ranged from 17 to 94 % (Mohamed Ali *et al*., 1990, Chauhan *et al*., 2007) due to considerable effects on yield components (Chauhan *et al*., 2007; Sharma and Pannu, 2007). Reduced leaf area index, crop growth rate, net assimilation rate, total dry matter, harvest index, partitioning coefficient (Shiv Ratan *et al*., 2005); N_2 assimilatory enzymes activity and plant water relation have been reported as a consequence of drought (Singh *et al*., 2003; Gunasekra *et al*., 2004). Singh *et al.* (1988) reported that mustard genotypes with drought tolerance trait(s) yielded better than those without such trait(s) under water stress. Transpiration efficiency (TE), defined as the amount of dry matter produced/unit amount of water transpired is one such trait, which influenced the performance of crop under water-limited conditions.The negative effects of drought during seed development may be mitigated by remobilization of assimilates that is by increasing harvest index. Exploitation of germplasm for improved TE and other physiological trait(s) would depend on the available variability in the germplasm as well as heritability of the traits. The information on nature and magnitude of variability for these characters is scanty in Indian mustard. The present investigation was under taken to assess extent and nature of variability for growth parameters and their interrelationships with seed yield and other related traits.

**Author for Correspondence: E-mail: adgseedicar@gmail.com*

Materials and Methods

The materials for the present investigation comprised 18 advanced breeding lines and four varieties of Indian mustard [*Brassica juncea* (L.) Czern. & Coss.]. These were grown in a randomized complete block design with three replications under rainfed conditions during *rabi* season of 2007-08 using only pre-sowing irrigation. There were four rows of 4 m length for each entry in a block. The row spacing was 30 cm and plant spacing with in a row was maintained at 10 cm by thinning. A fertilizer dose of 40:20:20 kg/ha ($N:P_2O_5:K_2O$) was applied at the time of sowing. Soil moisture content was recorded from the time of sowing till maturity at an interval of 15 days at three depths (15, 30 and 60 cm) using gravimetric method. The soil samples were dried in an oven at $75^o \pm 2^0$ C for at least 72 hr till constant weight was achieved. The soil moisture content was expressed in percentage on wet basis.

To study different growth parameters, the plant samples from 50 cm running row length were harvested above ground level at 35,75, 95 days after sowing (DAS). The shoot and leaves were separated and leaf area was recorded. Plant samples (shoot and leaves) were dried separately in an oven at $65 \pm 2^{\circ}$C for at least 72 hours till constant weight was achieved. The samples were weighed using an electronic balance and dry matter of leaves, shoot as well as shoot + leaves was expressed in g/m^2. For recording photosynthesis, transpiration and SPAD chlorophyll meter readings (SCMR), 3rd and 4th fully expanded leaf from the top was used from three randomly selected plants in each replication. Growth parameters were computed using leaf area and dry weight of leaves as well as total dry matter as per the methods of Radford (1967). Photosynthesis and transpiration rate were measured with the help of portable Photosynthesis system (CIRAS-2). Transpiration quotient (TQ), ratio of transpiration and photosynthesis was expressed as mmoles/µ mole. The SCMR measurements were obtained from the SPAD chlorophyll meter. Days to maturity were computed on plot basis. At the time of harvest, ten random competitive plants from each replication were taken from the two central rows to record seed yield/plant, yield components, biological yield/plant and harvest index.

The character means for each replication were subjected to analysis of variance according to the procedure outlined by Panse and Sukhatme (1967). Phenotypic (PCV) and genotypic (GCV) coefficients of variation were calculated following the method of Burton (1952). Heritability in broad sense (h^2_b) and expected genetic advance at 5% selection intensity were calculated following the methods of Hanson (1963) and Johnson *et al.* (1955), respectively. The correlation coefficients at phenotypic (r_{pxy}) and genotypic (r_{gxy}) level among different characters were computed according to the methods suggested by Searle (1971).

Results and Discussion

The soil moisture content at the time of sowing varied from 9.0-12.8% at 15 cm, 9.0-12.5% at 30 cm and 10.0-13.5% at 60 cm depth. There was a steady and rapid decline in soil moisture content at all the three soil depths up to 65 days after sowing (DAS) coinciding with 50% flowering in majority of the genotypes. The soil moisture content at this time reached 4.6%, 5.6% and 7.4% at 15, 30 and 60 cm, respectively. Thereafter, the moisture content stabilized and showed gradual decline. The reduction in soil moisture content from 65 DAS till the time of harvest was only 1.6% at 15 cm, 0.6% at 30 cm and 1.4% at 60 cm.

Highly significant genotypic differences were observed for leaf area index (LAI) and total dry matter (TDM) at 35, 75 and 95 DAS. However, TQ and SCMR showed highly significant genotypic differences at 35 and 75 DAS. The specific leaf weight (SLW) did not exhibit significant genotypic differences at 35 DAS but genotypes had highly significant differences at 75 and 95 DAS (Table 1). The genotypic differences were also highly significant for leaf area ratio (LAR), leaf growth rate (LGR), crop growth rate (CGR), relative growth rate (RGR) and net assimilation rate (NAR) during 35-75 and 75-95 DAS.

Variability

All the physiological characters investigated, *viz.*, LAI, LAR, LGR, SLW, CGR, RGR, NAR, TQ and SCMR had wide variation at both the phenotypic and genotypic levels. The range for phenotypic and genotypic coefficients of variability was 10.7 (SCMR at 35 DAS)-67.7% (LGR during 35-75 DAS) and 10.6 (SCMR at 35 DAS)-57.8 % (NAR during 75-95 DAS), respectively (Table 2). The PCV>35 %, 25-35%, 15-24% and <15% were classified as very high, high, moderate and low, respectively and GCV>20%, 10-20% and <10% were classified as high, moderate and low, respectively. The genotype BPR-538-12 and Rohini had the highest and lowest LAI at 35 DAS with high PCV and GCV. The minimum (0.4)

Table 1. Analysis of variance for physiological characters in Indian mustard under drought

Characters/degree of freedom	Source of variation (Mean sum of squares)			SEM (±)	CD (5%)
	Replication	Genotype	Error		
Leaf area index					
35 DAS*	0.020	0.095**	0.010	0.055	0.161
75 DAS	0.012	0.553**	0.029	0.097	0.282
95 DAS	0.004	0.031**	0.002	0.026	0.076
Leaf area ratio					
35 - 75 DAS	1.918	9.227 **	3.039	1.007	2.877
75 - 95 DAS	0.118	6.702 **	0.229	0.276	0.790
Leaf growth rate					
35 - 75 DAS	0.006	0.216**	0.069	0.152	0.435
75 - 95 DAS	0.394	0.535**	0.295	0.314	0.896
Specific leaf weight					
75 DAS	0.351	4.307**	0.280	0.299	0.873
95 DAS	0.153	2.154**	0.317	0.317	0.927
Total dry matter					
35 DAS	54.327	260.888**	62.746	4.468	13.052
75 DAS	56.096	22007.324**	466.636	12.185	35.594
95 DAS	1367.050	35736.899**	492.510	12.518	36.568
Crop growth rate					
35 - 75 DAS	0.346	21.469**	1.155	0.606	1.771
75 - 95 DAS	1.716	66.401**	0.905	0.537	1.568
Relative growth rate					
35 -75 DAS	4.012	53.897**	3.940	1.119	3.271
75 - 95 DAS	3.178	134.777**	4.128	1.146	3.347
Net assimilation rate					
35-75 DAS	0.149	1.441**	0.185	0.248	0.710
75 - 95 DAS	5.913	47.517**	1.434	0.691	1.976
Transpiration quotient					
35 DAS	0.001	0.040**	0.001	0.021	0.061
75 DAS	0.002	0.045**	0.026	0.026	0.075
SCMR					
35 DAS	0.210	79.618**	0.069	0.148	0.432
75 DAS	0.136	117.384**	0.056	0.133	0.389

*DAS: Days after sowing ; ** Significant at 1% probability level

and maximum (2.2) LAI at 75 DAS was recorded for the genotype RLM-619 and RCC-4, respectively, and the PCV and GCV were high. The range for LAI among the genotypes at 95 DAS was 0.12 (RLM-619)-0.45 (BPR 539-4) with an overall mean 0.26 ± 0.03 and the PCV and GCV were high.

The PCV was moderate and GCV was high for LAR during 35-75 DAS. The LAR was 3.23 and 20.28 for Rohini and BPR-541-5, respectively. LAR during 75-95 DAS varied from –8.91 (Rohini) to –1.50 (RLM-619). The mean LAR was –2.94 ± 0.31 with high PCV and GCV (Table 2). The LGR (mm^2/day) was minimum (0.35) for the genotype RLM-619 and maximum (3.09) for the genotype RCC-4. The character showed high GCV and PCV. The LGR during 75-95 DAS also had similar trend of variability but mean value was negative. SLW (mg/cm^2) had an appreciable range of variation at 75 and 95 DAS, respectively, and had moderate GCV and PCV. Total dry matter (g/m^2) increased consistently from 35 DAS to 95 DAS, respectively. The genotype Varuna had the highest TDM at 35 DAS whereas; RCC-4 recorded the highest value at 75 and 95 DAS. This character had moderate to high variability.

Crop growth rate (g/day/m^2) had substantial genetic and phenotypic variation at both the growth stages (Table 2). The range was 1.69 (Rohini)-12.79 (Urvashi)

Table 2. Range, mean, phenotypic coefficient of variability (PCV), genotypic coefficient of variability (GCV), heritability in broad-sense (h^2) and genetic advance (as % of mean) for physiological characters in Indian mustard under drought

Character	Range	Mean ± SEM	PCV (%)	GCV (%)	h^2 (%)	Genetic advance
Leaf area Index						
35 DAS*	0.34 - 1.07	0.64 ± 0.06	30.5	26.4	74.9	47.1
75 DAS	0.42 - 2.17	0.99 ± 0.10	45.8	42.3	85.6	80.7
95 DAS	0. 12 - 0.45	0.26 ± 0.03	41.8	37.8	81.8	70.3
Leaf area ratio						
35-75 DAS	3.23 - 20.28	10.31 ± 1.01	32.7	28.0	73.3	49.3
75-95 DAS	(-) 8.91- (-) 1.50	(-) 2.55 ± 0.28	60.6	57.6	90.4	113.2
Leaf growth rate (mm^2/day)						
35-75 DAS	0.35 - 3.09	0.510 ± 0.15	67.7	43.6	41.4	57.8
75-95 DAS	(-) 5.08 - (-) 0.793	(-) 2.94 ± 0.31	40.0	35.4	78.3	64.2
Specific leaf weight (mg/cm^2)						
75 DAS	5.34 - 9.52	6.92 ± 0.30	18.4	16.7	82.7	31.4
95 DAS	4.33 - 7.87	6.11 ± 0.32	15.8	12.8	65.9	21.4
Total dry matter (g/m^2)						
35 DAS	35.50 - 67.14	\49.74 ± 4.47	22.8	16.3	51.3	24.1
75 DAS	123.05 - 464.58	256.93 ± 12.19	34.0	33.0	93.9	65.8
95 DAS	237.94 - 683.22	481.84 ± 12.52	23.0	22.5	96.0	45.4
Crop growth rate (g/m^2/day)						
35-75 DAS	1.69 – 12.77	5.62 ± 0.61	50.1	46.3	85.4	88.2
75- 95 DAS	3.42 - 20.74	10.83 ± 0.54	44.0	43.7	96.0	87.1
Relative growth rate (mg/g/day)						
35 - 75 DAS	10.13 - 24.87	18.41 ± 1.12	24.7	22.2	80.9	41.1
75 - 95 DAS	5.48 - 27.74	15.10 ± 1.15	45.8	43.7	91.3	86.1
Net assimilation rate (mg/cm^2/day)						
35 - 75 DAS	0.56 – 5.72	2.00 ± 0.25	38.9	32.4	69.4	50.1
75 - 95 DAS	(-) 19.01 - (-) 2.76	(-) 6.78 ± 0.69	60.5	57.8	91.5	114.0
Transpiration quotient (m moles/µ mole)						
35 DAS	0.23 - 0.66	0.33 ± 0.02	35.6	33.9	90.3	66.3
75 DAS	0.23 - 0.68	0.34 ± 0.03	37.0	34.7	87.3	66.7
SCMR						
35 DAS	40.48 - 58.13	48.70 ± 0.15	10.7	10.6	99.7	21.8
75 DAS	30.45 - 51.76	41.83 ± 0.13	15.0	14.9	99.9	30.8

*DAS: Days after sowing

during 35-75 and 3.42 (Rohini)-20.74 (BPR-542-14) during 75-95 DAS. The overall mean value was more during 75-95 DAS (10.8g). RGR (mg/g/day) was the highest for the genotype BPR-537 (24.87) and RLM-619 (27.74) during 35-75 and 75-95 DAS, respectively. The mean RGR reduced during 75-95 DAS but showed more variation as compared to that of 35-75 DAS (Table 2). The genotype RLM-619 and Rohini showed the maximum and minimum NAR of 5.72 and -2.76 (mg/m^2/day), respectively. The mean NAR was negative between 75-95 DAS. The NAR had substantial genotypic and phenotypic variability. Transpiration quotient had the range 0.23-0.66 and 0.23-0.68 at 35 and 75 DAS. The genotype BPR-542-6 and Rohini had the maximum TQ at 35 and 75 DAS, respectively. TQ was highly variable at both the stages with high PCV and GCV. The SCMR values were the maximum for the genotype Rohini at both the stages with reduction in mean at 75 DAS. The character had low GCV and PCV at both the stages (Table 2).

Heritability and Genetic Advance

The heritability estimates varied substantially from 41.4% for LGR during 35-75 DAS to 99.9% for SCMR at 75 DAS. The genetic advance was the highest (88.2%) for CGR during 35-75 DAS and the lowest (21.4%) for SLW at 95 DAS. The heritability >80%, 60-80% and <60% were classified as high, moderate and low, respectively. The genetic advance was categorized as high (>50%), moderate (25-50%) and low (<25%). The LAI at 75 and 95 DAS had high heritability and genetic advance, but such estimates were low and moderate at 35 DAS. Both heritability and genetic advance were also high for LAR during 75-95 DAS. The heritability and genetic advance estimates were moderate during 35-75 DAS. The LGR had low and moderate heritability during 35-75 DAS and 75-95 DAS, respectively. Nevertheless, the genetic advance for LGR was high during both the stages. Moderate heritability for SLW at 75 and 95 DAS was accompanied by moderate genetic advance (Table 2). Heritability estimates for TDM ranged from 51.3% (35 DAS) to 96% (95 DAS). The genetic advance was high, moderate and low at 75, 95 and 35 DAS, respectively.

High heritability estimates coupled with high genetic advance were recorded for CGR at both the stages. Estimates of heritability and genetic advance were high for RGR during 75-95 DAS. However, high heritability was associated with moderate genetic advance during 35-75 DAS for this character. NAR during 35-75 and 75-95 DAS exhibited moderate to high heritability (69.4-91.5 %) coupled with high genetic advance (>50%). High estimate for heritability was associated with high genetic advance for TQ while SCMR had high heritability coupled with low to moderate genetic advance.

Correlations

Phenotypic Level

The leaf area index at 75 and 95 DAS was positively and significantly correlated with days to maturity, the correlation coefficients were 0.540** and 0.559**, respectively. Positive and significant association of days to maturity with LGR during 35-75 DAS (r_{pxy} = 0.445*) and TDM at 75 DAS (r_{pxy} = 0.556 **) was observed. The relationship of plant height with LAI at 35 DAS and TDM at 75 DAS was positive and significant. The correlation of LAI at 75 DAS and plant height was positive and highly significant (r_{pxy} = 0.588**). The LAI at 35 DAS positively and significantly influenced secondary branches/plant and siliquae on main shoot. A similar trend of association was recorded for LAI at 75 DAS and siliquae on main shoot. Biological yield/plant and seed yield/plant were positively and significantly related with LAI at 35 and 75 DAS.

Days to maturity recorded positive and highly significant association with TDM at 95 DAS, CGR and RGR during 35-75 DAS. The CGR during 35-75 DAS exhibited positive and significant association with plant height (r_{pxy} = 0.540**), siliquae on main shoot (r_{pxy} = 0.446*), biological yield/plant (r_{pxy} = 0.540**) and seed yield/plant (r_{pxy} = 0.480*). The inter-relationship of the RGR during 35-75 DAS was positive and significant with 1000-seed weight. However, the association between 1000-seed weight and RGR during 75-95 DAS was significant and negative (r_{pxy} = -0.452*). Reddy (1991) also reported positive and significant association of seed yield and LAI.

The leaf area index at 35 DAS had positive correlation with LAI at 75 DAS, LGR during 75-95 DAS, TDM at 35 and 75 DAS and CGR during 35-75 DAS. Mathur and Wattal (1996) also observed a positive association of LAI with TDM till 100 % flowering. The association between RGR (75-95 DAS) and LAI (35 DAS) was negative and significant (r_{pxy} = - 0.492*). Similarly, LAI at 75 DAS exhibited positive relationship with LGR between 35-75 and 75-95 DAS, TDM at 75 and 95 DAS, CGR and RGR between 35-75 DAS (Table 3.). Negative and significant association of LAI at 75 DAS was observed with RGR, NAR between 75-95 DAS and SCMR at 35 DAS. The LGR (75-95 DAS), SLW (95 DAS) and TQ (35 DAS) exhibited negative and significant associations with LAI at 95 DAS. The association of SLW (75 DAS), TDM (95 DAS), CGR and RGR (35-75 DAS) were positive and significant with LAI at 95 DAS. Negative and significant associations of NAR during 35-75 DAS (r = - 0.759**) and SCMR at 35 DAS (r_{pxy} = - 0.514*) were recorded. The LAR (35-75 DAS) and LGR (75-95 DAS) were positively and significantly interrelated (r_{pxy} = 0.482*). TQ at 35 and 75 DAS exhibited significant and positive correlation with LAR during 75-95 DAS. The LGR (35-75 DAS) had positive and significant association with CGR (35-75 DAS) and TDM at 35 DAS. The association between LGR (35-75 DAS) and SLW at 75 DAS was negative and significant (r_{pxy} = - 0.431*). SLW at 75 DAS showed negative and highly significant relationship with TDM at 75 and 95 DAS and CGR during 35-75 DAS. However, the correlation of SLW at 75 DAS was positive and highly significant with RGR during 35-75 DAS (Table 3).

Total dry matter at 75 and 95 DAS was positively and significantly related with CGR and RGR during 35-75 DAS. TDM at 75 DAS also showed positive association with NAR (35-75 DAS). The relationship of RGR and NAR (75-95 DAS) was significant and negative with TDM at 75 DAS. The TQ at 75 DAS and TDM at 95 DAS were negatively associated (r_{pxy} = - 0.578**). The TDM at 95 DAS exhibited positive and significant relationship with CGR (75-95 DAS). The CGR and RGR between 35-75 DAS were positively and significantly correlated with each other (Table 4). The association of CGR (35-75 DAS) was negative and significant with RGR and NAR during 75-95 DAS. The CGR, NAR and RGR during 75-95 DAS were positively and significantly interrelated

Table 3. Relationship among physiological character at phenotypic (light) and genotypic (bold) level in Indian mustard under drought

Character	LAI		LAR		LGR		SLW		TDM		
	75 DAS	95 DAS	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS	75 DAS	95 DAS	35 DAS	75 DAS	95 DAS
LAI (35 DAS)	0.521*	0.028	0.294	-0.275	0.099	0.499*	-0.180	-0.079	0.606**	0.509*	0.363
	0.620	**-0.005**	**0.230**	**-0.385**	**0.328**	**0.628**	**-0.209**	**-0.057**	**0.868**	**0.626**	**0.451**
LAI (75 DAS)		0.287	0.384	0.021	0.592**	0.495*	-0.422	-0.018	0.400	0.674**	0.492*
		0.343	**0.378**	**-0.008**	**0.890**	**0.567**	**-0.504**	**-0.037**	**0.559**	**0.722**	**0.558**
LAI (95 DAS)			-0.129	-0.070	0.360	-0.537**	0.539**	-0.430*	-0.083	0.384	0.575**
			-0.202	**-0.129**	**0.712**	**-0.543**	**-0.636**	**-0.565**	**-0.002**	**-0.466**	**0.665**
LAR (35-75 DAS)				-0.227	0.030	0.482*	0.141	0.274	0.033	-0.242	-0.045
				-0.341	**0.064**	**0.525**	**0.196**	**0.459**	**0.139**	**-0.260**	**-0.011**
LAR (75-95 DAS)					0.279	0.089	0.049	0.071	-0.036	0.002	-0.318
					0.414	**0.120**	**0.045**	**0.091**	**-0.056**	**0.013**	**-0.311**
LGR (35 -75 DAS)						0.246	-0.431*	-0.100	0.132	0.497*	0.352
						0.261	**-0.709**	**-0.303**	**0.497**	**0.825**	**0.582**
LGR (75-95 DAS)							0.065	0.326	0.424*	0.214	-0.40
							0.068	**0.394**	**0.601**	**0.257**	**-0.052**
SLW (75 DAS)								0.320	-0.025	-0.608**	-0.685**
								0.515	**-0.169**	**-0.680**	**-0.760**
SLW (95 DAS)									-0.075	-0.389	-0.150
									-0.035	**-0.522**	**-0.189**
TDM (35 DAS)										0.350	0.195
										0.525	**0.241**
TDM (75 DAS)											0.578*
											0.590

(Table 4). Negative and significant relationship between CGR (75-95 DAS) and TQ at 75 DAS was also observed (r_{pxy} = - 0.457*). The relative growth rate (35-75 DAS) showed negative and significant association with RGR (75-95 DAS), positive and significant relationship with NAR during 35-75 DAS (r_{pxy} = 0.464*) and TQ at 35 DAS (r_{pxy} = 0.500*). The RGR and NAR during 75-95 DAS were significantly correlated (r_{pxy} = 0.713**). TQ and SCMR at 35 DAS were positively and significantly associated with those of 75 DAS (Table 5).

Genotypic Level

The genotypic correlations were invariably higher than the phenotypic correlations. The genotypic and phenotypic correlations were in the same direction for all the characters except association of days to maturity with SCMR. Days to maturity had positive and moderate correlation with majority of the physiological characters studied, except LAR during 35-75 and 75-95 DAS, LGR during 75-95 DAS, TDM at 35 DAS, CGR during 75-95 DAS and SCMR at 75 DAS. However, SLW at 75 DAS was negatively correlated with days to maturity (r_{gxy} = - 0.760).

Plant height had high and positive correlation with LAI at 35 and 75 DAS, LGR (35-75 and 75-95 DAS), CGR and RGR (35-75 DAS). The association of plant height with LAR (35-75 DAS), TDM at 35 and 95 DAS was positive but moderate. Low to moderate and negative relationship of plant height with LAR (75-95 DAS), SLW at 75 DAS, RGR (75-95 DAS), NAR (75-95 DAS), TQ and SCMR at 35 and 75 DAS were observed. Primary branches/plant had positive and high genotypic correlation with LAI at 35 DAS (r_{gxy}= 0.722) whereas; its association with LAI at 75 DAS, LAR (35-75 DAS), LGR (75-95 DAS) and TDM (35 DAS) was positive and moderate. The relationship of primary branches/ plant with NAR during 35-75 DAS (r_{gxy} = -0.683), TQ (r_{gxy} = - 0.433) and SCMR at 35 DAS (r_{gxy} = -0.414) was negative and moderate. The association of secondary

Table 4. Relationship among physiological characters at phenotypic (light) and genotypic (bold) level in Indian mustard under drought

Character	CGR		RGR		NAR		TQ		SCMR	
	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS	35 DAS	75 DAS	35 DAS	75 DAS
LAI (35 DAS)	0.529*	0.151	0.317	-0.492*	-0.202	-0.326	-0.330	-0.161	-0.280	-0.291
	0.671	**-0.177**	**0.473**	**-0.603**	**-0.130**	**-0.336**	**-0.408**	**-0.189**	**-0.325**	**-0.334**
LAI (75 DAS)	0.701**	-0.213	0.440*	-0.438*	-0.065	-0.490*	-0.215	-0.022	-0.530*	-0.350
	0.750	**-0.233**	**0.532**	**-0.468**	**0.018**	**-0.499**	**-0.230**	**-0.014**	**-0.573**	**-0.381**
LAI (95 DAS)	0.492*	0.241	0.545**	-0.171	-0.399	-0.196	-0.429*	-0.331	-0.073	-0.045
	0.531	**0.262**	**0.654**	**-0.212**	**0.534**	**-0.194**	**-0.483**	**-0.401**	**-0.080**	**-0.053**
LAR (35-75 DAS)	-0.017	0.202	-0.083	0.059	-0.759**	-0.006	-0.113	-0.356	-0.514*	-0.403
	-0.075	**0.234**	**-0.116**	**0.059**	**-0.798**	**0.076**	**-0.175**	**-0.424**	**-0.603**	**-0.472**
LAR (75-95 DAS)	-0.246	-0.341	-0.419	0.282	0.196	0.368	0.560**	0.484*	0.272	0.262
	-0.324	**-0.354**	**-0.453**	**0.279**	**0.279**	**-0.343**	**0.622**	**0.530**	**0.285**	**0.270**
LGR (35 -75 DAS)	0.436*	-0.154	0.318	0.196	0.287	-0.416	0.045	0.153	-0.093	-0.68
	0.727	**-0.262**	**0.504**	**-0.388**	**0.422**	**-0.666**	**0.044**	**0.210**	**-0.142**	**-0.115**
LGR (75-95 DAS)	0.168	0.335	-0.096	-0.181	-0.399	-0.251	0.190	0.224	-0.323	-0.246
	0.201	**-0.377**	**-0.112**	**-0.227**	**-0.464**	**-0.292**	**0.214**	**0.289**	**-0.366**	**-0.276**
SLW (75 DAS)	-0.596**	-0.131	0.599**	0.181	-0.425*	-0.143	0.369	0.178	0.215	0.201
	-0.711	**-0.142**	**-0.676**	**0.219**	**-0.547**	**0.157**	**0.434**	**0.208**	**0.234**	**0.221**
SLW (95 DAS)	-0.351	0.170	-0.398	0.397	-0.383	0.308	0.253	0.228	-0.010	-0.019
	-0.459	**0.256**	**-0.556**	**0.499**	**-0.632**	**0.409**	**0.437**	**0.266**	**-0.002**	**-0.021**
TDM (35 DAS)	0.232	-0.212	-0.135	-0.301	-0.182	-0.277	-0.072	0.023	-0.071	0.003
	0.463	**-0.332**	**0.153**	**-0.475**	**-0.126**	**-0.416**	**-0.057**	**0.115**	**-0.102**	**0.016**
TDM (75 DAS)	0.883**	-0.406	0.443*	-0.701**	0.517**	-0.586**	-0.275	0.050	-0.193	-0.197
	0.932	**-0.416**	**0.797**	**-0.703**	**0.598**	**-0.620**	**-0.308**	**0.057**	**-0.199**	**-0.204**

branches/plant with other physiological characters, by and large, followed the trend of association as that of primary branches/plant.

The association of siliquae on main shoot was positive and high with LAI and TDM at 35 DAS and LGR during 35-75 DAS (r_{gxy} = 0.718). The association was positive and moderate with LAI at 75 DAS, LAR (35-75 DAS), LGR (75-95 DAS), TDM at 95 DAS, CGR and RGR (35-75 DAS). The LAR during 75-95 DAS had negative (r_{gxy} = - 0.596) correlation with siliquae on main shoot, RGR during 75-95 DAS(r_{gxy} = - 0.421), TQ and SCMR at 35 and 75 DAS. Positive association of low to moderate strength of siliqua length with LAI at 35, 75 and 95 DAS, CGR and RGR during 35-75 DAS was observed. SLW had negative relationship with siliqua length (r_{gxy} = - 0.671). The RGR and NAR (75-95 DAS), TQ at 35 and 75 DAS and SCMR at 35 DAS exhibited negative correlation with siliqua length. Moderate and negative relationship of siliqua length with LGR (75-95 DAS) and TDM at 75 DAS was observed. However, LGR (35-75 DAS) exhibited positive association of moderate strength with siliqua length.

The association of seeds/siliqua was positive with SLW at 75 DAS (r_{gxy}=0.488) and SCMR at 75 DAS (r_{gxy}=0.435). The RGR during 35-75 DAS (r_{gxy}=0.557) and LAI at 95 DAS (r_{gxy}=0.453) were positively correlated with 1000-seed weight but RGR during 75-95 DAS showed negative and moderate association with 1000-seed weight (r_{gxy}=-0.535). High and positive genotypic relationship of biological yield/plant was observed with LAI (35 and 75 DAS), LGR (35-75 DAS), TDM (35, 75 and 95 DAS), CGR and RGR during 35-75 DAS (Table 5). Specific leaf weight at 75 DAS, RGR and NAR during 75-95 DAS and TQ at 35 DAS exhibited negative correlations with biological yield/plant.

Seed yield/plant had high and positive relationship with LAI at 35 (r_{gxy}=0.861) and 75 DAS (r_{gxy}=0.747), CGR (r_{gxy}=0.679) and LGR during 35-75 DAS (r_{gxy}=0.857). It also exhibited positive association of moderate strength with LAI at 95 DAS, TDM at 35, 75

Table 5. Relationship among physiological characters at phenotypic (light) and genotypic (bold) level in Indian mustard under drought

Character	CGR		RGR		NAR		TQ		SCMR	
	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS	35-75 DAS	75-95 DAS	35 DAS	75 DAS	35 DAS	75 DAS
TDM (95 DAS)	0.618**	0.475*	0.595**	-0.065	0.268	0.150	-0.578**	-0.288	-0.228	-0.251
	0.684	**0.473**	**0.677**	**-0.066**	**0.316**	**0.129**	**-0.627**	**-0.321**	**-0.233**	**-0.255**
CGR (35-75 DAS)		-0.257	0.850**	-0.730**	0.351	-0.456*	-0.409	-0.105	-0.341	-0.293
		-0.270	**0.920**	**-0.751**	**0.456**	**-0.483**	**-0.481**	**-0.116**	**-0.367**	**-0.318**
CGR (75-95 DAS)			-0.088	0.661**	-0.247	0.770**	-0.388	-0.457*	-0.009	-0.071
			-0.073	**0.679**	**-0.250**	**0.794**	**-0.423**	**-0.519**	**-0.009**	**-0.071**
RGR (35-75 DAS)				-0.661**	0.464*	-0.316	0.500*	-0.278	-0.294	-0.326
				-0.682	**0.504**	**-0.363**	**-0.624**	**-0.330**	**-0.327**	**-0.366**
RGR (75-95 DAS)					-0.239	0.713**	0.137	0.003	0.191	0.122
					-0.263	**0.769**	**0.160**	**-0.019**	**0.202**	**0.127**
NAR (35-75 DAS)						-0.234	-0.044	0.142	0.331	0.101
						-0.309	**-0.052**	**0.212**	**0.397**	**0.116**
NAR (75-95 DAS)							-0.198	-0.168	0.144	0.075
							-0.217	**-0.217**	**0.150**	**0.082**
TQ (35 DAS)								0.780**	0.410	0.395
								0.865	**0.429**	**0.415**
TQ (75 DAS)									0.326	0.357
									0.351	**0.384**
SCMR (35 DAS)										0.719**
										0.721

*, **: Significant at 5% and 1% probability level, respectively.

and 95 DAS and RGR (35-75 DAS). However, TQ at 35 DAS and RGR (75-95 DAS) had negative relationship with seed yield.

High positive correlation of LAI and TDM at 35 DAS was observed. LAI at 35 DAS also had positive association with LAI at 75 DAS, LGR during 75-95 DAS, CGR during 35-75 DAS, TDM at 75 and 95 DAS (Table 4). RGR (75-95 DAS) recorded negative association of moderate magnitude with LAI at 35 DAS. LAI at 75 and 95 DAS had high and positive association with LGR during 35-75 DAS. Moderate to high positive relationship of LAI at 75 DAS with LGR during 75-95 DAS, TDM at 75 and 95 DAS, CGR and RGR between 35-75 DAS were also observed (Table 3). The LAI at 75 DAS had negative association of moderate magnitude with SLW at 75 DAS, RGR and NAR during 75-95 DAS and SCMR at 35 DAS. The LAI at 95 DAS exhibited negative and moderate relationship with LGR (75-95 DAS), SLW at 75 and 95 DAS, TDM at 75 DAS and TQ at 35 and 75 DAS. However, TDM at 95 DAS was positively correlated with LAI at 75 (r_{gxy} = 0.558) and 95 DAS (r_{gxy} = 0.665). The relationship of LAR (35-75 DAS) was negative and high with NAR (35-75 DAS), negative and moderate with SCMR (35 DAS), positive and moderate with LGR during 75-95 DAS and SLW at 95 DAS (Table 4).

Positive correlations of moderate magnitude were observed between LAR (75-95 DAS) and TQ (35 and 75 DAS). The LAR (75-95 DAS) also showed positive and negative association with LGR (35-75 DAS) and RGR (35-75 DAS). Highly positive association of LGR (35-75 DAS) was observed with TDM at 75 DAS and CGR during 35-75 DAS (Table 4). A negative and strong relationship was recorded between LGR (35-75 DAS) and SLW at 75 DAS. Relationship of LGR (75-95 DAS) with TDM at 35 DAS was positive and moderate (r_{gxy} = 0.601).

The SLW at 75 DAS showed highly negative association with TDM at 75 and 95 DAS, CGR and RGR during 35-75 DAS. The NAR (35-75 DAS) was also negatively associated with SLW (75 DAS). The associations of SLW at 95 DAS were negative and moderate with TDM at 75 DAS, CGR, RGR and NAR during 35-75 DAS (Table 3).TQ at 35 DAS, RGR and NAR during 75-95 DAS were positively associated with SLW at 95 DAS. The relationship of TDM at 35 DAS with CGR during 35-75 DAS was positive (r_{gxy} = 0.463). Negative associations of moderate magnitude were observed for TDM at 35 DAS with RGR and NAR (75-95 DAS). The genotypic correlations of TDM at 95 DAS were 0.684, 0.473 and 0.677, respectively, with CGR (35-75 and 75-95 DAS) and RGR (35-75 DAS).

The CGR and RGR (35-75 DAS) were positively correlated with each other while CGR (35-75 DAS) and RGR (75-95 DAS) were negatively correlated (Table 5). The association of CGR (35-75 DAS) was positive and negative with NAR during 35-75 and 75-95 DAS, respectively. The correlation of CGR (35-75 DAS) and TQ at 35 DAS was positive. CGR, RGR and NAR between 75-95 DAS were positively correlated (Table 5). Similarly, NAR (75-95 DAS) and SCMR (75 DAS) were positively associated with each other. TQ and SCMR at 35 DAS also had high positive genotypic correlation with that of 75 DAS (Table 5).

Conclusions

Physiological characters determining the growth and development of the crop such as LAI, LAR, LGR, SLW, TDM, CGR, RGR, NAR and TQ had moderate to high genetic variability. Except LGR between 35 and 75 DAS, TDM at 35 DAS and SCMR at 35 and 75 DAS all the growth parameters had high heritability and moderate to high genetic advance implying that additive gene effects were mainly responsible for the expression of these characters. Moderate to high variability available in the present materials could be quite useful for selection. The LAI and CGR also had positive correlations with seed yield. The relationship of days to maturity with LAI at 75 and 95 DAS, LGR, CGR, RGR between 35 and 75 DAS and TDM at 35, 75 and 95 DAS were positive and significant suggesting that days to maturity is directly related to characters influencing total dry matter production. LAI and TDM were also positively correlated at 35 and 75 DAS. The results suggested that under drought stress, 1000-seed weight, LAI, CGR. RGR, NAR and TQ could be the reliable selection criteria for yield enhancement. Negative genotypic correlation of moderate to high strength of TQ with plant height, primary branches/plant, siliquae on main shoot, siliqua length, biological yield and seed yield suggested that genotypes with low TQ conversely high water use efficiency (WUE) should be selected in the breeding programme to improve seed yield under drought stress.

References

Anonymous (2014) *Agricultural Statistics at a Glance–2013.* Directorate of Economics and Statistics. Department of Agriculture & Cooperation. Ministry of Agriculture, Government of India, New Delhi (www. dacnet.nic.in) June 9, 2014.

Burton GW (1952) Quantitative inheritance in grasses. *In: Proceedings Sixth International Grassland Cong*ress, Pennsylvania (USA) pp. 277-283..

Chauhan JS, MK Tyagi, A Kumar, NI Nashaat, M Singh, NB Singh, ML Jakhar and SJ Welham (2007) Drought effects on seed yield and its components in Indian mustard (*Brassica juncea* L.). *Plant Breed.* **126**: 399-402.

Gunasekera CP, LD Martin, RJ French and KHM Siddique (2004) Response of mustard and canola genotypes to soil moisture stress during the post-flowering period. *Handbook and Abstracts. 4th International Crop Science Congress*. September 26-October 1, Brisbane Queensland, Australia, 2004. pp.133.

Hanson WD (1963) Heritability. *In:* WD Hanson and HF Robinson (eds.) *Statistical Genetics and Plant Breeding. Publication*. **982,** Washington, DC, National Academy of Sciences, National Research Council USA, pp.125-139.

Johnson HW, HF Robinson and RE Comstock (1955) Genotypic and phenotypic correlations in soybean and their implications in selection. *Agronomy J.* **47**: 477-483.

Mathur D and PN Wattal (1996) Physiological analysis of growth and development in three species of rapeseed-mustard (*Brassica juncea, B. campestris* and *B. napus*) under irrigated and unirrigated conditions. *Indian J. Plant Physiol.* **1**(NS): 171-174.

Mohamed Ali, A I Ohlsson and H Sevensk (1990) Drought management. *In:* I Ohlsson and PR Kumar (Eds.) *Research on Rapeseed and mustard. Proceedings of an Indo-Swedish Symposium*, September 4-6, Swedish University of Agricultural Sciences, Uppsala, Sweden. 1989, pp. 49-67.

Panse VG and PV Sukhateme (1967) *Statistical Methods for Agricultural Workers.* 2nd edition. ICAR, New Delhi, 381p.

Radford PJ (1967) Growth analysis formulae, their use and disuse. *Crop Sci.* **7**: 171-175.

Reddy BN (1991) Correlation studies in Indian mustard. (*Brassica juncea* (L.) Czern & Coss). *J. Oilseeds Res.***8**: 248-250.

Searle SR (1971) Topics in variance components estimation. *Biometrics* **27**: 1-76.

Sharma KD and RK Pannu (2007) Biomass accumulation and its mobilization in Indian mustard, *Brassica juncea* (L.) Czern & Coss. under moisture stress. *J. Oilseeds Res.* **24**: 267-270.

Shiv Ratan, BD Chaudhary and Dhiraj Singh (2005) Partitioning coefficients of plant parts under different growth stages and environments in Indian mustard (*Brassica juncea* (L.) Czern & Coss.). *J. Oilseeds Res.* **22**: 259-262.

Singh Maharaj, JS Chauhan and PR Kumar (2003) Response of different rapeseed-mustard varieties for growth, yield and yield component under irrigated and rainfed condition. *Indian J. Plant Physiol.* **8** (NS): 53-59.

Singh RP, DP Singh and P Singh (1988) Variation for plant water relations and yield structure in *Brassica juncea* L. under drought conditions. *Narendra Deva J. Agric. Res.* **3**: 91-98.