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Stability behaviour in Indian mustard (*Brassica juncea* L.)

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Abstract
Experiments were conducted to study the stability behavior for seed yields its contributing traits and seed quality parameters of improved and high-yielding varieties of Indian mustard (*Brassica juncea* L.) during (*Rabi*) 2018–19 and 2019–20 under irrigated and rainfed environments. Irrigated environment was relatively better for the expression of wider range and higher mean for all parameters. Genotype × environment interaction was significant for days to 50 % flowering, days to maturity, primary branches/plant, secondary branches/plant, total branches/plant, and length of main raceme/plant, siliqua on main raceme/plant, siliqua/plant, harvest index and biological yield/plant. G × E (linear) was also turned significant to these traits including plant height and number of primary branches per plant. All 65 genotypes were tested for 3 stability parameters, *viz.*, mean, bi and *Š2*di. Out of these, the genotypes 'Kranti', 'NDR8501', 'SIVT17-83', 'SIVT17-23' and 'Vardan' were identified to be high yielding and stable. 'Varuna' and 'Vardan' were having superior performance for seed yield/plant but were found to be suitable for cultivation under irrigated (favorable) environment. Genotypes, *viz.*, 'Kranti', 'NDR8501', 'SIVT17-83', 'SIVT17-23', 'Varuna' and 'Vardan' thus may be included in further breeding programme to develop high-yielding stable genotypes over the environments. Direct selection in the segregating generations of such parents for seedling dry weight, speed of germination along with simultaneous selection for total branches/plant, siliqua on main raceme/plant and 1000-seed weight will be responsive for improvement of seed yield/plant in Indian mustard.

Keywords: *Brassica juncea*, G x E interaction, genotype, environment, stability

Introduction
Despite reckoned oil technology in the recent past, the demand-supply gap of edible oils in future is anticipated as well as better standard of living, the demand of edible oil has been estimated to be in world up to 11.12 million tonnes by 2030 (Paroda, 2000) [13]. There is equal to production of about 32.35 million tones & edible oilseed in the year 2030.

Rapeseed-mustard in a major oilseed crop which is being cultivated on acreage of 33.64 million hectare with a production of 72.37 million tones globally (FAO, 2019) [14]. In India, the area, production and productivity of this crop was about 6.12 million hectare, 9.26 million tones and 1511 kg/ha, respectively (AICRP-RM 2020). Thus, it ranks second after groundnut in area and third in production after soybean. Through, this crop has witnessed some genetic improvement during the last two decades but the progress has been realized rather slow, perhaps due to the narrow genetic base, inherent susceptibility to biotic and abiotic stresses, going on marginal and sub marginal lands, meager and inconsistent information relating to the genetic parameters underlying improvement. Keeping these in view, the present investigation was carried out accumulative 65 genetically as well as geographically wide genotypes for two consecutive years over two irrigated and rainfed environments in order to to identify the most stable high-yielding genotypes for sustainable production as well as some of backbone for a rational breeding program in Indian mustard.

Materials and Methods
The experiments were conducted at the experimental Research Farm of Genetics and Plant Breeding, Acharya Narendra Deva University of Agriculture and Technology, Narendra Nagar, Ayodhya (UP) during *Rabi*, 2018-19 to 2019-20 and under irrigated situation. The material for present study consisted of 65 genotypes of *Brassica. juncea* with wider adaptability in areas of their recommendation from states, *viz* Uttrakhand (Kranti) and Uttar Pradesh ('NDRE-4','NDRE7','Urvashi','Rohini','Varuna','Maya','NDRS2017','Ashirvad','SIVT16-90','UDN16-6','NDN16-8','UDN16-8','SBG16-14','SBG16-17','SIVT17-15',

’SIVT17-22’,’SIVT17-23’,’SIVT17-29’,’SIVT17-30’,’SIVT17-55’,’SIVT17-47’, ’NDN16-2’,’SIVT17-24’,’SIVT17-53’,’SIVT17-21’,’SIVT17-34’,’SIVT17-28’, ’SIVT17-12’,’NDN16-9’,’SIVT17-46’,’SIVT17-11’,’SIVT17-61’,’SIVT17-57’, ’SIVT17-38’,’SIVT17-129’,’SIVT17-73’,’SIVT17-51’,UDN16-41’,’SIVT17-66’, ’SBG16-27’,’UDN16-38’,’UDN16-32’,’SIVT17-17’,’SIVT17-37’,’SIVT17-33’, ’SIVT17-94’,’SIVT17-71’,’SIVT17-60’,’SIVT17-63’,’SIVT17-95’,’SIVT17-36’, ’SIVT17-59’,’SIVT17-93’,’SIVT17-62’,’UDN16-35’,’SIVT17-40’,’SIVT16-91’, ’SIVT17-90’,’SIVT17-103’,’SIVT17-83’,’SIVT17-41’,’SIVT17-128’,’NDR8501’, ’Kranti’ and ’Vardan’). During both the years, trials were laid out in randomized block design with 3 replications in plot size of 5.0 m ×2.25 m. Row-to-row and plant-to-plant distances were kept at 45 cm×15 cm about. The recommended packages of practices was followed time to time to raise an ideal crop. The data were recorded on 22 parameters, *viz*., germination (%), speed of germination, root length(cm), shoot length(cm), seedling length (cm), seedling dry weight (mg), vigour index-i, vigour index-ii, days to 50% flowering, days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, plant height (cm), length of main raceme (cm), number of siliquae on main raceme/ plant, number of siliquae/ plant, number of seeds/siliqua, 1000-seed weight (g), harvest index, biological yield/ plant (g) and seed yield/plant (g). Days to 50% flowering and days to maturity recorded on plot basis, the data for rest of the morphological traits were recorded on randomly selected 10 competitive plants in the middle 3 rows of each plot in all 3 replications. The data were subjected to analysis of variance as per the procedure suggested by Sukhatme and Amble (1989) [11]. Genotype-environment interactions were found to be significant in respect of all the parameters studied, hence the data were subjected to stability analysis (Eberhart and Russel, 1966) [4] to assess the stability of different genotypes. A genotype with regression coefficient of unity (bi =1) and the deviation not significantly different from zero (Š2di = 0) was taken to be a stable genotype with unity response.

Table 1: Pooled analysis of variance for different seed quality parameters in Indian mustard.

Source of variation	df	Germination (%)	Speed of Germination	Root length(cm)	Shoot length(cm)	Seedling length(cm)	Seedling dry weight(mg)	Vigour index-1	Vigour index-2
Genotypes (G)	64	6.645 **	4.213 **	1.003 **	1.677 **	3.237 **	0.277 **	30521.220 **	2388.391 **
Environments (E)	3	94.082 **	13.159 **	4.436 **	8.106 **	21.162 **	0.191 **	218325.100 **	3159.827 **
G × E	192	0.932	0.126	0.225	0.190	0.407	0.008	5951.132	113.669
E + (G × E)	195	2.366 **	0.326 **	0.289	0.312 **	0.726 **	0.011 **	9218.424 **	160.533 *
E (Linear)	1	282.245 **	39.477 **	13.307 **	24.317 **	63.487 **	0.573 **	654975.300 **	9479.481 **
G × E (Linear)	64	0.844	0.064	0.211	0.207	0.477	0.010	6577.573	102.338
Pooled Deviation	130	0.961	0.154	0.228	0.179	0.366	0.007	5551.175	117.499
Pooled Error	520	2.245	0.685	1.076	1.099	2.080	0.025	15385.190	253.003
Total	259	3.423	1.286	0.466	0.649	1.347	0.077	14482.440	711.046

*, ** Significant at 5% and 1% probability level

Table 2: Pooled analysis of variance for various parameters in Indian mustard.

Source of variation	df	Days to 50% flowering	Days to maturity	Number of primary branch per plant	Number of secondary branch per plant	Number of total branch per plant	Plant height (cm)	length of main raceme (cm)
Genotypes (G)	64	16.673 **	16.331 **	2.119 **	8.540 **	17.680 **	383.544 **	3.946 **
Environments (E)	3	272.999 **	212.587 **	15.913 **	50.968 **	127.881 **	3437.124 **	377.781 **
G × E	192	0.344 *	0.375 **	0.049 **	0.156 **	0.248 **	5.086	0.579 *
E + (G × E)	195	4.539 **	3.640 **	0.293 **	0.938 **	2.212 **	57.886 **	6.382 **
E (Linear)	1	818.996 **	637.761 **	47.738 **	152.905 **	383.643 **	10311.370 **	1133.342 **
G × E (Linear)	64	0.524 **	0.680 **	0.083 **	0.306 **	0.517 **	6.631 *	0.885 **
Pooled Deviation	130	0.251	0.219	0.032	0.080	0.112	4.247	0.420
Pooled Error	512	2.268	2.644	0.134	0.481	0.614	33.910	5.085
Total	259	7.537	6.776	0.744	2.817	6.034	138.358	23.078

Contd….

Source of variation	df	Number of siliqua on main raceme per plant	Number of siliqua per plant	Number of seed per siliqua	1000-seed weight (g)	Harvest index	Biological Yield per plant(g)	Seed Yield /plant(g)
Genotypes (G)	64	32.897 **	524.653 **	0.838 **	1.831 **	28.407 **	38.429 **	11.643 **
Environments(E)	3	251.713 **	3090.802 **	20.378 **	2.328 **	3.466 **	514.553 **	20.063 **
G × E	192	0.508 **	6.804 **	0.587	0.012	0.341 **	1.341 **	0.037
E + (G × E)	195	4.373 **	54.251 **	0.891 **	0.048 **	0.389 **	9.236 **	0.345 **
E (Linear)	1	755.139 **	9272.406 **	61.133 **	6.984 **	10.398 **	543.660 **	60.190 **
G × E (Linear)	64	0.990 **	11.439 **	0.785 **	0.012	0.579 **	2.540 **	0.043
Pooled Deviation	130	0.263	4.418	0.480	0.013	0.219	0.729	0.034
Pooled Error	512	3.283	35.811	0.867	0.039	2.544	12.153	0.560
Total	259	11.421	170.489	0.878	0.489	7.312	16.450	3.137

* &** Signficant at 5% & 1% respectively

Results and Discussion

Analysis of variance for 22 parameters was carried out individually as well as pooled over the years and locations. Analysis of variance revealed significant differences amongst genotypes for all the observed parameters in each of the 4 environments. Pooled analysis of variance over the 4 environments was also carried out in order to verify presence of G × E interactions (Table 1). G × E interaction variance was significant for all the observed parameters, except germination (%), speed of germination, root length(cm), shoot length(cm), seedling length (cm), seedling dry weight (mg), vigour index-I, vigour index-II, plant height (cm), number of seed/siliquae, 1000-seed weight, seed yield/plant(g). Variance due to genotype was also significant for all the observed parameters. Variance due to environment was also significant for all the observed characters. These results indicated presence of substantial amount of genotype×environment interaction. Stability analysis was carried out as per Eberhart and Russell (1966) [4] model for all the observed characters in order to verify presence of variance due to components of G×E interaction (Table 2).

The genotype × environment interaction was present and it was highly significant for all the characters studied, except for total number of siliquae/plant. Similar findings have been reported by Brar *et al.* (2007) [1]. As the environments selected in the present study were diverse (two irrigated and two rainfed), the presence of significant G × E for the observed characters indicates the relevance of stability analysis. The mean values over genotypes were generally lower under rainfed environment as compared to irrigated environments for the parameters, *viz.*, germination (%), speed of germination, root length(cm), shoot length(cm), seedling length (cm), seedling dry weight (g), vigour index-I, vigour index-II, days to 50% flowering, days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, plant height (cm), length of main raceme (cm), number of siliquae on main raceme/ plant, number of siliquae/ plant, number of seeds/siliqua, 1000-seed weight (g), harvest index, biological yield/ plant (g) and seed yield/plant (g). Similarly, range was wider under irrigated environments in comparison to rainfed environments for the above characters and reverse trend in range was observed for germination (%), speed of germination, root length(cm), shoot length(cm), seedling length (cm), seedling dry weight (g), vigour index-I, vigour index-II, plant height (cm), number of seed/siliquae, 1000-seed weight, seed yield/plant(g). The results indicated that the irrigated environment was relatively better for the expression of wider range and higher mean for the parameters, *viz.*, days to 50% flowering, days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, plant height (cm), length of main raceme (cm), number of siliquae on main raceme/ plant, number of siliquae/ plant, number of seeds/siliqua, 1000-seed weight (g), harvest index, biological yield/ plant (g) and seed yield/plant (g), while rainfed environment was better suited for expression of 1000-seed weight.

Analysis of variance for stability indicated significant differences among the genotypes for all 22 parameters observed, indicating the diversity in the selected genotypes. Significant differences were observed among the environments too, hence significant effect of environment was there in the expression of the traits. Genotype × environment interaction was significant for days to 50% flowering, days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, length of main raceme (cm), number of siliquae on main raceme/ plant, number of siliquae/ plant, harvest index and biological yield/ plant (g) indicating that the genotypes are varying over the environments due to G × E. The significant G × E interaction has been reported for various traits by Dhillon *et al.* (2001) [3], Brar *et al.* (2007) [1] and Yadav *et al.* (2010) [12] which confirm the findings of present investigation. G × E (linear) was also significant for all these 12 traits plant height and 1000-seed weight, indicating substantial amount of predictable G ×E interaction. Hence, we can predict the performance of genotypes over wide range of environments for these traits. Significant G × E (linear) for different traits has been reported by Chaudhary *et al.* (2004) [2], Brar *et al.* (2007) [1] and Yadav *et al.* (2010) [12]. Among the above traits, high G × E was observed for days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, number of siliquae on main raceme/ plant, number of siliquae/ plant, harvest index and biological yield/ plant (g). Significant deviations from regression have been reported earlier also by Henry and Dauly (1988) [6] and Brar *et al.* (2007) [1]. G × E (L) component was not significant for germination (%), speed of germination, root length(cm), shoot length(cm), seedling length (cm), seedling dry weight (g), vigour index-I, vigour index-II, days to 50 % flowering, days to maturity, number of primary branches/ plant, number of secondary branches/plant, number of total branches/ plant, plant height (cm), length of main raceme (cm), number of siliquae on main raceme/ plant, number of siliquae/ plant, number of seed/ siliqua, 1000-seed weight harvest index, biological yield/ plant (g) and seed yield/ plant (g). However, in the present study, genotypes were also tested for 3 parameters of stability for all the observed characters. In order to classify, the genotypes into various categories with respect to stability and suitability for particular environments, all 65 genotypes were tested for 3 stability parameters, *viz.*, mean, bi and Š2di. The genotypes showing superiority and stability for different traits have been summarized in Table 3. Out of all the genotypes, the genotypes 'Varuna', 'Kranti', 'NDR8501', 'SIVT17-83', 'SIVT17-23' and 'Vardan' were identified to be high yielding and stable genotypes. Thus, these 4 genotypes were suitable for rainfed as well as irrigated conditions. Stability of the genotypes for various traits on the basis of 3 parameters has earlier been reported by Dhillon *et al.* (2001) [3] and Brar *et al.* (2007) [1] which confirm the present findings where various genotypes are showing stability for 1 or more characters. Genotype 'Varuna', besides having stable and high performance for yield was also having superior performance for 1000-seed weight. Likewise, 'Vardan' also had stable and superior performance for shoot length, seedling length, number of primary branches/plant, number of secondary branches/plant, number of total branches/plant, number of siliqua on main raceme/plant, number of siliqua/plant and biological yield/plant. Genotype 'Kranti' also had stable and high performance for seedling dry weight (mg), vigor index-i and vigour index-ii along with seed yield/ plant. In addition to superiority and stability for seed yield/ plant, 'NDR8501' also showed stability for speed of germination. Similarly 'Varuna' and 'Vardan' were having superior performance for seed yield/plant but were found to be suitable for cultivation under rainfed (poor) environments. Gunasekera *et al.* (2006) [5] also reported wider adaptability and stability of Indian mustard genotypes in comparison to *B. napus*. Genotype. Four genotypes, *viz.*, 'Varuna', 'Vardan', 'Kranti' and 'NDR8501' should be included in any breeding programme where objective is really to develop high-yielding stable genotypes over the environments. Moreover, based on the results of present study, it is revealed that in segregating generations of such crosses including these parents, direct selection for 1000-seed weight, number of total branches/plant along with simultaneous selection for secondary branches/plant, siliqua length and total number of siliquae/plant will be responsive for improvement of seed yield/plant. Dhillon *et al.* (2001) [3] and Brar *et al.* (2007) [1] have also reported that the genotypes stable over environments can be used successfully for developing stable strains having wider adaptability in the future breeding programme.

Conclusion

The genotypes; Kranti, NDR8501, SIVT17-83, SIVT17-23, Varuna and Vardan exhibited higher mean and showed stable performance over environments for most of the yield components as well as for seed yield/ plant. Thus, these genotypes can be utilized to develop stable strains having wider adaptability for different sowing times.

Table 3: Genotypes showing stability for various parameters (Eberhart and Russell 1966) [4]

S. No.	Parameter	No. of most promising genotype	Name of the promising genotype
1.	Days to 50% flowering	16	NDRE-4,Rohini,Maya,Ashirvad,SBG16-14,SIVT17-47,SIVT17-24,SIVT17-53,SIVT17-21,SIVT17-34,NDN16-9,SIVT17-38,SBG16-27,SIVT16-91,SIVT17-90 and SIVT17-128
2.	Days to maturity	20	NDRE-7,UDN16-6,SIVT17-15,SIVT17-23,SIVT17-30,SIVT17-47,SIVT17-24,SIVT17-21,SIVT17-34,SIVT17-73,UDN16-41,UDN16-32,SIVT17-17,SIVT17-63,SIVT17-95,SIVT17-36,SIVT16-91,SIVT17-90,SIVT17-103 and SIVT17-128
3.	Number of primary branches/ plant	18	NDRS2017,Ashirvad,SIVT17-22,SIVT17-30,SIVT17-21,NDN16-9,SIVT17-61,SIVT17-38,SIVT17-129,SIVT17-51,SIVT17-66,SIVT17-37,SIVT17-71,SIVT17-63,UDN16-35,NDR8501 and Kranti
4.	Number of secondary branches/ plant	12	URVASHI,SBG16-17,SIVT17-22,SIVT17-30,SIVT17-55,SIVT17-53,SIVT17-21,NDN16-9,SIVT17-46,SIVT17-129,SIVT17-37 and SIVT17-63,
5.	Number of total branches/ plant	17	NDRS2017,SBG16-17,SIVT17-22,SIVT17-30,SIVT17-47,SIVT17-53,SIVT17-21,NDN16-9,SIVT17-46,SIVT17-61,SIVT17-129,SIVT17-51,SIVT17-37,SIVT17-71,SIVT17-63,UDN16-35 and Kranti
6.	Plant height (cm)	23	NDRE-4,Urvashi,Rohini,Varuna,Maya,SIVT16-90,UDN16-6,NDN16-8,UDN16-8,SBG16-14,SIVT17-24,SIVT17-28,SIVT17-11,UDN16-41,SBG16-27,UDN16-32,SIVT17-60,SIVT17-63,SIVT17-95,SIVT17-93,SIVT17-91,SIVT17-83 and SIVT17-128
7.	length of main raceme (cm)	19	Urvashi,NDRS2017,SBG16-17,SIVT17-22,SIVT17-55,NDN16-2SIVT17-53,SIVT17-12,NDN16-9,SIVT17-61,SIVT17-51,UDN16-38,SIVT17-17,SIVT17-59,SIVT17-62,SIVT17-83,NDR8501,Kranti and Vardan
8.	Number of siliqua on main raceme/ plant	17	Rohini,Varuna,SIVT16-90,UDN16-8,SBG16-14,SBG16-17,SIVT17-15,SIVT17-30,SIVT17-34,SIVT17-11,SIVT17-61,SIVT17-129,SIVT17-73,UDN16-38,SIVT17-62,SIVT17-128 and NDR8501
9.	Number of siliqua/ plant	19	Varuna,Ashirvad,UDN16-8,SIVT17-22,SIVT17-30,SIVT17-55,SIVT17-47,SIVT17-34,NDN16-9,SIVT17-61,UDN16-38,UDN16-32,SIVT17-94,SIVT17-59,SIVT17-62,SIVT17-83,SIVT17-128,Kranti and Vardan
10.	Number of seed/ siliqua	9	NDRE-7,SIVT17-15,SIVT17-21,SIVT17-33,SIVT17-71,SIVT17-63,SIV T17-40,SIVT16-91 and NDR8501
11.	1000-seed weight (g)	17	Urvashi,Varuna,NDRS2017,UDN16-6,UDN16-8,SIVT17-23,SIVT17-29,SIVT17-24,SIVT17-34,SIVT17-61,SIVT17-129,SIVT17-51,SIVT17-36,SIVT17-59,UDN16-35,SIVT17-128 and Kranti
12.	Harvest index	8	Maya,SIVT17-47,SIVT17-28,SIVT17-129,UDN16-32,SIVT17-33,SIVT17-63 and Vardan
13.	Biological Yield/ plant(g)	14	Urvashi,SIVT16-90,SIVT17-23,SIVT17-55,SIVT17-24,SIVT17-53SIVT17-34,SIVT17-28,SIVT17-46,SIVT17-73,SIVT17-60,SIVT17-63 and Vardan
14.	Seed Yield/ plant(g)	19	Rohini,Varuna,NDRS2017,SIVT17-15,SIVT17-23,SIVT17-28,SIVT17-12,SIVT17-46,UDN16-41,SIVT17-66,UDN16-32,SIVT17-33,SIVT17-60,SIVT17-63,SIVT17-59,SIVT17-62,SIVT17-83,SIVT17-41 and Vardan
15.	Germination (%)	12	NDRE-4,Rohini,NDN16-8,SIVT17-22,NDN16-2,SIVT17-34,SIVT17-94,SIVT17-95,SIVT17-93,UDN16-35,SIVT17-40 and SIVT17-83
16.	Speed of Germination	11	NDN16-8,SIVT17-22,SIVT17-23,SIVT17-55,NDN16-2,SIVT17-12,SIVT17-51, SIVT17-94,SIVT17-40,SIVT17-90 and SIVT17-41
17.	Root length(cm)	10	Maya,NDN16-2,SIVT17-21,SIVT17-11,SIVT17-38,SBG16-27,SIVT17-40,SIVT17-128,NDR8501 and Vardan
18.	Shoot length(cm)	9	Rohini,Varuna,Maya,NDRS2017,NDN16-2,SIVT17-21,SIVT17-51,SIVT17-93 and SIVT17-103
19.	Seedling length(cm)	9	NDRS2017,SIVT17-22,NDN16-2,SIVT17-21,SIVT17-34,SIVT17-71,SIVT17-63, SIVT17-40 and NDR8501
20.	Seedling dry weight(mg)	8	Rohini,Maya,SIVT17-55,SIVT17-28,SIVT17-12,SIVT17-57,SBG16-27 and SIVT17-91,
21.	Vigour index-1	11	Urvashi,Rohini,SIVT17-15,SIVT17-47,NDN16-2,SIVT17-21,SIVT17-51,

			UDN16-38,SIVT17-62,SIVT17-103 and NDR8501
22.	Vigour index-2	14	Urvashi,MAYA,ASHIRVAD,SBG16-14,SBG16-17,SIVT17-28,SIVT17-12, SIVT17-57,SIVT17-17,SIVT17-94,SIVT17-93UDN16-35,SIVT17-91 and NDR8501

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