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Assessing stability of Indian mustard (*Brasssica juncea* L. Czern) varieties under different agroforestry systems in Tarai region of Uttarakhand

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Abstract
The present research aimed to identify adaptable Brassica cultivars addressing climate restoration approaches under different agroforestry systems. Significant differences were observed among ten Indian mustard genotypes for all the studied traits under all environments, i.e., Open field, Poplar and Eucalyptus tree system. The genotype × environment (G×E) interaction was studied using the Eberhart and Russell stability model. Based on the stability parameters, genotypes were categorized as stable or unstable for all three environments.
Observations were recorded for yield and related traits *viz*., number of silique in the main raceme (NSM), the number of seeds per silique (SS), 1000 grain weight (GW) and grain yield. Stability analysis revealed that mustard variety CS56 had been found stable for seed yield in the Open field. RGN 73 had a high mean value and consistent performance in all environments for NSM. NDRE 4 had shown uniform performance for seeds/siliqua in all environments whereas RH7409 had recorded high mean performance and non-significant S^2_{di} for 1000 GW. However, the low value of b_i <1 suggested its suitability under Eucalyptus.

Keywords: Climate restoration, agroforestry systems, G × E, mustard, stable genotypes

Introduction
Currently the world is facing a serious issue of changing climate like fluctuating temperature extremes, drought, flood, salinity, and elevated greenhouse gases. Thus, it has become a prime requisite for us to shift our land cultivation practices in a much more organic and efficient way that will resist the changing climate and help restore the natural climate. The past two years of the COVID 19 pandemic have uncovered the truth about our food security and other resources (Edwards, 2021) [7]. To address the harmful impact of climate change, current research must be oriented towards developing varieties adapted to ecological conditions and providing some ecosystem services like developing such cultivars that are attractive to pollinators or contribute to the escalation of soil organic carbon (Beuren *et al.*, 2018). Climate robustness and buffering capacity of cultivars to newer locations without much reduction in yield will enhance food security and environmental sustainability.
Mustard is one of the earliest domesticated crops and is the third edible oilseed crop after soybean and palm oil. The crop usage is multidimensional; leaves are eaten as vegetables and salads, seeds as condiments and oil cake as animal feed. Oil content in seed varies between 35-45 % and extracted oil has a high proportion of essential fatty acids like linoleic and linolenic, which are not produced by the human body (Chand *et al.*, 2021) [3]. Increased temperature in mustard caused reduced days to flower and maturity which shortened the seed formation period and, hence, affected the yield and productivity of the crop (Rana *et al.*, 2011) [14]. The crop is reported to be sensitive to CO_2 and along with rising global temperature, the mustard yield is likely to be hampered in the coming time (Bhoomiraj *et al.*, 2010) [2]. Crop productivity is also affected by other local environmental factors like soil moisture content, relative humidity, light intensity (Mishra *et al.* 2019). The seed oil of mustard has antinutritional factors like erucic acid and glucosinolates, which can cause heart diseases if consumed at a high level. Thus it is imperative to develop such a variety with stable performance, wide adaptability with low erucic acid and low glucosinolate content. Agroforestry caters to the need for both an efficient land use system and climate amelioration (Kumar *et al.*, 2021) [9]. Trees are considered the best carbon capture technology, as carbon dioxide from the atmosphere is taken during photosynthesis and stored as biomass in different tree parts.

Leaf litter and other decaying parts add soil organic carbon to the soil. Keeping in view, the present research was conducted to assess the performance of ten Indian mustard genotypes under two different agroforestry systems, i.e., Poplar and Eucalyptus and in the open field.

Materials and Methods

The experimental material consisted of ten varieties of Indian mustard RGN-73, NDRE-4, PM-25, RH-749, PR-19, Maya, NRCHB 101, CS-56, PR-20 and Kranti. The experiment was laid out in randomized block design in three replication with 30cm row spacing at Old Forest Research Centre, Pantnagar, Uttarakhand during rabi season 2018-2019. Mustard Varieties were grown under two agroforestry systems, Poplar $7 \times 3m^2$ and Eucalyptus $7 \times 2m^2$, which differed in the amount of light that was intervened for understorey crop, humidity, and moisture content and other such local environmental factor. The other environment taken was an open field with ample sunlight and optimum conditions for the crop. Five randomly selected competitive plants from each experimental plot were selected and observations like the number of silique in the main raceme (NSM), number of seeds per silique (SS), 1000 grain weight (GW), seed yield per plant(g) were recorded. The mean value of recorded observation was statistically analyzed. The performance of genotypes under the agroforestry system is predicted through stability parameters, estimated using the stability model of Eberhart and Russel (1966) [6]. Statistical analysis was performed using OPSTAT and MS-Excel 2010.

Test of significance

(a) G×E ANOVA

The test of significance for ANOVA was tested using the F test. The mean squares (M.S) of genotype (G), environment (E), GxE interaction, environment linear [E (lin.)] and GxE(lin) all were tested against the M.S. pooled deviations to get the F values. Whereas M.S. pooled, deviations was tested against MSS pooled error to get the F value.

(b) Stability parameters

(i) S^2_{di}

The significance of stability parameters was tested using the F test. For calculating F values, M.S. pooled deviation of (G_1-G_{10}) was tested against M.S. pooled error.

(ii) Regression coefficient (b_i)

The significance of the regression coefficient (b_i) was tested using a T-test. The deviation of b_i from 0 was calculated by t_{cal}= b-0/b_e, where b_e was the error mean of b_i. The deviation of b_i from 1 was worked out by t_{cal}= b-1/b_e, where the error mean was b_i. The T calculated was compared with T tabulated at n-2 d.f., where n was the number of environments (Nadarjan, 2005) [11].

Result and discussions

Analysis of variance for G× E interactions revealed that the variance for genotypes and the environments was significant for all the four traits under study. Mustard genotypes had responded differently under the agroforestry system of Poplar and Eucalyptus and in the open field. The results were in close agreement with earlier findings of Brar *et al.*, 2007; [1] Sah *et al.*, 2009 [16] and Paul *et al.*, 2017 [12] in Indian mustard varieties for presence of variances in genotypes and Environment. G×E interactions for all the traits was found significant except for 1000 GW, which conveys that it is a stable trait and is not influenced by the environment, unlike the other three. The G×E interaction insignificant for oil content percentage in Indian mustard were reported by Dhillon *et al.*, 1999 [5] which had supported the current research findings. Since all the three environments chosen for the study differed in physical properties like the amount of light, humidity and soil characteristics, the significant G×E for observed traits emphasizes on relevance of stability analysis studies further (Sharma *et al.* 2016) [16]. G×E interaction studies and prediction about the stability of a genotype is carried out based on Eberhart and Russel (1966) [6]. This model further partitioned the G×E interaction into other components such as E+G×E, E (linear), G×E (linear), pooled deviations and pooled error. Significant E+G×E for all the characters suggested distinct nature of environments and role of G× E in the expression of the phenotype. Similar results about significant E+G×E for different traits in *Brassica juncea* were reported by Yadava *et al.*, 2010 [20]. The significance of E (linear) for all the traits confirmed significant differences among the environments and influenced the expression of traits. G×E (linear) was found significant for all traits except for 1000 GW, which indicates the contribution of linear component and that the behaviour of genotypes for these traits can be predicted.Similiar findings in twelve genotypes of brassica rapa in three environments for G × E interactions studies of yield and its related traits were also reported by Gazal *et al.*, 2013 [8]. and Priyamedha *et al.*, 2017 [13] has reported the stability of *Brassica juncea* genotypes for seed yield and its component traits under Jharkhand Condition.

Table 1: Analysis of variance of G × E interaction in mustard varieties for different characters

Source of variation	df	NSM	SS	1000GW	SY/ plant
Variety	9	22.003**	3.356**	2.212**	23.324**
Environment	2	394.756**	38.804**	3.565**	57.083**
G × E	18	21.199**	1.405	0.030	1.626*
E+ G × E	20	58.555**	5.144**	0.384**	7.171**
E (Linear)	1	789.513**	77.607**	7.131**	114.165**
G × E (Lin)	9	14.398**	2.167**	0.028	2.856**
Pooled Deviation	10	25.199**	0.578*	0.028**	0.356
Pooled Error	54	8.322	0.732	0.024	0.054
Total	29				

*, ** : Significant levels at 5% and 1%, respectively.

Mean squares for pooled deviation were also observed significant except for grain yield per plant, which suggested that prediction of the stability of performance of a variety over environment based on regression analysis of traits may not be completely reliable. Similar observations were reported by Tanin *et al.*, 2018 [19]. The significant G×E interaction for traits restricts the identification of genotypes with stable performance based on mean values for the trait. According to the model, three stability parameters, mean, regression coefficient (b) and mean square deviation from regression S^2di, are estimated for all the observed traits. These stability parameters categorize genotypes into various groups based on stability and suitability over the environment (Singh *et al.*, 2017). Estimates of stability parameters are given genotype-wise for all the traits in Table 2

Table 2: Mean yield and stability parameters estimates for ten varieties of mustard

Variety	NSM			SS			1000 GW			SY / plant		
	Mean	b	S^2_{di}	Mean	b	S^2_{di}	Mean	b	S^2_{di}	Mean	b	S^2_{di}
RGN-73	32.222	1.509	-2.083	11.00	0.440	-0.188	3.789	0.947	-0.005	6.700	0.902	-0.071
NDRE-4	26.833	1.270	13.945**	11.556	1.186	-0.205	3.578	1.284	-0.008	7.089	1.981	0.187
PM-25	28.111	0.508	35.575**	10.889	1.500	0.592	2.311	1.031	-0.006	1.833	0.432	-0.003
RH-749	30.000	0.503	87.496**	11.889	1.815	1.378*	5.289	0.899	0.003	9.989	1.483	1.173**
PR-19	29.667	0.562	11.158*	13.111	0.887	0.839*	3.644	1.020	0.077	6.556	0.782	0.311
Maya	24.556	0.917	-0.231	10.00	0.670	-0.173	2.844	1.221	0.023	2.678	0.457	-0.050
NRCHB 101	33.444	1.580	24.710**	9.667	1.277	-0.235	3.089	0.687	0.121	6.911	0.525	0.177
CS-56	32.000	1.442	31.289**	11.889	0.055	0.917*	4.067	0.695	-0.004	9.696	1.255	0.155
PR-20	29.000	1.009	6.449	10.00	0.816	0.588	4.211	1.095	0.005	5.022	0.899	0.052
Kranti	27.778	0.700	15.943*	10.889	1.354	-0.174	2.778	1.121	-0.003	9.422	1.284	-0.169
Mean	29.36			11.09			3.56			6.59		
CD	2.73			0.81			0.15			0.69		

*, ** : Significant levels at 5% and 1% respectively

As per Eberhart and Russell (1966) [6], a desirable genotype exhibit a high mean value for the trait, unit regression coefficient (b=1) and mean square deviation non-significant or equals to zero ($S^2d_i=0$). The non-significant value of $S^2d_i=0$ tells about the stability of genotype; only genotypes with non-significant S^2d_i are tested further for regression coefficient. The regression coefficient value is more concerned about genotype responsiveness in an environment.

The genotype RGN 73 has shown a high mean value, non-significant deviation from regression ($S^2d_i=0$) and regression coefficient (b) above unity for NSM, indicating average stability and high responsiveness of variety to favourable environments. Such variety, when cultivated in suitable environments, will give maximum yield. Likewise, for the trait seeds per silique (SS), NDRE 4 was found to be superior in performance with uniform stability (non-significant or low S^2d_i) and has high responsiveness to a favourable environment ($b_i > 1$). RH749 has a high mean value with high stability for 1000 GW and low responsiveness to the environment.

Other stable cultivars for the traits were PR 20 and CS56; out of these two, PR 20 has observed regression coefficient value near unity, showing linear response in all three environments. Sagolsem *et al.*, 2013 [15] had also reported similar findings for yield and related traits in Indian mustard varieties. CS 56 genotype was superior in performance, better stability and suitability in favourable conditions for seed yield/ plant. Kranti has good performance and average stability; however, it has $b_i > 1$ and showed high sensitivity to better environments. Thus, favourable growing conditions can yield maximum. Chattopadhyay *et al.,* 2012 [4] have reported similar seed yield/plant results for Kranti.

Table 3: Mean performance over three environments and estimates of Environmental Index (I_j)

Character Name	Mean±S.E.m	Environment Index		
		E1	E2	E3
NSM	29.36 ± 3.55	6.006	0.522	-6.528
SS	11.09± 0.54	2.111	-0.329	-1.789
1000GW	3.56± 0.12	0.583	0.027	-0.61
SY/Plant	6.59± 0.42	2.552	-0.370	-2.183

Environmental index (I_j) directly reflects the rich or poor environment. The negative value of Ij indicates the poor environment, while the positive value indicates the rich environment for the performance of a particular trait. E1, i.e., the Open field was a rich or favourable environment and the high mean value was observed for all the traits under study. E2, i.e., Poplar, was a favourable or rich environment for trait NSM and 1000 GW. However, E3, i.e., Eucalyptus, was a poor or less favourable environment for all traits (Table 3).

Conclusion

The presented study had shown significant and non-significant G×E interaction for different traits. Significant G×E interaction specifies the role of the environment in the expression of such traits. Further estimation of stability parameters has shown the suitability and stability of a variety in a wide range of environments or for the specific condition. CS56 was found superior in performance for seed yield with high responsiveness to favourable environment. Thus, with changing climate, such genotypes need to be selected with a wide range of adaptability and responsive to newer locations. Considering the land use system, intercropping mustard with a Poplar tree system will be more feasible than Eucalyptus.

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