



Stability Analysis of Indian Mustard Genotypes through Eberhart and Russell's Model

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Authors' contributions

This work was carried out in collaboration among all authors. Author PSK performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SRK designed the study, conducted the trial at field, managed the analyses of the study. Author SB, DT, MPM, PRK and SS reviewed the manuscript for the final submission. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The present study was undertaken to identify mustard genotypes with stable performance under late-sown conditions by evaluating genotype \times environment interactions across multiple sowing dates in the Eastern Vidarbha region of Maharashtra.

Study Design: A field experiment was conducted using eight mustard genotypes along with two check varieties (PM-26 and TAM 108-1) during the *rabi* seasons of 2020–2021, 2021–2022, 2022–2023 and 2023–2024. The genotypes were evaluated under four different sowing dates in each year like as — 30th October, 15th November, 30th November and 15th December and each of these treated as a distinct environment. A total of sixteen environments were generated over the four years. The study followed a randomized complete block design with three replications.

Place and Duration of Study: The experiment was carried out at the Research Farm of the All India Coordinated Research Project (AICRP) on Linseed and Mustard, College of Agriculture, Nagpur, Maharashtra. The study spanned four consecutive *rabi* seasons, from 2020–2021 to 2023–2024.

Methodology: Observations were recorded on five traits *viz.*, days to maturity, plant height, number of branches plant⁻¹, number of siliquae plant⁻¹ and seed yield plot⁻¹. The data were subjected to analysis of variance (ANOVA) to determine the significant differences of genotype, environment and their G \times E interaction. Stability analysis was performed using the Eberhart and Russell's model, which computes three parameters *viz.*, mean performance, regression coefficient (b_i) and mean square deviation from regression (\bar{S}^2di). These parameters were used to evaluate the adaptability and stability of genotypes across environments.

Results: The analysis of variance indicated significant differences among environments, genotypes and genotype \times environment interactions for all traits under study. The significant pooled deviation also confirmed the presence of differential genotype responses to varying environments. Stability analysis revealed that the genotypes *viz.*, ACN-237 and ACN-226 exhibited the highest mean for seed yield plot⁻¹, days to maturity and plant height along with non-significant deviation from regression (\bar{S}^2di) and regression coefficients (b_i) tends to unity. These results indicate that these genotypes possess wide adaptability and stable performance across sowing dates.

Conclusion: The genotypes *viz.*, ACN-237 and ACN-226 emerged as the most stable and high-yielding across varying environmental conditions induced by different sowing dates. Their consistent performance makes them suitable candidates for cultivation under late-sown conditions and valuable genetic material for developing mustard varieties with broad adaptability and stress tolerance.

Keywords: Indian mustard; G \times E interaction; stability analysis; eberhart and russell model; sowing dates.

1. INTRODUCTION

Rapeseed-Mustard is an important oilseed crop with both commercial and nutritional significance all over the world (Sachan et al., 2024). Mustard oil has a low level of saturated fatty acids, a moderate level of polyunsaturated fatty acids and a balanced amount of omega-3 and omega-6 fatty acids. In Asia, it is mainly grown in China, India, Pakistan and Bangladesh. Among different oilseed crops grown in India, the Rapeseed-Mustard contributes 29.5% in the total production of oilseeds (Sapkal et al., 2023). In India, Mustard has become particularly important in northern and eastern states and it ranks as the second most significant oilseed crop after soybean (Sharma et al, 2014). While mustard cultivation is predominantly concentrated in the northern states, some southern states also

contribute to its cultivation. In the context to Maharashtra, Eastern Vidarbha region has significant production of mustard as compared to rest of the region, where as the farmers grow mustard in last week of November to second week of December after harvesting of the paddy crop resulted into delayed planting reporting increased temperature above 30°C which leads to shortening of vegetative phase, advances in flowering time and decreased seed development period resulting into shrivelled seed along with high incidence of powdery mildew with low yield and low oil quantity and quality is the prime objective of the breeders in improving genotype in the region (Ingole et al., 2021).

The genetic potential and buffering capacity of plants play a crucial role in determining genotype

performance under different environments. Not all genotypes perform equally well in all environments, as the interplay between environment and genotype \times environment effects impacts genotype performance (Kumawat and Sharma, 2022). The stability of genotype is assessed by using models like Eberhart and Russell, 1966, Perkins and Jinks, 1968 and Freeman and Perkins, 1971. These models analyse genotype \times environment interaction under different environmental conditions to estimate genotype stability out of which Eberhart and Russell, 1966 model is simple and informative as compared to others.

With the aim of identifying genetically stable genotypes of Indian mustard which are suitable to late sown condition in the Eastern Vidarbha region of Maharashtra, the current study was designed to examine genotype \times environment interaction with different dates of sowing creating different environmental conditions for each genotype.

2. MATERIALS AND METHODS

The present research was conducted at Research farm of AICRP on Linseed and Mustard, College of Agriculture, Nagpur (21°08'27.7"N 79°04'26.7"E) with 8 genotypes viz. ACN-240, SKM-1626, ACN-226, ACN-244, ACN-250, ACN-255, T-9, ACN-237 along with two checks PM-26 and TAM 108-1 were evaluated in randomized block design in 3 replications for 4 consecutive years viz., *rabi* 2020-2021, 2021-2022, 2022-2023 and 2023-2024 in four different dates of sowing viz., 30th October, 15th November, 30th November and 15th December. Each genotype was grown by keeping 45 cm distance between two rows and 10 cm between two plants in a plot with 0.5 m distance between plot and 1 m distance between replications. The data was reported on days to maturity, plant height (cm), number of siliquae plant⁻¹, number of branches plant⁻¹ and seed yield plot⁻¹ (g) on randomly selected 5 competitive plants in the middle 4 rows of each plot in all replications except days to maturity and seed yield plot⁻¹, where data was recorded on plot basis. The recommended package of practices for raising of mustard crop was followed to raise a healthy crop.

The recorded data after calculating mean were subjected to analyse significance genotype-environment interactions for all the characters

under study as per the procedure prescribed by Eberhart and Russell, 1966. A genotype was considered to be a stable genotype having regression coefficient of unity ($b_i = 1$) and the deviation not significantly different from zero ($\bar{S}^2d_i = 0$).

3. RESULTS AND DISCUSSION

Plant breeder attempts to produce progressively better adapted populations to the existing or altered environments. Stability parameters have proved to be valuable for assessing the response of various genotypes under variable environmental conditions (Kumawat and Sharma, 2022).

The quantitative characters are highly influenced by the environment. The magnitude of this influence is reflected by G \times E interaction. This interaction generally remains confounded with variance and leads to biased estimates of genetic parameters. This bias can be minimized by growing the breeding materials over the environments. The study of G \times E interactions was made as per the procedure outlined by Eberhart and Russell., (1966).

3.1 Analysis of Variance

The analysis of variance showed the significant differences among genotypes for all the characters under study over the environment. The source of variation due to genotype \times environment interaction presented in Table 1 represents the significant difference in pooled data over environment, where genotype reported high significance for the characters viz. days to maturity, plant height (cm), number of branches plant⁻¹, number of siliquae plant⁻¹ and seed yield plot⁻¹ representing available genotypic variability of the genotypes. For environment, all the characters showed highly significant performance representing the influence of the environment on the genotype for all the characters under study. Similarly, for all the characters, high significance was reported due to interaction between genotype \times environment indicating the available variability due to interaction effect. Similar study was conducted by Kana Rama et al., (2016) using three dates of sowing creating different environments reported a significant genotype, environment and genotype \times environment interaction suggesting available genetic variability along with significant difference between environments.

Table 1. Analysis of variance (Eberhart and Russell model) for yield and yield contributing characters

Sources of variation	d. f.	Mean Sum of Squares				
		Days to maturity	Plant height (cm)	Number of branches plant ⁻¹	Number of siliquae plant ⁻¹	Seed yield plot ⁻¹ (g)
Genotype	9	78.09**	781.79**	0.44*	3347.43**	357221.27**
Environment	15	1274.91**	4371.02**	5.58**	12246.02**	1067483.90**
Gen x Env	135	11.35*	107.95*	0.19*	512.73*	25425.57*
Env + (Gen x Env)	150	137.71	534.26	0.73	1686.06	129631.40
Env (Lin.)	1	19123.60**	65565.35**	83.70**	183690.22**	16012258.56**
Gen x Env (Lin.)	9	9.71**	160.55**	0.29*	767.32**	36733.33**
Pooled Deviation	140	10.32**	93.78**	0.16**	445.09**	22156.09**
Pooled Error	288	9.31	129.53	0.15	342.58	28461.18

* and ** indicates significant at 5% and 1% respectively

Table 2. Mean value and stability parameters (b_i and \bar{S}^2di) of the mustard varieties for seed yield and its components

Sr. No.	Variety	Days to maturity			Plant height (cm)			Number of branches plant ⁻¹			Number of siliquae plant ⁻¹			Seed yield plot ⁻¹ (g)		
		Mean	\bar{S}^2di	b_i	Mean	\bar{S}^2di	b_i	Mean	\bar{S}^2di	b_i	Mean	\bar{S}^2di	b_i	Mean	\bar{S}^2di	b_i
1	ACN-240	106	3.267	1.064**	153.64	51.14*	1.127**	3.47	0.09*	1.293**	148.8	825.9**	1.352**	1522.1	37153.1**	1.05**
2	SKM-1626	106	3.098	1.076**	156.03	63.447*	1.138**	3.42	0.081*	1.206**	151.8	119.8	0.889**	1463.3	32144.4**	1.012**
3	ACN-226	106	1.943	1.063**	159.66	-3.78	0.935**	3.41	0.205**	0.902**	174.1	111.7	1.013**	1731.9	1226.7	1.192**
4	ACN-244	106	6.408**	0.983**	157.65	-5.67	1.052**	3.10	0.143**	1.099**	142.9	548.9**	0.728**	1511.0	12492.6*	1.107**
5	ACN-250	111	4.231*	0.894**	174.54	101.02**	0.943**	3.55	0.089*	0.712**	176.7	52.7	1.044**	1724.9	-1976.6	1.068**
6	ACN-255	108	24.896**	1.062**	160.12	112.17**	1.264**	3.36	0.032	0.999**	151.2	535.2**	1.072**	1351.0	40271.9**	0.693**
7	T-9	103	15.686**	0.898**	150.95	48.82*	1.024**	3.37	0.117**	0.983**	147.7	309.1**	0.941**	1455.8	4180.3	0.897**
8	ACN-237	104	1.203	1.025**	161.94	15.27	0.924**	3.55	0.129**	0.766**	175.2	292.3**	0.831**	1783.1	3026.9	1.166**
9	PM 26	105	5.322*	1.010**	150.05	21.23	0.887**	3.56	0.093*	0.902**	139.4	233.7**	0.823**	1406.0	-2371.5	0.883**
10	TAM 108-1	107	6.142**	0.925**	161.30	102.33**	0.706**	3.73	0.107**	1.139**	169.5	279.5**	1.308**	1484.1	542.6	0.931**
Grand Mean		106			158.59			3.45			157.7			1543.3		

* and ** indicate level of significance at 5% and 1% respectively

Partitioning of environment + (genotype × environment) interaction into environment (linear), genotype × environment (linear) and pooled deviation showed that significant mean square due to environment (linear) for all characters under study, indicated that significant differences were present between environments and had exhibited the considerable influence on expression of seed yield and its contributing characters. The environment (linear) component differed significantly indicating that environments affect significantly to the expression of genotypes. Genotypes × Environment (linear) showed significance for all the characters indicated divergent linear response to environmental changes. Similar results were reported by Kana Rama et al., (2016) in Indian mustard for days to 50 per cent flowering, primary branches plant⁻¹, secondary branches plant⁻¹, length of siliqua, seed yield plant⁻¹ and test weight. Jakhar and Yadava., (2010) also reported similar results by creating different environmental conditions through different sowing dates in Taramira (*Eruca sativa* Mill.). The pooled deviation also reported significant deviation for all characters under study, similar results were reported by Priyamedha et al., (2017) for plant height, number of siliquae on main shoot, number of seeds siliqua⁻¹, number of siliqua plant⁻¹, 1000 seed weight, days to maturity and seed yield plant⁻¹ in Indian mustard suggesting a significant genotype × environment interaction effect between the environments under study. Kumawat and Sharma., (2022) evaluated Indian mustard varieties for stability over three different environments created by three different dates of sowing which revealed that in all three environments significant differences were observed for all the characters.

3.2 Stability Parameters

A selection criterion to identify stable genotypes in different environment under study was considered as regression slope (b_i) as measure of stability according to Finlay and Wilkinson, 1963. Further, Eberhart and Russell, 1966 showed the need of both linear (b_i) and non-linear regression (\bar{S}^2di) in evaluating genotypes for phenotypic stability by measuring G × E interactions. The most stable genotypes would be the one with high mean performance and regression coefficient (b_i) close to unity as well as mean square deviation approaching to zero or non-significant. They further proposed that the genotype with mean yield less than the grand mean were considered to be poorly adapted

irrespective of their b_i and \bar{S}^2di values (Bains and Gupta, 1972).

Considering all the above-mentioned points, ACN-237 (104 days) was found to exhibit significantly lower mean than population mean (106 days) for days to maturity along with regression coefficient (b_i) tends to unity and non-significant deviations from linear regression (\bar{S}^2di) which suggest the genotypes ACN-237 is suitable for all environment. Similarly, ACN-240, SKM-1626 and ACN-226 (106 days) showed equal mean performance with population mean for days maturity along with regression coefficient (b_i) tends to unity and non-significant deviation from linear regression (\bar{S}^2di) which show the stable perform of genotypes namely ACN-240, SKM-1626 and ACN-226 in all environment (Table 2). Similar study conducted by Priyamedha et al., 2017 in Indian mustard reported that Pusa Bold, BAUSM-92-1-1, JN032 and RGN-73 having stable performance for days to maturity along with other yield attributing characters.

In case of plant height, ACN-237 (161.94 cm) and ACN-226 (159.66 cm) were observed to be associated with high mean performance and non-significant linear regression deviation (\bar{S}^2di) and regression coefficient ($b_i=0.924, 0.935$ respectively) less than unity which is less sensitive to environmental changes and can be adopted for poor environment for plant height. The genotype ACN-244 (157.65 cm) tends to population mean (158.59 cm) with non-significant linear regression deviation (\bar{S}^2di) and regression coefficient ($b_i=1.052$) nearly equals to unity was reported as average sensitivity to environment and adapted to all environments. The Gupta et al. 2021 reported stable performance for plant height over different environment created with rainfed and irrigated condition.

For the trait number of branches plant⁻¹, the genotype ACN-240 (3.47), ACN-250 (3.55), ACN-237 (3.55), PM 26 (3.56) and TAM 108-1 (3.73) showed higher mean as compared to population mean (3.45), whereas none of the genotype showed non-significant deviation from linear regression (\bar{S}^2di). However, ACN-255 (3.36) reported mean performance nearly equals to population mean along with non-significant deviation from linear regression (\bar{S}^2di) and regression coefficient (b_i) tends to unity which suggests stable performance among all the environments studied. Sagolsem et al., 2013 reported similar findings in Indian mustard for the

genotypes Sej-2, GM-2, NDRE-22, JD-6 and NDRE-7 for different environmental situations for number of branches plant⁻¹.

The genotypes ACN-250 (176.7) and ACN-226 (174.1) reported as highest mean performance over population mean (157.7) for number of siliquae plant⁻¹ along with non-significant deviation from linear regression and regression coefficient (b_i) tends to unity suggesting to perform well in all environment. However, the genotype ACN-237 (175.2) reported high mean performance compared to population mean and regression coefficient (b_i) less than unity however significant deviation was reported from linear regression (\bar{S}^2di) which might showed unstable performance in few environments. Similarly, Priyamedha et al., 2017 reported stable performance of the genotype Kranti on the basis of mean performance, deviation from linear regression (\bar{S}^2di) and regression coefficient (b_i) for number of siliquae plant⁻¹ under different environment studied.

In case of seed yield plot⁻¹, ACN-237 (1783.1 g) and ACN-226 (1731.9 g) reported significantly high mean performance as compared to population mean (1543.3 g) along with non-significant linear regression deviation (\bar{S}^2di) and regression coefficient (b_i) more than unity representing sensitivity to environmental fluctuation but adopted to high yielding condition *i.e.* under timely sown condition in the study. However, ACN-250 (1724.9) also reported high mean performance along with non-significant linear regression deviation (\bar{S}^2di) and regression coefficient (b_i) tends to unity which perform stable under all environment *i.e.* under all dates of sowing creating stressed environment. These results were supported by Sagolsem et al., 2013, Priyamedha et al., 2017, Gupta et al., 2021 and Kamdi et al., 2022 in Indian mustard under different environmental conditions.

In Table 2 on considering all characters under study, it was concluded that not all of the genotypes were ideally stable for all characters. The stability parameters exhibited by ACN-237 reported high mean performance for all the characters except for days to maturity where less than population mean preferred for earliness, along with stable performance for the characters *viz.* days to maturity, plant height and seed yield plot⁻¹ in all environments, non-significant deviation from linear regression (\bar{S}^2di) and regression coefficient (b_i) tends to unity. The

genotype ACN-226 also showed stable performance for seed yield plot⁻¹, number of siliquae plant⁻¹, plant height and days to maturity in all environments as it showed high mean performance, non-significant deviation from linear regression (\bar{S}^2di) and regression coefficient (b_i) not deviating from unity. The genotype ACN-237 and ACN-226 reported stable performance under all the environments studied with different dates of sowing. The results were in accordance with Kumawat and Sharma, 2022 in Indian mustard reported that the varieties namely RGN-48, RGN-73, Maya, PCR-7, CS-52 and RH-749 had higher mean for seed yield and $b_i = 1$ which can be used as stable varieties over the environments and varieties RGN-13, RGN-229, RGN-236 and RGN-303 have superior performance and responsive to optimum sowing conditions as they showed greater mean with significantly higher regression coefficient (b_i).

4. CONCLUSION

It was concluded from this study that the genotypes ACN-237 and ACN-226 were identified as best stable genotypes for four date of sowing (30th October, 15th November, 30th November and 15th December) for four consecutive years. Therefore, it is suggested that these genotypes are suitable for the late sown conditions. These genotypes can be utilized to develop stable genotypes for late sown conditions in future breeding program.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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