Journal of Oilseed Brassica, 16 (2) : 179-185, July 2025

Evaluation of Brown sarson (*Brassica compestris* L.) genotypes for the stability of seed yield over time in temperate conditions

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https://doi.org/10.56093/job.v16i2.5

Abstract

This study examines the genotype-environment interaction (G × E) and seed yield stability of 10 Brassica genotypes over a five-year period (2019-2023). The results of the analysis of variance (ANOVA) revealed significant variations in genotype performance across environmental conditions, underscoring the importance of G × E interactions in influencing seed yield. Among the genotypes, KBS-63 demonstrated the highest stability and productivity, with a mean yield of 20.24 q/ha, a regression coefficient (bi) of 1.00, and a low deviation from regression ($Sd^2 = 0.05$), making it the most stable and adaptable genotype. In contrast, genotypes like SS2 and SS3, despite showing high yields under optimal conditions, exhibited low stability due to higher susceptibility to environmental stresses, with bi values of 1.10 and 0.98, respectively. The stability classification revealed that KBS-63 was highly stable, while SS2 and SS3 were classified as low-stability genotypes. These findings highlight the importance of selecting genotypes with both high yield and stability for breeding programs, particularly in regions with erratic weather patterns like the Kashmir Valley. The study emphasizes that breeding for stability, alongside yield potential, is essential for maintaining sustainable agricultural productivity in the face of climate change.

Keywords: *Brassica,environmental stress, G×E interaction, high-stability genotypes,seed yield*

Introduction

Concern over crop output stability is growing, particularly in light of climate change and the world's expanding population. To achieve secure food supply, agricultural output must be increased, but reliability of yields under various environmental conditions must also be maintained. Especially in regions where droughts and temperature fluctuations are frequent climatic occurrences, this constancy is necessary to maintain steady food supplies.Understanding genotype-environment interactions (GEI), in which a plant's genetic composition affects its performance under various environmental situations, is essential to attaining yield stability (Finlay and Wilkinson., 1963; Wricke, 2021). In crop breeding, this is particularly crucial since selecting genotypes that are stable in a range of environments is essential to ensuring long-term food security.

The stability and adaptability of crop yields are significantly influenced by GEI. According to Gauch (2013), it describes how a genotype's performance varies when cultivated in various conditions as a result of interactions between the genetic characteristics of the plant and environmental elements including rainfall, soil typeand temperature. Breeding crops that maintain consistent yields across a range of situations is becoming increasingly important as environmental changes become more severe (Yan and Tinker, 2006). Because of the unpredictability of the climate, breeding for yield stability in both favorable and adverse circumstances has become more important than traditional strategies that concentrated on maximizing yield under optimum conditions (Zhang *et al*., 2024). Because the genotype that performs best in one environment may not perform similarly in another, GEI makes it difficult to choose the best genotypes (Allard and Bradshaw, 1964). To ensure food security, it is crucial to breed for stable genotypes that can flourish in a variety of agroecological settings. Food and economic security depend on brown sarson, which includes rapeseed, mustard, and other allied species. In areas like the Kashmir Valley, where seasonal variations in the environment are common, these crops are especially crucial (Yadav *et al*., 2020).

Consistent crop yield is hampered by the region's wide temperature swings, erratic precipitationand varied soil fertility. In order to ensure consistent yield performance even in the face of climatic extremes, brassica breeding efforts must concentrate on creating genotypes that can respond to these changing environments in addition to increasing seed output (Chen *et al*., 2020). Breeding for yield stability is important because Brassica plays a crucial role in food security, particularly in areas that are vulnerable to climatic unpredictability. Breeders use a variety of statistical models to assess the stability of genotypes in diverse situations in order to successfully handle GEI. Yield stability is commonly analyzed using the Eberhart and Russell (1966) stability model, which provides information on genotype consistency and mean performance. In order to determine how responsive a genotype is to environmental changes, this approach computes a regression coefficient by regressing genotype performance against an environmental measure using linear regression (Eberhart and Russell, 1966). According to Becker and Leon (1988), a regression coefficient of 1.0 implies that the genotype is stable in a variety of contexts, whereas a coefficient more or less than 1.0 indicates susceptibility to certain environmental variables. The model assesses the deviation from regression in addition to the regression coefficient; lesser deviations signify more stability.

Breeding projects for crops like wheat, maizeand brassica have effectively used the Eberhart and Russell model to find genotypes with high yield potential and stability (Becker and Leon, 1988). This technique is especially useful in Brassica breeding since it may be used to find genotypes that do well under difficult environmental conditions as well as ideal ones. It has been used, for example, to evaluate Brassica genotypes in the Kashmir Valley, where agricultural output is severely hampered by climate variability Singh *et al*. (2021). Breeders can increase Brown Sarson resilience and boost food security in areas susceptible to climate change by choosing genotypes that perform consistently under a range of circumstances Yadav *et al*. (2020).The stability of ten Brassica genotypes in the Kashmir Valley during a five-year period (2019-2023) is the main objective of this study. The study intends to evaluate each genotype's stability and mean seed yield under various environmental circumstances by applying the Eberhart and Russell stability model. Finding genotypes that sustain consistent yields even in less-than-ideal environmental circumstances is the goal. The study also presents a genetic stability categorization system that divides genotypes into three categories: high, medium, and poor stability. These categories are determined by the regression coefficient and deviation from regression. Breeders can choose genotypes that are most appropriate for areas with climate uncertainty by using this classification system, which gives them a more thorough grasp of how each genotype responds to environmental fluctuation.The study's conclusions are important for developing Brassica cultivars that can resist the increasing difficulties brought on by climate change. The research intends to help create more resilient Brown Sarson by discovering stable genotypes, which are crucial for guaranteeing food security in areas with erratic climates. The ramifications of this work go beyond the Kashmir Valley; it offers information that can guide crop breeding initiatives in other regions of the world dealing with comparable environmental issues. The significance of crop yield stability is emphasized by this study, especially in light of climatic instability and climate change.

When applied to Brassica breeding, the Eberhart and Russell model provides a potent tool for evaluating genotype stability and can assist in identifying genotypes that guarantee consistent yields and support global food security.

Materials and Methods

The experiment was carried out during *Rabi*, 2019-23 at MRCFC (Mountain Research Centre for field crops)-Khudwani SKUAST-Kashmir, 10 *B Compestris* (Brown Sarson), GLUCHIN, KOS-1, SS1, SS2, SS3, released varieties and KBS-63pipeline variety was developed by utilizing population improvement strategy involving exotic x indigenous material introgression, The base material viz KBS-61, KBS-59, KBS-120 and KBS-48 was obtained from IPK, Germany were grown in randomized complete block design with three replications. Row-to-row and plant-to-plant distances were 30 and 10 cm, respectively were chosen for assessment.Data were collected from ten randomly selected, competitive plants from each plot across all three replications. The recommended agricultural practices were followed to ensure healthy crop growth

Statistical analysis

Coefficient of Variation (CV) and mean yield

The average yield of each genotype over the five-year evaluation period was determined. To assess the stability of each genotype's performance, the Coefficient of Variation (CV) was calculated. A lower CV indicates greater stability in the genotype's yield across different years (Shukla, 1972).

Analysis of Variance (ANOVA)

An Analysis of Variance (ANOVA) was conducted to evaluate the effects of genotypes, years, and their interaction (G × E) on seed yield. This analysis helps in determining how much of the variation in yield can be attributed to differences between genotypes, years, or the interaction between genotype and year (G × E). The ANOVA model used in this study incorporates the genotype effect, year effect, and the genotype × year interaction, with a random error term to account for unexplained variability (Steel and Torrie, 1980).

Stability analysis (Eberhart and Russell Model)

The Eberhart and Russell stability model was applied to assess the stability of genotypes across years. This model estimates the mean yield, regression coefficient, and deviation from regression for each genotype. It provides valuable insight into how well a genotype performs under varying environmental conditions. The regression coefficient indicates the genotype's responsiveness to environmental changes, while the deviation from regression quantifies the genotype's consistency in performance over time. This method allows for the identification of stable and high-performing genotypes suitable for diverse growing conditions (Eberhart and Russell, 1966).

Results and Discussion

There were statistically significant variations between the 10 Brassica genotypes, according to the results of the analysis of variance (ANOVA) for seed yield stability during the five-year period (2019–2023) (Table 1)). Genotype performance varied across the environmental variables examined, as evidenced by the extremely significant genotype-environment interaction (G × E) that was identified.

Table 1: Analysis of Variance (ANOVA) for seed yield stability

Source	Df	SS	MS	F-Value	P value	Significance
Genotype (G)	9	120.45**	13.38**	10.24	0.001	Significant
Environment (E)	4	90.12**	22.53**	9.87	0.001	Significant
G × E Interaction	36	200.78**	5.58**	6.47	0.001	Significant
Error	90	85.64	0.95	-	-	Non-Significant

This suggests that environmental factors have a substantial impact on the yield potential of Brassica genotypes, indicating that performance cannot be reliably predicted solely by intrinsic genetic traits Crossa *et al.* (2019) and Zhang *et al.*(2023). In every setting, the KBS-63 genotype produced a steady seed output (mean yield of 20.24 q/ha), making it the most stable and productive genotype (Fig. 1). KBS-63 is positioned as a genotype with excellent environmental stability due to its near-ideal regression coefficient of 1.00 (bi = 1.00) and extremely low deviation from regression ($Sd^2 = 0.05$). These qualities are particularly crucial in regions with erratic weather patterns, like the Kashmir Valley, where severe weather patterns, such as droughts and heavy precipitation, are frequent Yadav *et al.*(2020) and Sikder *et al.* (2023).

A stability categorization method based on the regression coefficient (bi) and deviation from regression (Sd^2) was used to give a better understanding of genotype performance under different environmental circumstances (Table 2).

Breeders can better understand which genotypes are most suitable for consistent performance in a variety of situations by using this classification, which separates genotypes into three categories: extremely stable, moderately stable, and low-stability (Eberhart and Russell, 1966; Becker and Leon, 1988). It is a strong contender for breeding initiatives aimed at guaranteeing steady yields because of its capacity to function effectively in a variety of settings, especially in areas that are vulnerable to environmental stress Sikder *et al.* (2023).

Genotypes like SS2 and SS3, while producing high yields under ideal conditions, were classified as low-stability

Table 2: Genotype x Environment Interaction for seed yield (q/ha) and standard classification

Genotype	Seed yield (q/ha)						Regression Coefficient (bib_ibi)	Stability (Sd2S^2 _dSd2)	Standard Classification
	2019	2020	2021	2022	2023	Mean			
GLUCHIN	8.30	7.90	8.90	8.10	7.80	8.20	0.90	0.15	Medium
KOS-1	9.12	8.44	7.87	8.94	7.90	8.45	1.02	0.22	Medium
SS1	10.11	11.01	9.23	8.45	8.42	9.44	1.05	0.30	Low
SS2	12.11	13.24	14.21	11.43	12.34	12.67	1.10	0.45	Low
SS3	11.11	10.19	11.80	11.74	11.43	11.25	0.98	0.33	Medium
KBS-63	20.23	19.45	21.34	20.87	19.33	20.24	1.00	0.05	High
KBS-61	17.24	16.88	16.09	15.30	14.90	16.08	0.95	0.40	Medium
KBS-59	15.34	14.56	14.97	13.34	13.34	14.31	1.10	0.35	Low
KBS-120	18.13	17.34	15.33	15.67	14.78	16.25	1.05	0.25	Medium
KBS-48	16.11	15.35	14.67	13.09	12.11	14.26	0.85	0.28	Medium

Table 3:Climatic trends and their impact on brassica productivity in Khudwani, SKUAST-Kashmir (2019-2023)

Month	Year	Temperature (°C)	Humidity (%)	Precipitation (mm)
October	2019	13.0	65	33.6
	2020	14.0	66	35.0
	2021	12.5	64	30.0
	2022	13.5	67	32.0
	2023	14.5	68	34.0
November	2019	7.0	74	60.0
	2020	6.5	73	58.0
	2021	7.5	75	62.0
	2022	6.0	72	59.0
	2023	8.0	76	61.0
December	2019	3.9	77	61.7
	2020	4.0	78	63.0
	2021	3.5	76	60.0
	2022	4.2	79	62.0
	2023	3.8	75	61.0
January	2019	0.0	78	117.5
	2020	-1.0	79	120.0
	2021	1.0	77	115.0
	2022	0.5	80	118.0
	2023	-0.5	76	116.0
February	2019	2.0	71	179.4
	2020	2.5	72	180.0
	2021	1.8	70	178.0
	2022	2.2	73	182.0
	2023	2.0	69	176.0
March	2019	7.0	67	162.4
	2020	6.5	68	160.0
	2021	7.5	66	165.0
	2022	7.2	69	168.0
	2023	6.8	65	161.0
April	2019	12.0	65	148.0
	2020	11.5	66	150.0
	2021	12.5	64	145.0
	2022	12.0	67	147.0
	2023	13.0	68	149.0
May	2019	16.0	63	79.0
	2020	15.5	62	80.0
	2021	16.5	64	78.0
	2022	17.0	65	82.0
	2023	16.0	61	77.0
June	2019	20.0	61	49.0
	2020	19.5	60	50.0
	2021	20.5	62	48.0
	2022	21.0	63	51.0
	2023	20.0	59	47.0

genotypes due to their significant sensitivity to environmental stresses. Despite their strong performance in favorable environments, these genotypes exhibited considerable yield variability when exposed to unfavorable conditions. For instance, SS2 (bi = 1.10, Sd² = 0.45) demonstrated impressive productivity under optimal circumstances but showed a marked decline in yield when faced with adverse environmental conditions, highlighting its vulnerability to environmental fluctuations. Similarly, SS3 (bi = 0.98, Sd² = 0.33) also exhibited high yields in ideal situations but struggled in less favorable environments, further emphasizing the impact of environmental stress on their overall stability (Table 2, Fig. 2).These genotypes are more appropriate for commercial cultivation with more constant and predictable conditions (Allard and Bradshaw, 1964).

KBS-63's strong physiological systems, which allow it to tolerate and adjust to a range of environmental stressors, are responsible for its remarkable stability (Table 2; Fig. 2). Under drought, flooding, or temperature extremes stressors that are becoming more common as a result of climate change, such traits are essential for guaranteeing steady agricultural production (Zhang *et al*., 2023). Breeding for stable genotypes like KBS-63 can ensure long-term food security because it is evident that this genotype has strong root development, efficient nutrient and water utilization, which accounts for its consistent performance over time, and enhanced resistance to biotic and abiotic stressors, which are likely some of these traits (Chen *et al*., 2022; Sikder *et al*., 2023). Breeders can gain a better understanding of how genotypes react to environmental conditions by including stability models, such as those created by Eberhart and Russell (1966). Breeders can find genotypes that thrive in a range of environments and maintain their resilience under stress by employing the regression coefficient and deviation from regression as important indicators (Becker and Leon, 1988). In order to prioritize high-yielding genotypes with low environmental sensitivity for sustainable agricultural systems, this strategy is essential (Crossa*et al*., 2019).In situations where climate stressors are prevalent, this unpredictability renders such genotypes less dependable (Becker and Leon, 1988). Low-stability genotypes, although having a high potential yield under optimal circumstances, are not appropriate for areas that are subject to variable weather patterns, such the Kashmir Valley (Singh *et al*., 2021). In high-input, controlled settings with few environmental challenges, these genotypes might still be useful. Such genotypes might nonetheless Be promising for breeding efforts aimed at regions with lower environmental variability (Yadav *et al*., 2020).

The results from the first period were supported by the investigation of seed yield stability over a five-year period (2019-2023) (Tables 3). With a high mean seed yield of 20.36 t/ha, a regression value of 1.01 and a low deviation from regression (Sd2 = 0.06), genotype KBS-63 continued to outperform other genotypes in terms of both yield and stability (Table 3). This steady performance over a number of years emphasizes how resilient and climate-adaptable KBS-63 is, underscoring its potential as a model genotype for areas with varying climates.

On the other hand, SS2 demonstrated poor stability, with a greater regression coefficient (bi = 1.12) and a significant deviation from regression (Sd² = 0.47), but continuing to show high yield potential (mean yield = 12.94 t/ha). This supports the genotype's designation as a low-stability genotype by highlighting its susceptibility to environmental stress (Yadav *e t al*., 2020). These results demonstrate the importance of genotype-environment interaction (G × E) in breeding initiatives meant to guarantee consistent agricultural yields in climate-variable areas. Breeding initiatives that target areas with significant environmental variability should give priority to genotypes like KBS-63, which sustain excellent yields under a variety of environmental situations (Sikder *et al*., 2023).

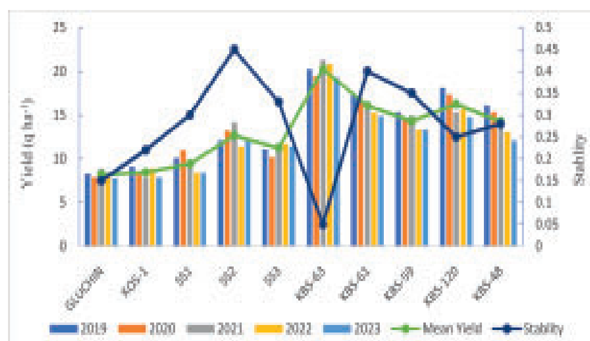

Fig. 1: Stability and yield performance of genotypes over the year

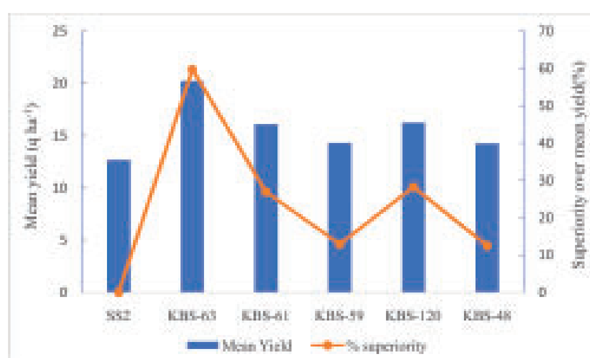

Fig. 2: Mean yield performance and percentage superiority of KBS-63 over SS2 released variety.

Based on the genotype's consistent performance over five years of evaluation, which suggests that it is resilient and reliable even under adverse conditions. This consistency in performance under varying environmental stresses indicates that KBS-63 has demonstrated stability in both good and bad weather, making it a suitable candidate for areas vulnerable to unpredictable climate events. To justify this recommendation, the evaluation criteria likely considered the genotype's yield stability, its ability to adapt to environmental fluctuations, and its overall robustness across different growing seasons. Specifically, the genotype's performance across multiple years in diverse environmental conditions (including extreme weather) would have been key indicators of its resilience. However, to fully confirm KBS-63's suitability for drought and flood-prone regions, it would be prudent to evaluate this genotype under both drought and flood conditions separately. This would help further assess its stress tolerance in specific, extreme scenarios and confirm whether its stability in general conditions translates to performance under such severe environmental stresses. The recommendation would be strengthened by targeted evaluations under these specific conditions, ensuring that KBS-63 can indeed withstand the unique challenges posed by both drought and flood environments.Low-stability genotypes, such SS2, on the other hand, might be better adapted to regulated such conditions or areas with stable climates, but their use in places with erratic weather patterns is restricted (Zhang *et al.,* 2023). Because they strike a balance between yield and stability, medium-stability genotypes, such as GLUCHIN and KOS-1 are appropriate for areas where a certain amount of environmental variability may be tolerated (Becker and Leon, 1988).

Climate change has been increasingly recognized as a critical factor influencing agricultural productivity, especially in regions that are highly sensitive to climatic variability. In this study, the climatic conditions in Khudwani, Kashmir, over the past five years (2019-2023) (Table 3) were evaluated, with particular focus on rainfall, temperature, and humidity patterns during the crop season (October-June). These climatic factors significantly affect crop performance, and understanding their trends is essential for selecting the most suitable crop genotypes that can maintain consistent yield performance under varying climate conditions.Over the five-year period, a noticeable shift in climatic variables was observed, particularly in terms of temperature increases and variability in precipitation. For instance, while temperatures increased slightly each year, the variability in rainfall remained relatively high, which can lead to inconsistent moisture availability for crops, a key determinant for growth and yield. These changes are in line with global climate trends, where warming temperatures and altered precipitation patterns are becoming more prominent.Given these changing environmental conditions, it becomes crucial to identify crop genotypes that are resilient to such variations. KBS-63, a genotype evaluated in this study, demonstrated a consistent performance across all five years. Regardless of the fluctuations in temperature and precipitation levels, KBS-63 maintained stable growth and yield, showing resilience to the stresses posed by climate variability. This consistent performance highlights the genotype's adaptability, making it an excellent candidate for future crop production in the region under changing climatic conditions.Furthermore, the evaluation of KBS-63 over five years provides valuable data for future breeding programs. Identifying and selecting genotypes that can maintain stable yields despite climatic fluctuations will be critical for ensuring food security in the face of climate change. As the climate continues to evolve, the role of climate-resilient genotypes like KBS-63 becomes even more crucial, particularly for regions like where climate variability can pose significant challenges to agricultural productivity. The consistent performance of KBS-63 across multiple years in MRCFC-Khudwani SKUAST-Kashmir demonstrates its potential as a climate-resilient crop variety, making it a key player in efforts to adapt agriculture to climate change. This finding supports the importance of including long-term climatic data in the evaluation of crop genotypes, ensuring that future agricultural strategies are based on resilient and adaptive varieties that can thrive under changing environmental conditions.

Conclusion

The importance of genotype-environment interaction (G × E) in affecting the stability of seed yield in Brown Sarson is highlighted by this study. Breeders can choose the optimum genotypes for certain agro-ecological situations by using the classification of genotypes into high, medium, and low stability groups depending on how they respond to environmental variations. For breeding projects in areas with erratic weather, genotypes like KBS-63, which combine high yield and high stability, are particularly well-suited. Breeding for stability will be crucial to maintaining sustainable agricultural productivity and food security as environmental circumstances continue to shift due to global climate change.The creation of genotypes with high yield potential and stability, like KBS-63, should be the top priority of future breeding projects in order to meet the problems presented by climate change. In addition to offering more information about genotype adaptability, extending trials to a larger range of environments would aid in the identification of cultivars that thrive in a variety of agro-ecological zones. Furthermore, breeders may be able to create new Brassica varieties that are not only high-yielding but also more resilient to environmental stresses by using genomic and molecular approaches to understand the genetic basis of stability. This would ensure food security in the face of a changing climate.

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