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Research Paper

Parametric stability analyses for grain yielding traits in brown sarson (*Brassica rapa* L.)

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ABSTRACT

This research aimed to assess genotype-environment interaction and identify stable high-yielding brown sarson (*Brassica spp.*) cultivars suitable for Kashmir. Twelve genetically diverse genotypes were evaluated for grain yield and its components using a randomized block design. Significant variations in grain yield were observed within and across the years, highlighting the influence of environmental factors. Stability analysis for grain yield was performed to understand the Genotype × Environment (G × E) interactions. The significant mean squares for G × E (linear) indicated notable genetic differences among the genotypes in their linear responses to varying environments. Among the tested genotypes, KBS-63 emerged as highly stable and high-yielding, showcasing consistency and resilience across different years. This study underscores the critical role of stability analysis in selecting genotypes that can thrive in fluctuating environmental conditions, thereby promoting sustainable agriculture and reducing reliance on imported edible oils.

Key words: *Brassica*, G×E interaction, grain yield, Kashmir valley stability

Brown sarson (*Brassica rapa* L.), an important *rabi* oilseed crop of the Indian temperate zone, holds immense economic, nutritional and agronomic significance, particularly in the north-western Himalayan region including the Kashmir valley. It is a major source of sarson oil, a staple cooking medium for millions, valued not only for its culinary uses but also for its therapeutic and industrial applications. The oil's high content of monounsaturated and polyunsaturated fatty acids makes it a healthier alternative, increasingly preferred in health-conscious diets (Kumar *et al.*, 2020). Despite its importance, domestic production of edible oils remains insufficient, making India the largest importer of edible oils globally. In 2022–2023, the country imported approximately 15 million tonnes to bridge the demand-supply gap (Ministry of Consumer Affairs, Food and Public Distribution, 2023). This growing dependency on imports exerts significant pressure on national resources and highlights the urgent need to bolster indigenous oilseed production (Alemu *et al.,* 2024). In this context, brown sarson emerges as a promising crop to enhance edible oil self-sufficiency, particularly in the temperate zones where its adaptability and performance can be optimized. However, one of the major challenges in brown sarson cultivation is the wide fluctuation in yield across seasons and locations, primarily due to genotype × environment (G × E) interactions. These interactions complicate the selection of stable, high-yielding genotypes and limit the crop's full potential. The present research addresses this critical gap by evaluating twelve genetically diverse brown sarson genotypes under multi-year field conditions to assess their grain yield performance and stability. Using parametric stability analysis based on the Eberhart and Russell (1966) model, the study dissects the G × E interactions to identify genotypes that exhibit both high yield and temporal stability. The findings are of strategic significance for crop improvement programs in temperate agro-ecosystems. Identifying stable and high-yielding genotypes can lead to the release of region-specific varieties tailored for the Kashmir valley and similar environments. Moreover, promoting such resilient cultivars will contribute directly to national goals of import substitution, agricultural sustainability and livelihood enhancement in marginal hill regions. This study, therefore, not only strengthens the scientific understanding of genotype performance under variable environments but also offers practical solutions for increasing oilseed productivity and resilience, key components in ensuring food and nutritional security in India.

MATERIALS AND METHODS

Plant material: The present investigation involved twelve genotypes of brown sarson (*Brassica rapa* L.), including ten advanced breeding lines *viz.,* KBS-1, KBS-80, KBS-15, KBS-14, KBS-8, KBS-35, KBS-151, KBS-34, KBS-102 and KBS-63 sourced from the National Bureau of Plant Genetic Resources (NBPGR), New Delhi. Two released varieties, SS1 and SS2, were included as standard checks to facilitate the comparative evaluation.

Experimental site and layout: Field experiments were conducted at the Mountain Research Centre for Field Crops, Khudwani (SKUAST-Kashmir), Anantnag, during three consecutive *rabi* seasons (2020–21, 2021–22 and 2022–23). The site is located in the temperate agro-ecological zone of Jammu and Kashmir at an altitude of ~1560 meters, characterized by cold winters, moderate rainfall and alluvial soils suitable for oilseed production. The genotypes were evaluated in a Randomized Block Design (RBD) with three replications in each season. Each plot comprised two rows, 4 meters long, with 30 cm row-to-row and 10 cm plant-to-plant spacing, ensuring optimal growth and uniform plant distribution.

Trait measurement: Observations were recorded on five yield-contributing traits from five randomly selected competitive plants per plot in each replication.

Plant height (cm): Measured from the base of the plant to the tip of the terminal raceme using a measuring scale at physiological maturity.

Primary branches per plant: Counted manually as the total number of branches emerging directly from the main stem.

Secondary branches per plant: Counted as branches arising from the primary branches.

Days to maturity: Recorded as the number of days from sowing to when 90% of the siliquae turned brown.

Grain yield (g): At harvest, plants from the entire plot (two rows of 4 m) were harvested, dried, and threshed. The grain yield was recorded per plot (g) using a digital balance and then converted to kilograms per hectare (kg/ha) for standardization.

Statistical analysis: The pooled data across three environments (years) were subjected to Analysis of Variance (ANOVA) to detect significant differences due to genotypes, environments, and their interactions (G × E). The stability of genotypic performance was evaluated using the model proposed by Eberhart and Russell (1966).

This model estimates two key parameters for each genotype:

Regression coefficient (bi): Represents the linear response of a genotype to environmental changes. A bi value of ~1 indicates average responsiveness.

Deviation from regression (S^2di): Represents the unexplained or non-linear component of G × E interaction. A low or non-significant S^2di indicates stability. The mean performance, regression coefficient (bi) and deviation from regression (S^2di) were computed using the following regression model:

$$Yij = \mu i + \beta i + Ij + \delta ij + \varepsilon ij$$

Where:

- Yij : performance of the *i*th genotype in the *j*th environment
- μi : mean performance of the *i*th genotype across environments
- βi : regression coefficient (slope) of the *i*th genotype
- Ij : environmental index for the *j*th environment
- δij : deviation from regression
- εij : random error

Genotypes with bi ≈ 1 and low S^2di were considered stable and widely adaptable, while those with bi > 1 or < 1 were considered responsive to specific favorable or unfavorable environments, respectively.

RESULTS AND DISCUSSION

The results of the stability analysis of the 12 genotypes evaluated for grain yield across different environments reveal significant effects of Genotype (G), Environment (E) and the Genotype × Environment (G × E) interaction on the expression of grain yield and its associated yield components. These findings are essential for identifying stable and high-performing genotypes suitable for cultivation across varying environmental conditions.

Analysis of variance (ANOVA): The ANOVA results for the stability analysis confirmed that all the main effects-Genotype (G), Environment (E) and Genotype × Environment (G × E) interactions-were significant. This indicates that both the genetic factors (i.e., the genotypes) and the environmental conditions played crucial roles in shaping the performance of the genotypes. Moreover, the G × E interaction was significant for all the studied traits, highlighting the complex nature of genotype-environment interactions and their influence on the stability and adaptability of the genotypes under varying environmental conditions. The environment factor showed significant linear and nonlinear components, suggesting a considerable variation in the environmental conditions across the years where the genotypes were evaluated. The environment (linear) showed a higher magnitude of mean squares compared to genotype × environment (linear), indicating that the predictable component of the environment was the dominant factor in driving the variation observed in grain yield. The non-linear component (pooled deviation) for all traits under study was also significant, pointing to the fact that genotype performance was influenced by unpredictable environmental factors. This finding aligns with the studies by Kumar *et al.* (2022), which emphasized the importance of both linear and nonlinear interactions in assessing genotype stability. The significant genotype × environment (linear) interaction for grain yield further supports the notion that genotypes responded differently to environmental changes, underscoring the importance of evaluating genotypes across multiple environments to determine their stability. The significance of the pooled deviation from regression (S^2di) for all characters suggests that deviations from the linear regression were substantial, contributing to the instability of the genotypes in certain environments.

Stability parameters for grain yield: The stability parameters for grain yield, including the regression coefficient (bi) and deviation from regression (S^2di), provide valuable insights into the adaptability and stability of the genotypes. According to Eberhart and Russell (1966), a genotype that exhibits a bi value of 1.0 (indicating no sensitivity to environmental fluctuations) and a S^2di value of 0 (indicating no deviation from the regression line) is considered stable and widely adaptable. The results for the regression coefficient (bi) and deviation from regression (S^2di) of the 12 genotypes indicate a range of responses to environmental variability (Table 1).

Table 1. Stability parameters of the genotypes studied

Genotype	Mean grain yield (g)	Regression coefficient (bi)	Deviation from regression (S^2di)
KBS-1	8	1.0	0.01
KBS-80	10	1.2	0.02
KBS-15	10	1.1	0.03
KBS-14	10	1.1	0.02
KBS-8	8	0.9	0.01
KBS-35	10	1.0	0.01
KBS-151	9	1.0	0.02
KBS-34	9	1.1	0.03
KBS-102	11	1.1	0.01
KBS-63	21	1.0	0.00
SS2	11	1.1	0.02
SS1	8	0.9	0.01

KBS-63 genotype stood out as the most stable and high-yielding. It exhibited a regression coefficient of 1.0 and the lowest deviation from regression ($S^2di = 0.00$), making it highly adaptable and stable across all environments. This finding is in agreement with Sharma *et al.* (2020), who found that genotypes with a regression coefficient close to unity and a minimal deviation from regression are highly stable and perform consistently across diverse environments. KBS-1, KBS-8 and SS1 genotypes, with bi values close to 1.0 but low grain yields, suggest that while these genotypes maintain some level of stability, their overall productivity may not be as high as the more adaptable genotypes like KBS-63. The genotypes KBS-80, KBS-15, KBS-14, KBS-35 and KBS-151 had regression coefficients ranging from 0.9 to 1.2 and displayed low deviations from regression (S^2di ranging from 0.01 to 0.03). This suggests that these genotypes, though slightly more sensitive to environmental changes, still exhibited relatively stable performance and could be considered for cultivation in specific environments where their higher yield potential might be realized. KBS-34 and KBS-102 genotypes had bi values greater than 1 (1.1), indicating a positive response to improving environments, though they exhibited a slightly higher deviation from the regression line, pointing to a higher level of instability in response to environmental fluctuations. SS2 with a bi value of 1.1 and a deviation from regression (S^2di) of 0.02, also showed a good level of stability and adaptability but was somewhat more sensitive to environmental changes compared to the highly stable genotypes like KBS-63. These findings are visually supported by (Fig. 1) which depicts the grain yield trends of the top five genotypes over three years, and (Fig. 2) which highlights the consistent performance of KBS-63 across environments.

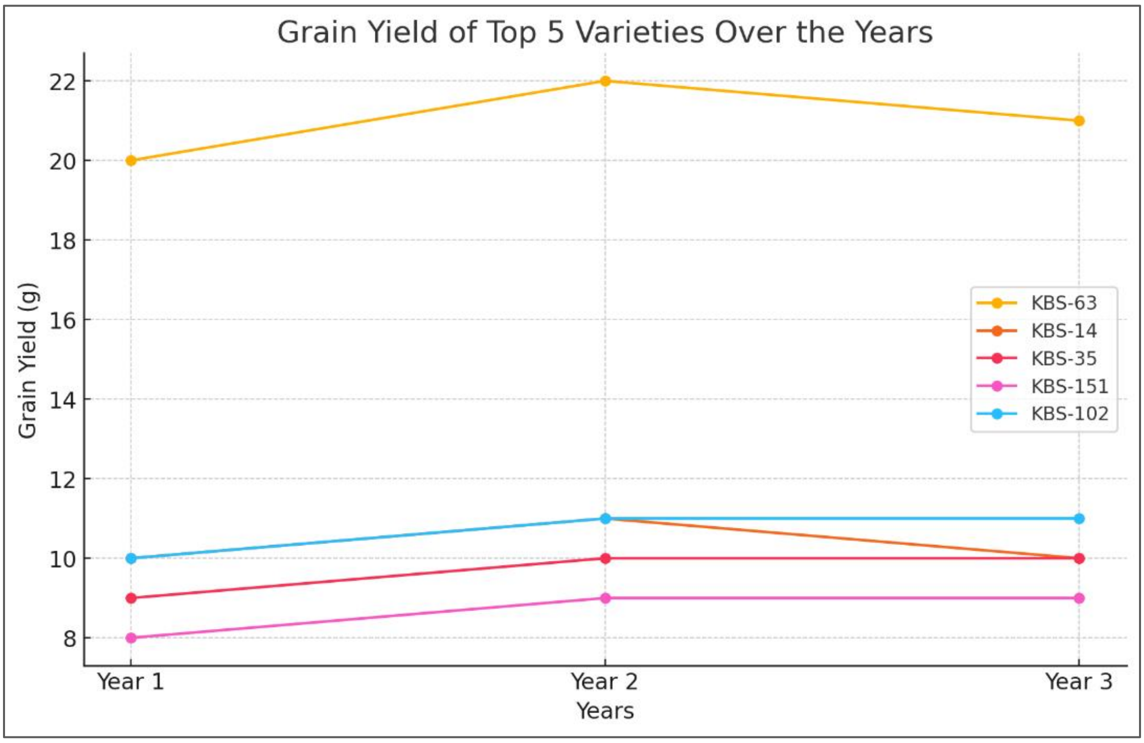

Fig. 1: The graph showing the grain yield of the top 5 varieties over three years. The varieties included are KBS-63, KBS-14, KBS-35, KBS-151 and KBS-102

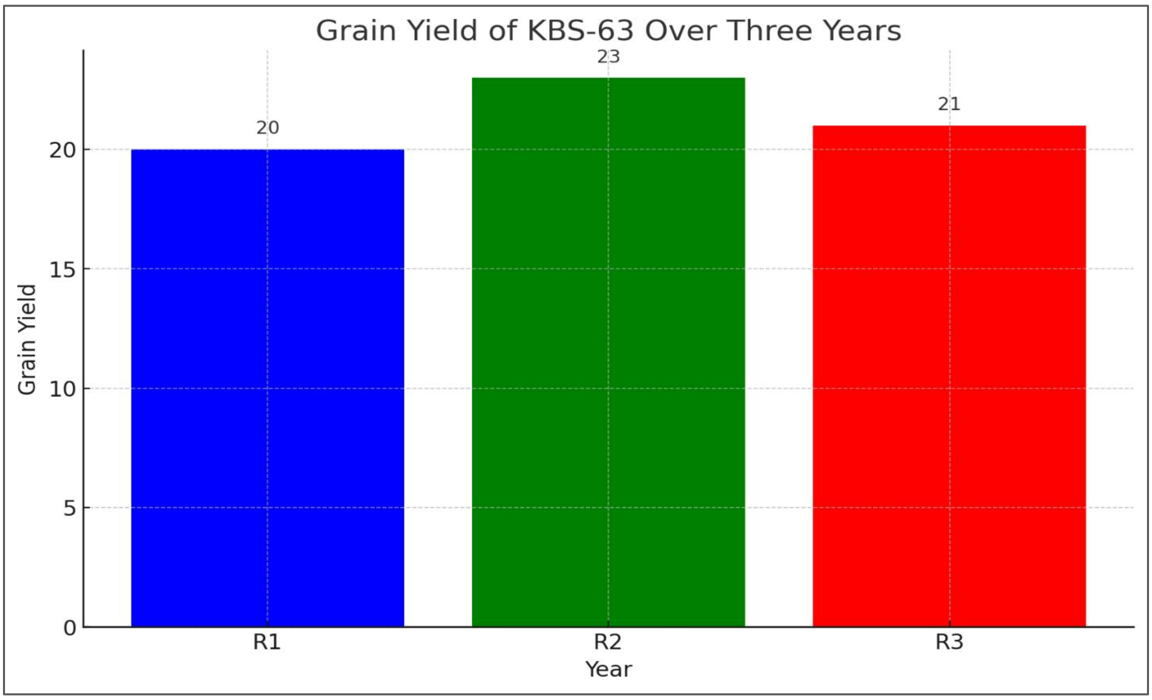

Fig. 2: Graph showing performance of KBS 63 over years

Interpretation of stability parameters: Stability analysis using the regression coefficient (bi) and deviation from regression (S^2di) provides a comprehensive understanding of the genotypic performance across different environmental conditions. The regression coefficient (bi) indicates how a genotype responds to environmental changes. A value of bi = 1 suggests that the genotype is stable and has a consistent performance across environments, while bi values greater than 1 suggest that the genotype performs better in favorable environments and may be more sensitive to environmental improvements. The deviation from regression (S^2di) is an indicator of the non-linear interaction between the genotype and the environment. A value close to 0 means that the genotype's response to environmental changes is predictable, whereas higher values of S^2di suggest a greater level of unpredictability in the genotype's performance across environments. In this study, KBS-63 showed best performance due to its bi value close to 1 and its non-significant S^2di value, indicating that it was both stable and adaptable, as it consistently produced high yields across all environments with little deviation from expected performance. In contrast, genotypes such as KBS-34 and KBS-102, with higher bi values (1.1), exhibited sensitivity to improving environments, and also showed larger deviations from regression, indicating a more erratic performance. This suggests that these genotypes may be suitable for specific high-input environments but may not perform well under variable conditions.

Implications for breeding and commercial cultivation: The identification of stable and high-yielding genotypes is critical for both breeding programs and commercial cultivation. In this study, KBS-63 emerged as the most stable and high-yielding genotype, making it a prime candidate for widespread commercial cultivation, especially in environments with fluctuating climatic conditions. Genotypes such as KBS-14, KBS-35 and KBS-151, although not as stable as KBS-63, also showed good stability and high yield potential. These genotypes may be recommended for cultivation in specific regions where their adaptability can be fully utilized (Nadim *et al.,* 2025). Moreover, the findings underscore the importance of evaluating genotypes across diverse environments to fully assess their stability and adaptability. Given the ongoing challenges posed by climate change, the ability to identify and utilize stable, high-yielding genotypes like KBS-63 in the present study is crucial for maintaining and enhancing crop productivity across varying environmental conditions (Pandey *et al.,* 2021; Alemu *et al.,* 2024). Recent studies on genotype-environment interactions (GEIs) and stability analysis have highlighted the complexity of these interactions and their importance in crop improvement programs (Bomma *et al.,* 2024). Zhang *et al.* (2023) emphasized the need for incorporating both biotic and abiotic stress factors into GEI studies to better predict the performance of genotypes under changing environmental conditions. In a similar vein, Singh *et al.* (2022) explored the role of molecular markers in identifying stable genotypes with high yield potential, further supporting the use of stability parameters like bi and S^2di in the selection of genotypes for diverse environments. Furthermore, Patel *et al.* (2023) conducted a comprehensive meta-analysis of stability parameters in cereal crops, confirming that genotypes with low deviation from regression and a bi value close to 1 tend to outperform other genotypes in terms of yield stability and adaptability. These findings are consistent with the results of the current study, reinforcing the idea that KBS-63 is a genotype that combines high yield with exceptional stability.

CONCLUSION

The cultivar KBS-63 was the most stable cultivar for grain yield over all the years. Hence, this cultivar is recommended for cultivation. Genotypes such as KBS-14, KBS-35 and KBS-151 showed better performance under varying environmental conditions and are also recommended for broader testing and potential release. The study confirms that stability analysis is crucial in identifying genotypes with high yield potential and stability across diverse environments. KBS-63's consistent and high grain yield across different years makes it a commercially feasible variety. Its resilience to varying conditions further supports its viability for large-scale cultivation.

CONFLICT OF INTEREST

All the authors affirm that there is no conflict of interest among them. All research activities comply with relevant legal, institutional and ethical standards.

AUTHOR CONTRIBUTION

All the authors contributed equally in this research article.

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