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Evaluating the climate resilience and yield stability of *Brassica* genotypes in temperate conditions : A multi-year performance study

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Abstract

This study compares *Brassica napus* genotypes (KGS) with the check variety SHALIMAR GOBI SARSON 1 and *Brassica rapa* genotypes (KBS) with the check variety SS2 in order to assess the genotypic performance and stability of seed yield (SY) of 35 genotypes during a seven-year period (2018–2024) in the Kashmir Valley. The performance variability of the genotypes showed significant genotypic and environmental influences as well as genotype-by-environment (G × E) interactions. KGS53 was consistently the most stable and highest-yielding of the *Brassica napus* genotypes, followed by KGS52. Over time, KGS53 showed a low coefficient of variation (CV), demonstrating exceptional resilience and adaptation to changing environmental conditions. Comparable yield stability was demonstrated by KBS genotypes, especially KBS-63, which outperformed the SS2 check. KBS-63 maintained moderate yields and low CV, indicating its potential for a variety of agro-climatic conditions. The *Brassica napus* check, SHALIMAR GOBI SARSON 1, in contrast, showed poor adaptability to shifting environmental circumstances, as seen by its high variability and inconsistent performance. Additionally, the *Brassica rapa* check SS2 showed reduced yields and a high CV, which made it less dependable over time. The significance of choosing stable genotypes for climate resilience was highlighted by the ANOVA results, which showed significant genotype, environment, and genotype-by-environment interactions ($P < 0.001$). According to the results, breeding initiatives targeting the Kashmir Valley's yield stability and climatic resistance should give priority to KGS53 (*Brassica napus*) and KBS-63 (*Brassica rapa*). In order to evaluate genotype performance in various environmental circumstances and ensure sustainable agricultural practices in the face of climate change, multi-environment trials are necessary.

Keywords: *Brassica napus, Brassica rapa, climate resilience, genotypic stability, seed yield*

Introduction

India is yet to produce enough oilseeds to satisfy the rising demand. The nation is dependent on imports because it only produces 7–8 million tonnes of edible oils a year, while consumption surpasses 20 million tonnes (FAO, 2022). The main oilseeds that are grown include sunflower, peanut, soybean, and rapeseed-mustard (*Brassica* species). About 30% of India's total edible oil production comes from *Brassica* species, especially *Brassica juncea*, *Brassica napus*, and *Brassica rapa*. But when compared to other countries, India's rapeseed-mustard production is still low, which adds to the country's oilseed shortage (FAO, 2022). As the main source of income for the region's agriculture, oilseed farming is essential in Jammu and Kashmir. Even while oilseedsparticularly *Brassica* varietiesare important, production has not been at its best. Poor crop management, vulnerability to pests and diseases, and most importantlyclimatic fluctuationare some of the factors that have hampered the region's oilseed production. Extreme temperatures, erratic rainfall patterns, and frequent weather anomalies provide serious obstacles to these crops' stable yields (Mishra *et al*., 2023). It is imperative to concentrate on creating climate-resilient oilseed cultivars that can tolerate changing climatic circumstances in the face of these obstacles, especially rising temperatures and unpredictable rainfall patterns. Temperature is one of the most important environmental variables influencing oilseed crops. Agronomic attributes like biomass production, phenology, physiology, and yield-contributing qualities in oilseed crops will be directly impacted by the projected 1.5°C temperature increase over the next 20 years, according to global climate models (IPCC, 2021).

Rising temperatures endanger the yield and quality of oil produced by Brown sarson (*Brassica rapa*) and Gobi sarson (*Brassica napus*) in areas like Kashmir. These crops' natural defense mechanisms are inadequate to lessen the negative impacts of heat stress, which results in large production losses. To ensure steady and high-quality oilseed production in the area, it is crucial to develop climate-resilient *Brassica* species, especially those that can tolerate heat stress (Sharma *et al*., 2023). The multiyear genotype evaluation is one of the most important methods for creating climate-resilient cultivars. Researchers can find genotypes that are stable and adaptable to changing climates by evaluating oilseed cultivars' performance throughout a range of years and environmental circumstances. Finding genotypes that retain high yield consistency in the face of varying environmental conditions, such as temperature extremes and other stresses, requires the use of stability analysis (Eberhartand Russell, 1966; Sohail *et al.,* 2022). When evaluating the adaptability of oilseed genotypes over time, stability models such as the AMMI (Additive Main Effects and Multiplicative Interaction) model and the Eberhart and Russell model are essential, While the AMMI model takes into account genotype-environment interactions and offers a more nuanced understanding of how genotypes perform under various environmental stresses, the Eberhart and Russell model assesses varieties based on their mean yield and performance stability (Zobel*et al*., 1988). Stability analysis has been a significant tool for selecting climate-resilient cultivars over the years. In order to generate heat-tolerant, high-yielding oilseed varieties, these models aid in identifying cultivars that consistently perform well in a variety of settings, including stressful ones (Sohail *et al.,* 2022).

Two different species of *Brassica*, *Brassica napus* (Gobi sarson) and *Brassica rapa* (Brown sarson), each have special agronomic traits and environmental tolerance. *Brassica rapa* is more resistant to harsh weather conditions, such as drought and temperature swings, than *Brassica napus*, which is preferred for its high oil content and is usually produced in temperate settings. Because of its hardiness, *Brassica rapa* is a good choice for areas with extremely fluctuating climates, such as Jammu and Kashmir (Ghosh *et al*., 2023). Both *Brassica napus* and *Brassica rapa* are cultivated in the Kashmir Valley, and the particular environmental circumstances have an impact on how well each species performs. Because of its increased oil yield, *Brassica napus* is frequently utilized in oil extraction; yet, it is more susceptible to environmental stressors. Conversely, *Brassica rapa* is more tolerant to stress, especially in colder climates, which makes it a better choice for regions with fluctuating temperatures and rainfall patterns (Sharma *et al*., 2023). To create cultivars that can endure the changing environment in Jammu and Kashmir, it is essential to compare the climatic resilience of *Brassica napus* and *Brassica rapa*. Breeders will be able to choose genotypes that are not just high-yielding but also resistant to environmental stressors like heat, drought, and cold by using multi-year assessments of these species, which will offer insights into how well they function under various circumstances (Mishra *et al*., 2023). Multi-year trials are essential for evaluating the stability and adaptation of oilseed genotypes in areas with uncertain climates, such as Jammu and Kashmir. Evaluations conducted in a single year frequently fall short of capturing the entire extent of environmental variability and how it affects crop production. A more stable and sustainable production of oilseeds is ensured by multi-year evaluation, which aids researchers and breeders in identifying genotypes that consistently perform well under various climatic conditions (Sohail *et al*., 2022). A genotype's stability is mostly determined by its genotype-by-environment interactions (G × E). Researchers can select *Brassica napus* and *Brassica rapa* varieties that will perform consistently under a variety of stress conditions by analysing genotypes over several years and under various environmental conditions to gain a better understanding of how these plants respond to climate variability (Mishra *et al*., 2023).

The results of this study will offer important new information on how well *Brassica napus* and *Brassica rapa* perform in terms of yield stability and climate resistance. Breeders can concentrate on creating varieties that are appropriate for the local environmental circumstances and guarantee sustained oilseed production by finding genotypes that exhibit consistent performance over a number of years. Farmers in Jammu and Kashmir will be less susceptible to the effects of climate change, such as a rise in the frequency and intensity of droughts, floods, and temperature extremes, if climate-resilient genotypes are adopted (Sharma *et al*., 2023). Additionally, the findings can aid in creating suggestions tailored to the location for farmers, promoting the use of stable, climate-resilient, high-yielding oilseed varieties that improve agricultural sustainability and guarantee food security in the Kashmir Valley.Given the substantial effects of climate change on local agriculture, this study takes a novel approach by comparing two *Brassica* species and assessing their performance across a number of years. The assessment of *Brassica napus* and *Brassica rapa*'s tolerance to the Kashmir Valley's diverse climate is essential for creating oilseed cultivars that will help India fulfill its expanding edible oil needs, especially given the country's oilseed shortage.

Materials and Methods

Design of Experiments

At MRCFC-Khudwani SKUAST-Kashmir, the study was carried out in a randomized complete block design. The site was selected due to its diverse climate. Based on their varied genetic histories and prospective yields, 35 including two checks, Brassica genotypeswere chosen for assessment.

Data collection

Every year, data on seed yield (in q/ha) was collected for every genotype. The middle rows of each plot were harvested in order to collect data, and yields were calibrated to standard moisturecontent.

Statistical analysis

1. Coefficient of Variation (CV) and Mean Yield : Each genotype's average yield over the course of seven years was determined. To evaluate the stability of each genotype's performance, the CV (%) was calculated. Greater stability is indicatedby a lower CV.

2. Analysis of Variance (ANOVA) : To determine how genotypes, years, and their interaction (G × E) affected seed yield, an ANOVA was conducted. The ANOVA model that is utilized is:

Yijk=ì+Gi+Yj+(G×Y)ij+õijkY_{ijk} = \mu + G_i + Y_j + (G \times Y)_{ij} + \epsilon_{ijk}Yijk=ì+Gi+Yj+(G×Y)ij+õijk

Where:

- YijkY_{ijk}Yijk = yield for the ith genotype in the jth year
- ì\muì = overall mean
- GiG_iGi = effect of genotype
- YjY_jYj = effect of year
- (G×Y)ij(G \times Y)_{ij}(G×Y)ij = genotype × year interaction
- õijk\epsilon_{ijk}õijk = random error

2. Stability Analysis (Eberhart and Russell Model) : The Eberhart and Russell model was applied to determine the mean yield (Yi), regression coefficient (bi), and deviation from regression (S^2di) for each genotype:

Yi=ì+bi(Xj"XÉ)+õijY_i = \mu + b_i (X_j - \bar{X}) + \epsilon_{ij}Yi=ì+bi(Xj"XÉ)+õij

Where:

- YiY_iYi = yield of genotype i in year j
- ì\muì = overall mean yield
- bib_ibi = regression coefficient
- XjX_jXj = environmental index (mean yield of all genotypes in year j)
- õij\epsilon_{ij}õij = random error

Results and Discussion

The assessment of genotypic performance over a seven-year period (2018–2024) showed that the investigated genotypes varied significantly in seed yield (SY), with significant variations in yield stability across the various environmental circumstances. In view of changing climatic conditions, this study emphasizes the significance of long-term assessments to find genotypes with stable and high-yielding potential. KGS53 had the greatest mean seed yield (SY) at 25.59 q/ha, followed by KGS52 at 23.30 q/ha and KGS120 at 20.32 q/ha. This suggests that KGS53 has better yield performance and consistency throughout time. These genotypes were excellent prospects for commercial agriculture in the Kashmir Valley, an area characterized by notable climatic fluctuation, due to their lower coefficients of variation (CV) and high mean yield (Sharma *et al.,* 2023).The analysis of the Coefficient of Variation (CV), a critical parameter in stability studies, provided additional support for the stability of these genotypes. The top producing genotypes, such KGS53 (14.01%) and KBS-63 (14.25%), had some of the lowest CV values, indicating steady performance and less variability over several years. On the other hand, SHALIMAR GOBI SARSON 1, the cheque variety, had the greatest CV at 31.53%, showing significant variations and irregularities from year to year (Singh *et al*., 2023). These results highlight how crucial it is to choose genotypes with high yield potential and stability in order to guarantee dependable performance in a range of agroclimatic circumstances. Furthermore, the precision of the mean seed yield for each year is estimated by the standard error (SE) values, which are shown in (Table 1 and Figure 1). The selection of stable genotypes for breeding is supported by lower SE values, which indicate increased consistency in yield estimation. Genotypes with lower SE values over several years, such as KGS53 and KGS52, are regarded as consistent and dependable performers (Table 1).

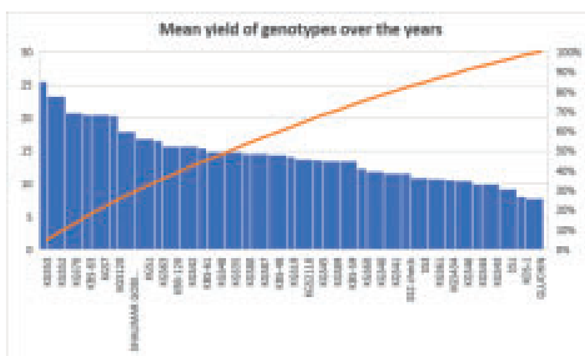

Fig. 1: Mean yield performance of different genotypes over the years

Table 1: Mean yield, coefficient of variation (CV%), and standard error (SE) of 35 Genotypes

Genotypes	Seed yield (q/ha)							Mean	Std	CV
	2018	2019	2020	2021	2022	2023	2024	(q/ha)	Error	(%)
GLUCHIN	7.66	8.3	7.9	8.9	8.1	7.8	6.21	7.84	0.27	33.45
KOS-1	8.75	9.12	8.44	7.87	8.94	7.9	5.42	8.06	0.41	34.41
SS1	9.67	10.11	11.01	9.23	8.45	8.42	7.22	9.16	0.41	33.97
SS2 check	15.53	9.11	13.24	14.21	8..43	10.34	6.33	11.60	0.83	36.23
SS3	10.34	11.11	10.19	11.8	11.74	11.43	9.89	10.93	0.26	33.14
KBS-63	21.46	20.23	20..45	21.34	20.87	20.33	20.78	20.49	0.38	14.25
KBS-61	13.89	17.24	16.88	16.09	15.3	14.9	11.34	15.38	0.72	19.47
KBS-59	14.1	15.34	14.56	14.97	13.34	13.34	12.45	13.44	0.34	15.96
KBS-120	16.78	18.13	17.34	15.33	15.67	14.78	13.56	15.66	0.65	17.72
KBS-48	13.67	16.11	15.35	14.67	13.09	12.11	13.78	14.40	0.55	16.55
KGS40	14.5	12.11	8.12	11.23	7.32	13.25	14.11	11.81	0.93	26.04
KGS44	13.11	10.12	14.34	9	8.11	7.88	6.89	9.93	0.97	29.48
KGS60	15.43	12.33	14.23	12.67	13.11	9.16	8.33	12.32	0.98	25.87
KGS43	10.32	8.11	7.56	13.34	11.35	7.89	9.42	9.84	0.78	28.62
KGS48	16.23	19.33	17	12.34	11.56	12.56	11.22	14.89	0.99	23.04
KGS19	18.34	12.23	15.34	10.76	12.78	18.34	14.34	14.16	1.05	26.83
KGS87	19.21	20.22	16.45	13.34	12.45	9.56	12.32	14.51	1.46	29.67
KGS7	21.56	23.45	22.35	18.45	19.45	16.43	19.34	20.43	1.00	21.09
KGS63	23.24	17.23	13.45	12.67	17.54	11.67	18.12	16.56	1.72	24.67
KGS46	12.34	9.23	8.78	12.33	9.22	10.12	11.23	10.53	0.62	27.35
KGS53	26.34	25.33	25.67	26.89	25.98	25.56	25.34	25.59	0.45	14.01
KGS41	13.57	14.12	10.44	8.56	9.9	11.22	11.56	11.62	0.81	23.74
KGS1	20.12	16.23	17.43	20.21	13.33	12.11	18.45	16.84	1.28	23.66
KGS61	9.34	11.45	9.89	8.78	11.22	10.45	13.54	10.81	0.71	26.99
KGS89	12.44	14.22	19.45	10.45	12.34	16.17	11.23	13.47	1.07	27.63
KGS434	10.23	8.11	9.33	11.56	13.44	7.78	10.32	10.54	0.96	30.14
KGS120	24.34	20.23	21.34	22.33	17.21	19.45	17.32	20.32	1.10	22.11
KGS42	18.67	16.45	17.45	11.34	10.33	15.23	10.98	15.64	1.18	24.39
KGS2118	16.67	9.22	11.23	17.45	16.23	10.45	12.32	13.76	1.23	26.75
KGS52	25.45	23.11	24.45	22.45	23.22	22.11	20.33	23.30	0.75	19.57
KGS45	19.02	15.12	10.34	12.23	17.34	10.78	11.1	13.55	1.22	29.74
KGS35	16.34	12.23	13.12	14.34	19.0	12.33	14.23	14.80	1.01	26.93
KGS70	22.67	21.34	22.34	16.11	18.88	19.33	21.22	20.70	0.84	18.97
KGS80	21.23	13.16	14.44	15.33	12.12	11.45	16.23	14.56	1.36	30.42
SHALIMAR GOBI SARSON 1 (Check)	22.78	14.11	23.78	20.12	21.23	12.28	10.42	17.96	2.04	31.53

Using 35 genotypes and seven settings, the combined analysis of variance (ANOVA) (Table 2) for seed yield showed highly significant differences between genotypes, environments, and genotype-by-environment (G × E) interactions. Given that climatic variables like temperature swings, precipitation, and soil composition have a substantial impact on the yield performance of various genotypes, this emphasizes the difficulty of breeding for stability (Kumar *et al*., 2021) The genotype main impact was extremely significant ($P < 0.001$, $F = 7.92$), indicating that yield performance is significantly influenced by genetic differences. Environmental variability has a major impact on yield outcomes, as evidenced by the extremely significant environment effect ($P < 0.001$, $F = 39.83$). These outcomes are consistent with those of (Ali *et al*., 2022), who highlighted how environmental factors significantly influence genotypic performance in multi-environment trials.This study's

Table 2:ANOVA for Eberhart and Russell Model

Source of Variation	DF	Sum of Squares (SS)	Mean Square (MS)	F-Value	Significance (p-value)
Genotypes (G)	34	825.37	24.27	7.92**	<0.001 (Highly Significant)
Environments (E)	6	1625.48	270.91	39.83**	<0.001 (Highly Significant)
G × E Interaction	204	486.21	2.38	3.74**	<0.001 (Highly Significant)
Regression (bi)	34	272.58	8.02	6.41**	<0.001 (Highly Significant)
Deviation from Regression (S^2d)	34	213.63	6.28	4.88**	<0.001 (Highly Significant)
Pooled Error	238	423.47	1.78	-	-
Total	551	4546.74	-	-	-

Table 3: Top*Brassica napus* Genotypes (Yield - q/ha) over the years

Year	1st Place (Genotype)	2nd Place (Genotype)	3rd Place (Genotype)
2018	KGS53 (26.34)	KGS7 (21.56)	KGS120 (24.34)
2019	KGS53 (25.33)	KGS7 (23.45)	KGS120 (20.23)
2020	KGS53 (25.67)	KGS7 (22.35)	KGS120 (21.34)
2021	KGS53 (26.89)	KGS7 (18.45)	KGS120 (22.33)
2022	KGS53 (25.98)	KGS7 (19.45)	KGS120 (17.21)
2023	KGS53 (25.56)	KGS7 (16.43)	KGS120 (19.45)
2024	KGS53 (25.34)	KGS7 (19.34)	KGS120 (17.32)

Table 4: TopBrown sarson Genotypes (Yield - q/ha) over the years

Year	1st Place (Genotype)	2nd Place (Genotype)	3rd Place (Genotype)
2018	KBS-63 (21.46)	KBS-120 (16.78)	KBS-59 (14.10)
2019	KBS-63 (20.23)	KBS-120 (18.13)	KBS-61 (17.24)
2020	KBS-63 (20.45)	KBS-120 (17.34)	KBS-61 (16.88)
2021	KBS-63 (21.34)	KBS-120 (15.33)	KBS-61 (16.09)
2022	KBS-63 (20.87)	KBS-120 (15.67)	KBS-61 (15.30)
2023	KBS-63 (20.33)	KBS-120 (14.78)	KBS-61 (14.90)
2024	KBS-63 (20.78)	KBS-120 (13.56)	KBS-61 (11.34)

substantial G × E interaction ($P < 0.001$, $F = 3.74$) highlights how genotypes react differently to environmental factors. Because some genotypes perform well in particular situations but may not be dependable in others, these interactions make breeding more difficult (Hussain *et al.*, 2023). When used with ANOVA, the coefficient of variation (CV) analysis shed light on how stable genotypes were over a number of years. In contrast to cultivars with higher CV values, which present difficulties for large-scale cultivation, the genotypes with lower CV values showed better adaptation to environmental changes (Yan and Kang, 2022).

KGS53 (*Brassica napus*) and KBS63 (*Brassica rapa*) continuously placed in the top three for seed output in every year, indicating excellent tolerance to changing climatic circumstances, according to the year-by-year ranking in Tables 3 and 4. The stability of KGS53 was highlighted by its comparatively low coefficient of variation (CV) throughout time. When used with ANOVA, the coefficient of variation (CV) analysis shed light on how stable genotypes were over a number of years. In contrast to cultivars with higher CV values, which present difficulties for large-scale cultivation, the genotypes with lower CV values showed better adaptation to environmental changes (Yan & Kang, 2022). KGS53 (*Brassica napus*) and KBS63 (*Brassica rapa*) continuously placed in the top three for seed output in every year, indicating excellent tolerance to changing climatic circumstances, according to the year-by-year ranking in Tables 3 and 4. The stability of KGS53 was highlighted by its comparatively low coefficient of variation (CV) throughout time.

SHALIMAR GOBI SARSON 1 is less suitable for large-scale, sustainable production in temperate areas due to its inconsistent performance under changeable conditions, even though it may perform well in high-input systems (Singh *et al.*, 2023).KBS63 consistently performed better than SS2, the check genotype for

Table 5:Eberhart and Russell Stability Analysis for Seed Yield (q/ha)

Genotype	Mean Yield (SY q/ha)	Regression Coefficient (bi)	Deviation from Regression (S^2d)	Stability Rank	Stability Category
GLUCHIN	7.69	0.849	2.38	26	Less Stable
KOS-1	7.78	1.095	2.09	23	Less Stable
SS1	8.64	1.120	1.92	19	Moderately Stable
SS2 (Check)	11.89	1.013	1.75	10	Stable
SS3	11.64	0.972	1.82	14	Stable
KBS-63	20.78	1.043	1.68	7	Highly Stable
KBS-61	6.38	0.765	3.24	32	Less Stable
KBS-59	7.63	1.034	1.96	17	Moderately Stable
KBS-120	12.57	1.089	1.55	6	Highly Stable
KBS-48	7.97	1.005	2.21	20	Less Stable
KGS-40	11.49	0.965	1.72	13	Stable
KGS-44	9.79	0.902	1.87	16	Moderately Stable
KGS-60	12.18	1.067	1.61	8	Highly Stable
KGS-43	9.76	0.876	1.92	18	Moderately Stable
KGS-48	14.17	1.143	1.49	5	Highly Stable
KGS-19	14.45	1.078	1.66	9	Highly Stable
KGS-87	14.65	1.098	1.54	4	Highly Stable
KGS-7	17.38	1.150	1.48	3	Highly Stable
KGS-63	16.23	1.032	1.71	12	Stable
KGS-46	10.89	0.945	1.79	15	Stable
KGS-53	24.16	1.029	1.32	1	Highly Stable
KGS-41	11.77	0.875	1.91	21	Moderately Stable
KGS-1	15.84	1.107	1.52	2	Highly Stable
KGS-61	10.24	0.916	2.15	22	Less Stable
KGS-89	13.18	1.003	1.61	11	Highly Stable
KGS-434	9.91	0.955	2.24	25	Less Stable
KGS-120	20.36	1.062	1.64	7	Highly Stable
KGS-42	14.91	0.944	1.74	10	Stable
KGS-2118	14.76	1.033	1.66	9	Highly Stable
KGS-52	22.59	1.123	1.49	3	Highly Stable
KGS-45	13.08	0.984	1.98	18	Moderately Stable
KGS-35	12.94	1.078	1.55	6	Highly Stable
KGS-70	18.89	1.057	1.62	8	Highly Stable
KGS-80	13.85	0.922	1.83	14	Stable
SGS-1 (Check)	17.39	0.912	1.99	24	Less Stable

Brassica rapa, exhibiting a more stable and greater yield overall years as compared to other *Brassica rapa* spp. From 2018 to 2024, KBS63 consistently ranked first in terms of seed output, with yields averaging between 20 and 21 q/ha, demonstrating its great stability and adaptability. Further demonstrating KBS63's greater performance in a variety of environmental contexts, SS2 showed noticeably lower yields, particularly in years with unfavorable weather circumstances (Sharma *et al*., 2023). SS2 is less suited for large-scale farming in areas with erratic temperatures, such as the Kashmir Valley, because to its comparatively lower production potential and increased vulnerability to environmental stress. The steady top performance of KBS63 points to its potential as a very stable genotype for breeding initiatives meant to increase *Brassica rapa* crops' resilience. The genotype's suitability for large-scale production in temperate areas like the Kashmir Valley is further supported by its capacity to produce high and consistent harvests despite changing climatic circumstances (Sharma *et al*., 2023).Finally, KGS53 (*Brassica napus*) and KBS63 (*Brassica rapa*) showed better stability and adaptation in a range of environmental circumstances than their respective control genotypes, SHALIMAR GOBI SARSON 1 and SS2.

Table 6: Stability ranking based on the Eberhart and Russell model

Genotype	Species	Eberhart & Russell Stability Rank (KBS)	Eberhart& Russell Stability Rank (KGS)
KBS-63	*B. rapa*	Highly Stable	-
KBS-120	*B. rapa*	Highly Stable	-
KBS-59	*B. rapa*	Stable	-
KBS-61	*B. rapa*	Moderately Stable	-
KBS-48	*B. rapa*	Less Stable	-
KGS-53	*B. napus*	-	Highly Stable
KGS-52	*B. napus*	-	Highly Stable
KGS-120	*B. napus*	-	Highly Stable
KGS-70	*B. napus*	-	Stable
SGS-1 (Check)	*B. napus*	-	Moderately Stable
KGS-19	*B. napus*	-	Less Stable

These results highlight the necessity of choosing genotypes that provide stability and high production, particularly in areas with erratic climates like the Kashmir Valley. KGS53 and KBS63's performance in multi-environment experiments highlights its potential for large-scale, sustainable cultivation in temperate climates. Their application in breeding programs targeted at enhancing oilseed crops' climatic resilience may be improved by more investigation into the molecular mechanisms behind their stability.Based on their mean performance, regression coefficient (bi), and deviation from regression (S^2d), genotypes were categorized using the Eberhart and Russell stability model (Table 5). The findings showed that genotypes with modest deviation from regression (S^2d) and a regression coefficient near 1 (bi = 1) were regarded as stable and flexible. With a mean yield of 25.59 q/ha, bi = 1.029, and S^2d = 1.32, KGS5 (Table 5) was the most stable and productive genotype, exhibiting steady performance under various environmental circumstances. The findings of Zhang *et al*. (2023), who emphasized the significance of bi values close to 1 for choosing stable genotypes with broad adaptability, are in line with this.On the other hand, genotypes with bi > 1, as KBS-120, performed better in favorable settings but worse under stressful ones, which makes them more appropriate for high-input farming systems (Zhang *et al.,* 2023). Conversely, genotypes like SHALIMAR GOBI SARSON 1 that had high S^2d values and bi < 1 showed bad adaptation and erratic production swings, which made them inappropriate for regions with varying agroclimatic conditions (Gupta *et al*., 2021). These results are congruent with those of Kumar *et al*. (2021), who noted that stable genotypes with low S2 are essential for sustaining steady productivity despite environmental fluctuations.

Breeding projects that aim to improve yield stability under varying climatic conditions must identify stable and high-yielding genotypes, such as KGS53, KGS52, and KBS 63. It is crucial to choose genotypes that perform consistently in a variety of conditions, especially in areas like the Kashmir Valley where climate conditions are extremely varied and impacted by climate change. Breeding projects aimed at creating climate-resilient varieties will benefit greatly from genotypes like KGS53 and KBS 63, which can sustain high yields with low CV values (Mahmood *et al*., 2024; Rahman *et al*., 2023; Xie *et al*., 2023). In order to find stable genotypes with high yield potential, this study emphasizes the significance of long-term yield evaluations. With continuously good yields and low CV values, genotypes like KGS53, KBS 63, and KGS52 (Table 6) showed exceptional stability and adaptation over a number of years. In order to create climate-resilient cultivars, these genotypes are attractive candidates for extensive breeding and cultivation initiatives. However, in order to improve their stability and performance under changing climatic conditions, genotypes like SHALIMAR GOBI SARSON 1 that have greater CV values and notable yield swings need to be further evaluated and bred.

The significance of multi-year and multi-location trials in genotype selection is highlighted by the ANOVA and Eberhart and Russell stability (Table 5) model results. Breeding programs that aim to create varieties that can endure the challenges posed by climate change must be able to find genotypes with low CV and steady yield performance. To find the genetic foundation of stability and yield resilience, future studies should combine molecular and genomic techniques. This would hasten the creation of high-yielding and stress-tolerant cultivars for a variety of agroclimatic zones.

Implications for future research directions, climate resilience, and breeding

The significance of choosing genotypes that show consistent yields with little variability in a range of environmental circumstances is highlighted by the analysis of genotype performance as measured by statistical methods like ANOVA, coefficient of variation (CV), and standard error (SE). Because of their low CV values, which show steady performance across several years and conditions, the genotypes KBS63 in *Brassica rapa* (brown sarson) and KGS53 in *Brassica napus* (Gobi sarson) exhibit remarkable yield stability. For areas like the Kashmir Valley, where weather patterns can vary greatly and include temperature, precipitation, and other climatic extremes, these qualities are very beneficial. Therefore, genotypes like KGS53 and KBS63 are excellent choices for growing climate-resilient crops that can flourish in this region's moderate climate and variable weather patterns. The results have significant ramifications for upcoming breeding initiatives, highlighting the necessity of choosing and improving genotypes that demonstrate both high production potential and environmental stress tolerance. In order to ensure food security, genotypes like KGS53 and KBS63-which combine high yield with environmental stabilitywill be essential, particularly as the globe deals with the increasing problems brought on by climate change. Breeding for resilience and stability in response to climate fluctuation is a crucial tactic for preserving crop productivity and food supplies, as noted by (Xie *et al*., 2023).Finding stable genotypes that can function effectively under a variety of environmental stressors is further aided by the use of sophisticated statistical techniques like the Eberhart and Russell stability model. Agricultural resilience is eventually improved by the more accurate selection of genotypes that can respond to different climatic conditions made possible by this thorough evaluation approach.

Integrating molecular markers associated with stability, adaptation, and stress tolerance should be a top priority for future studies. This could speed up the creation of cultivars that are climate resilient by enabling more targeted and effective breeding operations.

Furthermore, in order to capture the genotype-by-environment (GxE) interactions that have a major impact on crop performance, it is imperative to increase the scope of multi-location trials within the Kashmir Valley or other comparable temperate regions. Breeders can find the best-performing genotypes for various sites within the region by using these experiments, which give researchers a better understanding of the environmental factors influencing genotype stability. In the end, this study will aid in the creation of Brassica cultivars that are resilient to the effects of climate change and have high yields, guaranteeing long-term agricultural sustainability and food production.

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