Journal of Experimental Agriculture International

Volume 46, Issue 7, Page 29-39, 2024; Article no.JEAI.115554
ISSN: 2457-0591
(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)

Stability Assessment of Groundnut ABLs Using AMMI and GGE Biplot Analysis for Yield Performance under Multi-environments

Premika B. P. [a], Venkataravana P. [a], Sowjanya B. A. [a*] and Priyadarshini S.K. [a]

[a] *College of Sericulture, Chintamani, University of Agricultural Sciences, Bengaluru, Karnataka, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/jeai/2024/v46i72554

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/115554

Original Research Article

Received: 15/02/2024
Accepted: 19/04/2024
Published: 03/06/2024

ABSTRACT

The current study focused on Identification of stable line among the eight groundnut ABLs and two checks were assessed in three different environments in Karnataka during the 2020-2021 Kharif and Rabi seasons with randomized complete block design (RCBD) with three replications. The analysis of variance revealed significant differences ($p \leq 0.01$) among the genotypes, environments, and the genotype by environment interaction (G×E) for kernel yield. The AMMI analysis also showed highly significant differences ($p \leq 0.01$) for varieties, environments, and their interaction on kernel yield. The IPCA1 and IPCA2 components explained 72.72% and 25.00% of the total G×E sum of squares, respectively. The variations in kernel yield were attributed to the environment (16.44%), ABLs (81.87%), and ABLs by environment interaction (1.68%). ABLs T65, T77, T81, and T82 were identified as stable across all three environments based on ASV and SI for kernel yield

**Corresponding author: E-mail: sowjanyabas@gmail.com;*

Cite as: *Premika B. P., Venkataravana P., Sowjanya B. A., & Priyadarshini S.K. (2024). Stability Assessment of Groundnut ABLs Using AMMI and GGE Biplot Analysis for Yield Performance under Multi-environments. Journal of Experimental Agriculture International, 46(7), 29–39. https://doi.org/10.9734/jeai/2024/v46i72554*

per plant. These stable lines can be used as parents in breeding programs. The AMMI model and GGE biplots were effective tools for evaluating the adaptability and stability of groundnut genotypes in diverse environments.

Keywords: Groundnut; ABLs; ASV; SI; AMMI; stability analysis; GGE biplot.

1. INTRODUCTION

Groundnut, also known as peanut, is a significant legume crop that is ranked 12th among the world's food crops [1]. It is a valuable source of vegetable oil and is rich in protein, minerals, vitamins, and carbohydrates. The kernel of groundnut contains approximately 46-52% oil, 25-30% crude protein, and 12-18% carbohydrates [2]. "Additionally, groundnuts can improve soil fertility through nitrogen fixation when used in crop rotation, making them beneficial for agriculture. Groundnut is commonly cultivated in semiarid countries with moist weather, including Africa, America, and Asia, as stated by Singh and Singh" [3]. "Groundnut is commonly grown in semiarid countries with moist weather, such as Africa, America" [4]. "It is cultivated globally on 27.9 million hectares, producing 47 million tonnes with an average productivity of 1685 kg/ha. India contributes 22% to the global production, cultivating it on 6.014 million hectares and yielding 10.02 million tonnes (1703 kg/ha). In Karnataka, the current groundnut productivity is 720 kg per hectare, which is lower than the national average of 999 kg per ha" [5]. Despite the advent of numerous high-yielding crop varieties in recent years, TMV-2, a crop variety developed 82 years ago, continues to be the preferred choice among many farmers for cultivation. This enduring preference for TMV-2 is attributed to its remarkable resilience and adaptability to a wide range of environmental conditions, making it a reliable option for consistent yields.

Despite the availability of high-yielding groundnut varieties, TMV-2, which was developed 82 years ago, remains a preferred choice. However, its removal from the official seed supply list by the government has made it difficult to access. Addressing the productivity gap in groundnut cultivation necessitates the development of new varieties that not only yield higher but also retain the favorable pod and kernel characteristics of TMV-2. The widespread issue of low productivity is exacerbated by the slow adoption of these improved varieties and their variable performance under different environmental conditions. Furthermore, groundnut productivity is influenced by genotype by environment interactions (GEI), indicating that the relationship between various traits and yield can be either beneficial or detrimental [6].

In order achieve the goal to increase production, it is important to adapt genotypes to changes in the environment over time and location. The interaction between genotype and environment can lead to inconsistent crop yields due to various factors such as unpredictable rainfall, limited resources in farming communities, crop diseases, and the inherent potential of genotypes. However, there is potential to identify or develop stable genotypes that yield well in different environments [7]. The AMMI model [8, 9] and the GGE biplot [10-12] are commonly used methods to analyze genotype-environment interactions and crop attributes. AMMI helps to understand the effects of genotype and environment, while the GGE biplot focuses on the interaction between genotype and environment, providing a comprehensive analysis and assessment of genotypes [13, 12].

Genotype stability analysis is essential for identifying genotypes that can consistently perform well in various environments [14]. "This interaction between genotype and environment is crucial for breeders to enhance breeding programs and minimize negative agro-climatic effects. Unfortunately, the influence of environmental conditions on quantitative traits in groundnut genotypes has not been extensively studied. Stable genotypes are able to adjust their phenotypic responses in order to maintain consistency even in the face of environmental fluctuations" [15]. Therefore, this study aimed to assess the performance of TMV-2 type groundnut advanced breeding lines in different locations and identify adaptable lines that are suitable for cultivation.

2. MATERIALS AND METHODS

Study was conducted to evaluate eight groundnut genotypes and two control varieties across three different environments during 2021-Kharif and Rabi seasons (Table 1). The groundnut varieties used as parents in the crosses and checks were detailed in Table 2 and while the geographical and climatic data for each environment were provided in Table 3. The dibbling method of sowing was done in both Kharif and Rabi seasons at all three locations, with a randomized complete block design with three replications and 30 x 10 cm spacing between rows and plants. The standard crop management practices were adopted except for the spray of fungicides during the crop growth period in all environments. Kernel yield and other yield-related traits were recorded.

To accurately assess the interaction effects between advanced breeding lines (ABLs), parents, and different seasons on the growth trait indicated by the Genotypic Stability Index (GSI), data collected across three distinct seasons were analyzed utilizing the Additive Main Effects and Multiplicative Interaction (AMMI) model. This sophisticated statistical model facilitates a comprehensive evaluation of both the additive main effects, which are the direct influences of ABLs and parents, as well as the effects of seasons on the trait of interest and the multiplicative interaction effects which show the combination of ABLs and parents interact with seasonal variations to influence the trait. Initially, the analysis commenced with a univariate.

Table 1. List of genotypes used in the experiments along with checks

Sl. No.	Genotypes	Pedigree
1.	T77	TMV-2 × ICGV-91114
2.	T89	TMV-2 × ICGV-91114
3.	T81	TMV-2 × ICGV-91114
4.	T82	TMV-2 × TG-69
5.	T79	TMV-2 × TG-69
6.	T65	TMV-2 × ICGV-00350
7.	T72	TMV-2 × ICGV-00350
8.	T61	TMV-2 × ICGV-00350

Sl. No.	Checks
1.	TMV-2
2.	Kadiri 6

Table 2. Salient features of groundnut varieties used as parents in the crosses and checks

Varieties	Year of release	Provenance	Parentage	Special features
TMV-2	1940	TNAU, Coimbatore	Selection from Gudiyathambunch	Old variety, wider adaptability, desirable pod and kernel shape & size, kernels small with salmon color testa, susceptible to drought and foliar diseases.
ICGV-91114	2007	ICRISAT, Hyderabad	ICGV-86055 ×ICGV-86353 Bulk pedigree method	Early maturing, moderate yielding, bold seeded, tolerant to drought & LLS, good seed size, better digestibility and palatability of haulms
ICGV-00350	2012	ICRISAT, Hyderabad	ICGV-87290 × ICGV-87846 Bulk pedigree method	High yield and high oil content, resistant to LLS and rust and tolerant to drought and stem rot.
TG-69	2011	BARC, Trombay,Mumbai	Mutant variety	High harvesting index, shelling *per cent* and SMK *per cent.*
Kadiri6	2003	ARS, Kadiri, Anantapur	JL-24×AH-316	Early maturing and

Table 3. Description of three locations used for evaluation of groundnut varieties

Locations	Environment label	Geographical position		Altitude (m.a.s.l)
		Latitude	Longitude	
National Seed Project (NSP), University of Agricultural Sciences, GKVK, Bengaluru	E1	$13^0$08"N	$77^0$34" E	924m
Agriculture Research Station, Balajigapade	E2	$13^0$43"N	$77^0$79"E	915m
Organic Farming Research Station, Mandya	E3	$12^0$37"N	$76^0$66"E	678m

Analysis of Variance (ANOVA), a procedure tailored to rigorously ascertain the additive main effects attributed to the ABLs, parents, and the three seasons under study. This step, documented in Table 5, is crucial for establishing a foundational understanding of the individual contributions of these factors to the trait being examined. Subsequently, the analysis advanced to a more nuanced stage involving the Interaction Principal Component Analysis (IPC), a pivotal component of the AMMI model. This stage specifically targets the (ABLs + parents) × season interaction, providing a multidimensional view of how these factors collectively influence the trait in question. The IPC analysis is particularly adept at disentangling the complex interactions that are not readily apparent from the main effects alone, thus offering a more granular insight into the dynamics at play. The employment of the AMMI model in this context is underpinned by its capacity to simultaneously handle additive and multiplicative effects, rendering it an invaluable tool in the field of agricultural research for dissecting and understanding the multifaceted interactions between genetic lines, environmental conditions, and their combined influence on phenotypic outcomes. This methodological approach affords researchers a nuanced perspective on the genetic and environmental factors shaping trait expression, thereby informing targeted breeding and selection strategies to enhance crop performance across varying conditions.

$$Y_{ij}=\mu+g_i+e_j+\sum_{k=1}^{n}\lambda_k\alpha_{ik}\gamma_{jk}+\varepsilon_{ij}$$

Where.,

μ is the grand mean; αg is the deviation of genotype g from the grand mean, βe is the deviation of the environment e; λn is the singular value for IPCA, γgn is the genotype eigenvector for axis n, and δen is the environment eigenvector; εger is error term and ρge is PCA residual. “Accordingly, genotypes with low magnitude regardless of the sign of interaction principal component analysis scores have general or wider adaptability while genotypes with high magnitude of IPCA scores have specific adaptability” [16-18].

The AMMI stability value (ASV) for the i^{th} genotype was computed for each genotype and environment based on the proportion of IPCA1 to IPCA2 in the interaction SS as follows [19].

$$\text{ASV} = \sqrt{[\frac{SSIPC1}{SSIPC2}]\,(\text{IPC1 score})^{\mathbf{2}} + (\text{IPC2 score})^{\mathbf{2}}}$$

Where,

“The sum of squares (SS) related to the first two IPCs are denoted as SSIPC 1 and SSIPC 2. In theory, ASV is the separation between zero and an IPC 1 vs. IPC 2 scatter plot in two dimensions” [19]. “In order to account for the relative contributions of IPC 1 and IPC 2 scores to the total GSI sum of squares, the IPC 1 score which typically contributes proportionately more to GSI is weighted by the proportional difference between IPC 1 and IPC 2 values”. [20] Greater stability is indicated by lower magnitude ASV estimates, whereas lesser stability of genotypes is indicated by higher magnitude ASV estimates [19].

3. RESULTS AND DISCUSSION

3.1 Combined Analysis of Variance

Analysis of variance revealed that there were statistically significant differences ($P<0.01$) among the varieties, across different environments, and also in the interaction between varieties and environments regarding kernel yield, as shown in Table 4. This finding suggests that there is a substantial genetic variation among the groundnut varieties being studied. Such genetic diversity indicates the potential for selecting varieties that not only yield high but are also stable across various environmental conditions. The results further underscore the fact that environmental conditions influence groundnut yield and that the performance of different groundnut varieties can vary significantly depending on the environmental context. This finding aligns with previous research which has similarly identified significant variations in the performance of groundnut varieties across different environments. The implication of these results is significant for breeding programs. It highlights the necessity of considering both the genetic makeup of the varieties and the environmental factors influencing crop yield during the selection process for high-yielding and environmentally resilient groundnut varieties [21,22].

3.2 Additive Main Effects and Multiple Interaction (AMMI) Model

The results of the combined analysis of variance showed highly significant variations among environments, genotype × environment interaction, IPCA-1, and IPCA-2 (Table 5) [23]. This finding indicates differences in yield performance among groundnut varieties across various testing environments, underscoring a strong genotype by environment interaction. The GEI value represent a significant effect on the kernel yield of groundnuts and other yield attributing traits and highlighted significant variations in how varieties responded to changes in growing environments and the distinguishing characteristics of the test environments. Except for days to 50% flowering, locational contexts displayed significant mean squares for all traits, demonstrating the potential of temporal environments to differentiate the ABLs under study. The noteworthy mean squares associated with ABLs further underscored the variations among the ABLs for each trait (Table 4). Similar outcomes as reported by Yayis *et al.,* [24] and Akande *et al.,* [25]. The interaction between genotype and environment (G × E) was predominantly influenced by IPCA-1 (72.72%) and IPCA-2 (25.00%), which were utilized to construct a two-dimensional GGE biplot. Gauch and Zobel [26] along with Amare and Tamado [21] proposed that the optimal model for AMMI could be forecasted by considering the initial two IPCA components.

3.3 To Identify Specifically Stable Adaptable or Widely Adaptable TMV-2 Type Groundnut Advanced Breeding Lines

3.3.1 GGE biplot analysis of GEI patterns

The GGE bi-plot graph, which displays the distribution of ABLs based on their IPCs, offers a qualitative assessment of the stability and adaptability of ABLs across different spatial settings [25]. The traditional GGE bi-plot, also referred to as the SREG (sites regression) model, was initially introduced by Yan et al. [27]. This model incorporates genotype (G) and genotype × environment (GE) data, providing a comprehensive analytical approach that effectively visualizes the interactions between each ABL and its corresponding location environment.

Table 4. The pooled ANOVA estimation of groundnut ABLs across three locations for yield and its contributing traits during *Rabi* 2021-22

Source of variation	Degrees of freedom	Plant height (cm)	Primary branches plant^{-1}	Days to 50% flowering	Pods plant^{-1}	Pod yield plant^{-1}(g)
Replication	6	2.51	0.61	8.64	4.19	3.29
ABLs	8	66.71**	5.17**	48.45**	82.60**	13.29**
Location	2	1.67**	0.16**	25.64**	14.75**	8.14**
ABLs×Location	16	11.09**	0.52**	8.46**	1.73**	1.23**
Pooled error	48	8.08	0.63	6.50	2.94	3.11

Source of variation	Degrees of freedom	Kernel yield plant^{-1} (g)	Shelling per cent	Sound mature kernel	Test weight (g)
Replication	6	1.53	0.25	26.90	2.63
ABLs	8	3.74**	182.73**	195.44**	534.54**
Location	2	2.16**	9.17**	8.21**	35.18**
ABLs×Location	16	0.44**	1.09**	23.65**	17.30**
Pooled error	48	0.81	0.18	24.70	17.86

*Significant at P =0.05; **Significant at P=0.01*

Table 5. AMMI ANOVA of groundnut ABLs evaluated across three locations for yield and its attributing traits during *Kharif* and *Rabi* 2021-22

Source of variation	Degrees of freedom	Kernel yield plant^{-1}(g) (*Kharif*)		Kernel yield plant^{-1}(g) (*Rabi*)	
		Mean sum of squares	% variation	Mean sum of squares	% variation
Total	80	0.32		1.12	
Treatments	26	0.99**	99.23	1.58**	46.04
ABLs	8	2.64**	81.87	3.74**	33.35
Environments	2	2.18**	16.44	2.17**	4.83
ABLs × Location	16	0.02**	1.68	0.44**	7.84
IPCA1	9	0.03**	72.72	0.74**	95.17
IPCA2	7	0.01**	25.00	004**	4.80
Error	48	0.003	0.61	0.81	43.72

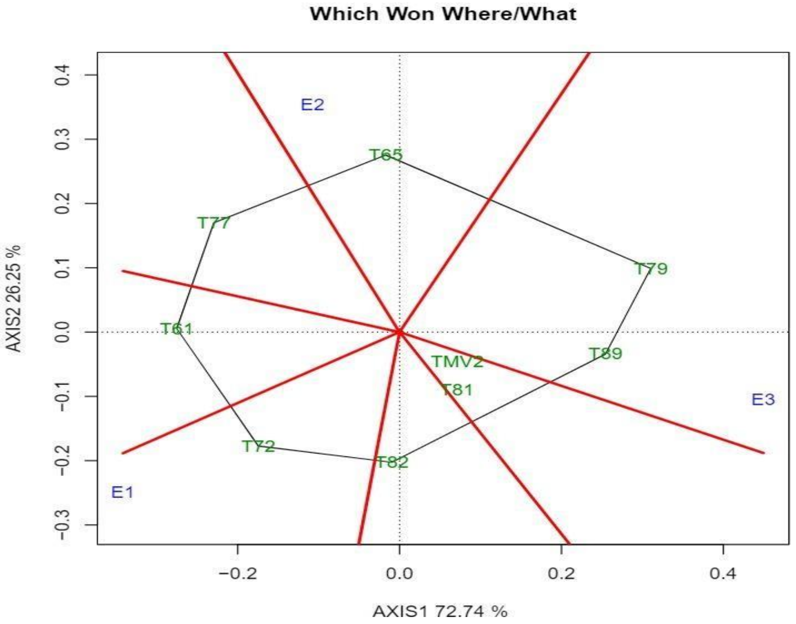

Fig. 1. Polygon view of GGE bi-plot based on the symmetrical scaling for "which won-where" pattern of ABLs and locational environments for kernel yield plant^{-1} (g) during *Kharif* 2021

The graph depicting the results for Kernel yield plant-1 in the Kharif season of 2021 indicated that T72 and T82 emerged as the top-performing genotypes in environment 1 (GKVK), while T77, T65, and T61 were the winning genotypes in environment 2 (Mandya). Additionally, T89 was identified as the winning genotype in environment 3 (Balajigapade) as illustrated in Fig 1.

During *Rabi* 2021, as per our graph for kernel yield plant^{-1} T72 was found to be the winning genotype in environment 1 (GKVK), T65 and T79 were discovered to be the winning genotype in environment 2 (Mandya), and T89 were shown to be the winning genotype in environment3 (Fig. 2).

3.4 AMMI Model-Based Stability Parameters

3.4.1 AMMI Stability value (ASV)

ASV provides an impartial assessment of stability, facilitating the identification of ABLs that exhibit consistency across all three seasonal conditions. ASV is determined by measuring the distance from zero on a two-dimensional scatter plot of IPCA 1 (Interaction Principal Component Analysis Axis 1) scores against IPCA 2 (Interaction Principal Component Analysis Axis 2) scores. The IPC scores and ASV values for the Kharif 2021 and Rabi 2021 seasons are presented in table 6. The stable genotypes for the Kharif 2021 and Rabi 2021 seasons are

Table 6. Estimates of ASV and SI to assess stability of groundnut ABLs across three locations during *Kharif* and *Rabi* 2021-22

ABLs	Kernel yield plant^{-1}(g) (*Kharif*)							Kernel yield plant^{-1}(g) (*Rabi*)						
	MEAN	RY	IPCA1	IPCA2	ASV	RASV	SI	MEAN	RY	IPCA1	IPCA2	ASV	RASV	SI
T61	16.57	4	0.28	-0.01	0.47	8	12	16.38	6	-0.36	-0.23	1.60	4	10
T65	17.89	1	0.02	-0.28	0.28	4	5	18.09	1	-0.53	0.05	2.34	8	9
T72	16.51	5	0.17	0.18	0.35	5	10	16.29	7	0.46	-0.21	2.04	6	13
T77	16.89	3	0.23	-0.17	0.43	6	9	17.05	2	-0.18	-0.24	0.81	2	4
T79	17.08	2	-0.31	-0.10	0.54	9	11	16.68	3	-0.48	0.35	2.15	7	10
T81	16.33	7	-0.07	0.09	0.15	2	9	16.55	4	0.23	0.04	1.02	3	7
T82	16.43	6	0.01	0.20	0.20	3	9	16.32	6	-0.18	-0.03	0.78	1	7
T89	16.14	9	-0.25	0.03	0.43	7	16	15.8	8	0.59	0.23	2.64	9	17
TMV2	16.29	8	-0.07	0.05	0.13	1	9	16.45	5	0.43	0.04	1.92	5	10

Table 7. Stable and adaptable groundnut ABLs across three locations identified based on the stability index for different traits during *Kharif* and *Rabi* 2021

Traits	Adaptable ABLs during *Kharif* 2021	Adaptable ABLs during *Rabi* 2021	Stable ABLs
Plant height (cm)	T81, T82, T77	T61, T81, T82	T81, T82
Primary branches plant^{-1}	T81, T82, T72	T82, T65, T79, TMV-2	T82
Days to 50% flowering	T81, T72, T61	T81, T72, T89	T81, T72
Pods plant^{-1}	T65, T61, T72	T72, T82, T65,T61	T65, T61, T72
Pod yield plant^{-1}(g)	T82, T72, T65	T82, T81, T65	T82, T65
Kernel yield plant^{-1}(g)	T65, T77, T81, T82	T77, T81, T82, T65	T65, T77, T81, T82
Shelling per cent	T77, T65, TMV-2, T61	T77, T65,TMV-2, T61	T77, T65, TMV-2, T61
Sound mature kernel	T89, T77, T82, TMV-2	T77, T61, T81, T89	T89, T77
Test weight(g)	T82, T72, T65	T81, T82, T79, T65	T82, T65

listed in (Table 7). In a similar vein, Ajay et al [26] conducted a stability analysis on fifty-two peanut genotypes over a span of two years, considering two phosphorous levels. They employed the AMMI model to investigate the interaction between genotype and environment (GEI) [28].

This study holds significant relevance in addressing the pressing challenges faced by agricultural systems globally, particularly in regions characterized by diverse agro-environments like Karnataka, India. Understanding the performance and stability of crop genotypes across different environments is crucial for developing resilient and high-yielding varieties that can withstand environmental stresses [29, 30]. The findings of this study provide valuable insights into the adaptability of groundnut ABLs to varying soil quality, precipitation patterns, and other environmental variables prevalent in the study area. By elucidating genotype-environment interactions, the research aids in tailoring crop management practices and breeding strategies to optimize productivity and mitigate the impact of environmental fluctuations on crop yields [31-33].

Soil quality plays a pivotal role in shaping crop performance and stability, as it directly influences nutrient availability [34], water retention [35], and overall plant health [36, 37]. By evaluating groundnut ABLs across diverse soil types present in Karnataka, this study sheds light on the genotype-specific responses to soil characteristics such as fertility, texture, and pH [38, 39]. Understanding how different genotypes interact with soil conditions allows for the selection of varieties with enhanced adaptability and resilience to specific soil types, thereby maximizing yield potential and ensuring sustainable crop production [40, 41].

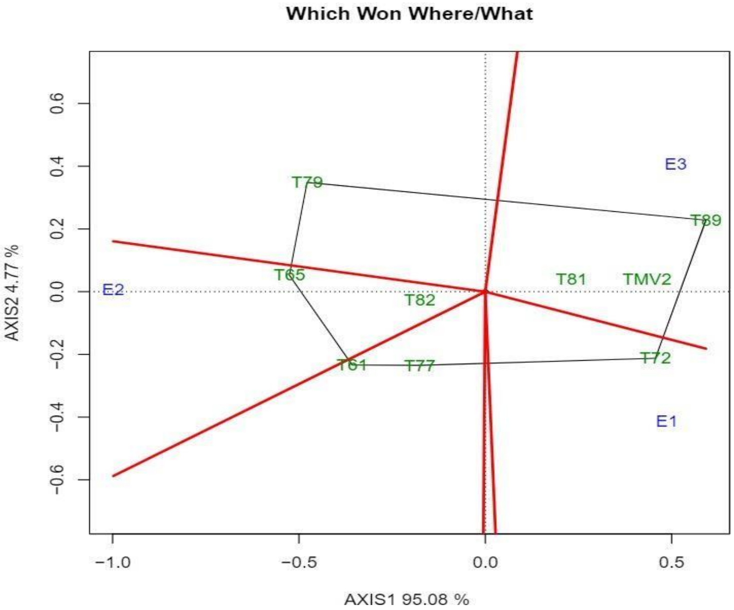

Fig. 2. Polygon view of GGE bi-plot based on the symmetrical scaling for "which won-where" pattern of ABLs and locational environments for kernel yield plant^{-1}(g) during *Rabi* 2021

Furthermore, the influence of precipitation patterns and other environmental variables on groundnut performance underscores the need for climate-resilient crop varieties [42, 43]. As climate change continues to manifest through shifts in rainfall patterns [44, 45], temperature extremes, and unpredictable weather events [46, 47], the development of genotypes capable of thriving under varying climatic conditions becomes imperative [48, 49]. This study elucidates the differential responses of groundnut ABLs to precipitation regimes, highlighting the importance of incorporating genotype-specific adaptive traits in breeding programs [50, 51]. By identifying stable genotypes that exhibit consistent performance across different environmental conditions, this research contributes to the development of climate-smart agricultural practices aimed at enhancing food security and resilience in the face of climate variability [52, 53].

4. CONCLUSION

The investigation of G×E interactions in multi-environment trials was conducted using the well-established AMMI and biplot models. To better recommend stable and high-yielding groundnut ABLs, it is more suitable to simultaneously consider stability measures and yield. In this particular research, the advantages of both AMMI and biplot models were combined to enhance the reliability of the analysis of trials conducted across multiple locations. A pooled analysis of variance for kernel yield was performed on the ABLs, revealing significant ($p \leq 0.01$) differences among genotypes, environments, and the G×E interaction. This highlighted the substantial variability attributed to the ABLs and their interaction with spatial environments for all traits examined in the study. The AMMI analysis was utilized to identify and characterize GSI, while the GGE bi-plot was employed to interpret GSI patterns of ABLs and pinpoint those with specific or wide adaptation. The AMMI analysis demonstrated highly significant ($p \leq 0.01$) differences for varieties, environments, and their interaction on kernel yield. The first and second interaction principal component axes (IPCA1 and IPCA2) were also found to be highly significant ($p \leq 0.01$), explaining 72.72% and 25.00% of the total G×E sum of squares, respectively. The environment, ABLs, and ABLs by environment interaction accounted for 16.44%, 81.87%, and 1.68% of the variations, respectively, indicating substantial differences in response among ABLs to changes in growing environments and the discriminating ability of the test environments. AMMI Stability Value (ASV) and Stability Index (SI) were estimated and were used to assess relative stability of ABLs. The results showed that ABLs T65, T77, T81, and T82 exhibited stability across all three locations and in both seasons, based on their ASV and SI values for kernel yield plant-1. These stable lines will undergo further evaluation in future years to determine their kernel yield potential. If validated, these stable lines can be released as a new variety or used as parents in the development of segregating populations. The use of the AMMI model and GGE biplot proved to be valuable methodologies in evaluating the adaptability and stability of groundnut genotypes in different environmental conditions. These two approaches complemented each other in providing a comprehensive assessment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Dabessa A, Alemu B, Abebe Z, Lule D. Genotype by environment interaction and kernel yield stability of groundnut (*Arachis hypogaea* L.) varieties in Western Oromia, Ethiopia. Journal of Agriculture and Crops. 2016;2(11):113-20.
2. Anonymous. Crop wise 4th advance estimates of area, production and yield of various principle crops during 2019-20. Commission of Agriculture, Rajathan-Jaipur. 2020.
3. Azrai M, Efendi R, Muliadi A, Aqil M, Suwarti Zainuddin B, Syam A, Junaedi Syah UT, Dermail A, Marwiyah S. Genotype by environment interaction on tropical maize hybrids under normal irrigation and waterlogging conditions. Frontiers in Sustainable Food Systems. 2022;6:913211.
4. Jasani H. Groundnut Package of Practices. Agropedia; 2009
5. Singh U, Singh B. Tropical grain legumes as important human foods. Economic botany. 1992;46:310-21.
6. Anonymous, Indiastat, 2021
7. Patil AS, Hedvat I, Levy Y, Galili S, Hovav R. Genotype-by-environment effects on the performance of recombinant inbred lines of Virginia-type peanut. Euphytica. 2018;214 (5):1-15.
8. Gauch HG, Zobel RW. Identifying mega-environments and targeting genotypes. Crop Science. 1997;37:311-326.
9. Crossa J, Gauch HG Jr, Zobel RW. Additive main effect and multiplicative interactions analysis of two international maize cultivar trials. Crop Sci. 1990;30: 493-500
10. Ebdon JS, Gauch HG Jr. 2002a. Additive main effect and multiplicative interactions analysis of national turf grass performance trials: I. Interpretation of genotype x Environment Interaction. Crop Sci. 2002a; 42:489-496.
11. Blanche SB, Myers GO, Kang MS. GGE biplot and traditional stability measures for interpreting genotype by environment interactions. J. Crop Improve. 2007;20: 123-135.
12. Khalil IA, Rahman H, Rehman NU, Arif M, Khalil IH, Iqbal M, Ullah H, Afridi, K, Sajjad M, Ishaq M. 2011. Evaluation of maize hybrids for grain yield stability in north-west of Pakistan. Sarhad J. Agriv. 2011;27(2): 213-218
13. Yan W, Kang MS, Ma B, Woods S, Cornelius PL. GGE biplot vs. AMMI analysis of genotype-by-environment data. Crop Science. 2007;47:641-653
14. Gauch HG, Piepho HP, Annicchiarico P. Statistical analysis of yield trials by AMMI and GGE: Further considerations. Crop Science. 2008;48:866-889
15. Comstock RE, Moll RH. Genotype-environment interactions. Symposium on statistical genetics and plant breeding. National Academy of Sciences. 1963;169-196
16. Patil AS, Nandanwar HR, Punewar AA, Shah KP. Stability for yield and its component traits in groundnut (*Arachis hypogaea* L*.).* Int. j. bio-resour. stress manag.2014;5(2):240-245
17. Gauch HG, Zobel RW. Predictive and postdictive success of statistical analyses of yield trials. Theor. Appl. Genet., 1988; 76(1):1-10.
18. Gauch HJ. Statistical analysis of regional yield trials: AMMI analysis of factorial designs. Elsevier Science Publishers; 1992.
19. Umma K, Jamil H, Ismail H, Niaz FR. Stability for BRRI developed promising hybrid rice for yield and it's related traits. Journal of Applied Science and Agriculture. 2014;9:56-62
20. Premika BP, Venkataravana P, Sowjanya BA. and Priyadarshini S.K. Adaptability Studies in Advanced Breeding Lines of Groundnut (*Arachis hypogea* L.). Biological Forum – An International Journal 2023;15 (8a):456-468.
21. Purchase JL, Hatting H, Vandenventer CS. Genotype by environments interaction of wheat in South Africa: stability analysis of

yield performance. South Africa Journal of Plant Science, 2000;17:101-107

22. Amare, Tamado T. Genotype by environment interaction and stability of pod yield of elite breeding lines of groundnut (*Arachis hypogaea* L.) in Eastern Ethiopia. Star Journal, 2014;3:43-46
23. Tulole LB, Erasto S, Theofora M, Leah M. On-farm evaluation of promising groundnut varieties for adaptation and adoption in Tanzania. African Journal of Agricultural Research. 2008;vol. 3, pp. 531-536
24. Yayis R, Agdew B, Yasin G. Genotype × environment interaction and additive main effect and multiplicative interaction analysis for field pea yield stability in SNNPR state, Ethiopia. International Journal of Sustainable Agricultural Research. 2014;1:28-38
25. Akande SR, Taiwo LB, Adegbite AA, Owolade OF. Genotype x environment interaction for soybean grain yield and other reproductive characters in the forest and savanna agro-ecologies of South-west Nigeria. African Journal of Plant Science. 2009;3:127-132
26. Gauch G, Zobel RW. AMMI analysis of yield trials. In: Genotype by environment interaction (Kang, M. and Gauch, H. eds.). New York.: Boca Raton. CRC Press. 1996; 85-122
27. Yan W, Hunt LA, Sheng Q, Szlavnics Z. Cultivar evaluation and mega environment investigation based on the GGE biplot. *Crop* Science. 2000;40(3):597-605
28. Ajay BC, Bera SK, Singh AL, Kumar N, Gangadhar K, Kona P. Evaluation of genotype × environment interaction and yield stability analysis in peanut under phosphorus stress condition using stability parameters of AMMI model. Agric. Res. 2020;9(4):477-486
29. Araya-Alman, M., Olivares, B., Acevedo-Opazo, C. et al. Relationship between soil properties and banana productivity in the two main cultivation areas in Venezuela. J SoilSciPlantNutr. 2020;20(3):2512-2524. Available:https://doi.org/10.1007/s42729-020-00317-8
30. Campos BO. Banana production in Venezuela: Novel solutions to productivity and plant health. Springer Nature; 2023.
31. Hernandez R, Olivares B, Arias A, Molina JC, Pereira Y. Eco-territorial adaptability of tomato crops for sustainable agricultural production in Carabobo, Venezuela. Idesia.2020;38(2):95-102. Available:http://dx.doi.org/10.4067/S071834292020000200095
32. Hernández R, Olivares B, Arias A, Molina JC, Pereira Y. Agroclimatic zoning of corn crop for sustainable agricultural production in Carabobo, Venezuela. Revista Universitaria de Geografía. 2018ª;27(2): 139-159.
33. Hernández R, Olivares B, Arias A, Molina JC, Pereira Y. Identification of potential agroclimatic zones for the production of onion (*Allium cepa* L.) in Carabobo, Venezuela. Journal of the Selva Andina Biosphere. 2018b;6(2):70-82. Available:http://www.scielo.org.bo/pdf/jsab/v6n2/v6n2_a03.pdf
34. Calero J, Olivares BO, Rey JC, Lobo D, Landa BB, Gómez JA. Correlation of banana productivity levels and soil morphological properties using regularized optimal scaling regression. Catena. 2022; 208:105718. Available:https://doi.org/10.1016/j.catena.2021.105718
35. Olivares BO, Vega A, Calderón MAR, Rey JC, Lobo D, Gómez JA, Landa BB. Identification of Soil Properties Associated with the Incidence of Banana Wilt Using Supervised Methods. Plants. 2070;11. Available:https://doi.org/10.3390/plants11152070
36. Rey JC, Olivares BO, Perichi G, Lobo D. Relationship of Microbial Activity with Soil Properties in Banana Plantations in Venezuela. Sustainability. 2022;14:13531. Available:https://doi.org/10.3390/su142013531
37. Olivares B. Machine learning and the new sustainable agriculture: Applications in banana production systems of Venezuela. Agricultural Research Updates. 2022;42: 133 - 157.
38. Rodríguez-Yzquierdo G, Olivares BO, Silva-Escobar O, González-Ulloa A, Soto-Suarez M, Betancourt-Vásquez M.. Mapping of the Susceptibility of Colombian Musaceae Lands to a Deadly Disease: *Fusarium oxysporum* f. sp. cubense Tropical Race 4. Horticulturae. 2023;9: 757. Available:https://doi.org/10.3390/horticulturae9070757
39. Rodríguez-Yzquierdo G, Olivares BO, González-Ulloa A, León-Pacheco R, Gómez-Correa JC, Yacomelo-Hernández M, Carrascal-Pérez F, Florez-Cordero E, Soto-Suárez M, Dita M, et al. Soil

Predisposing Factors to *Fusarium oxysporum f*.sp Cubense Tropical Race 4 on Banana Crops of La Guajira, Colombia. Agronomy. 2023;13:2588. Available:https://doi.org/10.3390/agronomy13102588

40. Hernández R, Olivares B. Application of multivariate techniques in the agricultural land's aptitude in Carabobo, Venezuela. Tropical and Subtropical Agroecosystems. 2020;23(2):1-12. Available:https://n9.cl/zeedh
41. Hernández R, Olivare, B. Ecoterritorial sectorization for the sustainable agricultural production of potato (*Solanum tuberosum* L.) in Carabobo, Venezuela. Agricultural Science and Technology. 2019;20(2):339-354.
42. Hernández R, Olivares B, Coelho R, Molina JC, Pereira Y. Analysis of climate types: Main strategies for sustainable decisions in agricultural areas of Carabobo, Venezuela. *Scientia agropecuaria*. 2018c;9(3): 359 – 369. DOI: 10.17268/sci.agropecu.2018.03.07
43. Lobo D, Olivares B, Cortez A, Rodríguez MF. y Rey JC. Socio-economic characteristics and methods of agricultural production of indigenous community Kashaama, Anzoategui, Venezuela. Rev. Fac. Agron. (LUZ). 2017;34(2):187-215.
44. López M, Olivares B. Normalized Difference Vegetation Index (NDVI) applied to the agricultural indigenous territory of Kashaama, Venezuela. UNED Research Journal. 2019;11(2):112-121. Available:https://doi.org/10.22458/urj.v11i2.2299
45. López-Beltrán M, Olivares B, Lobo-Luján D. Changes in land use and vegetation in the agrarian community Kashaama, Anzoátegui, Venezuela: 2001-2013. Revista Geográfica De América Central. 2019;2(63):269-291. DOI: https://doi.org/10.15359/rgac.63-2.10
46. Montenegro E, Pitti J, Olivares B. Adaptation to climate change in indigenous food systems of the Teribe in Panama: A training based on CRISTAL 2.0. Luna Azul. 2021;51(2):182 - 197. Available:https://n9.cl/qwvwz
47. Montenegro E, Pitti J, Olivares B. Identificación de los principales cultivos de subsistencia del Teribe: Un estudio de caso basado en técnicas multivariadas. Idesia. 2021;39(3):83-94. Available:http://dx.doi.org/10.4067/S0718-34292021000300083
48. Rodríguez M, Olivares B, Cortez A, Parra R, Lobo D. y Rey JC. Análisis temporal de la sequía meteorológica en localidades semiáridas de Venezuela. UGCiencia Disponible en. 2016b;22(1):11-24. DOI:https://doi.org/10.18634/ugcj.22v.1i.481
49. Rodríguez MF, Olivares B, Cortez A, Rey JC. y Lobo D. Desarrollo del sistema de información de la red de pluviómetros alternativos en medios rurales. Caso: Anzoátegui, Venezuela. Acta Universitaria. 2016a;26(4):65-76. DOI: 10.15174/au.2016.961
50. Rodríguez MF, Cortez A, Olivares B, Rey JC, Parra Ry Lobo D. Análisis espacio temporal de la precipitación del estado Anzoátegui y sus alrededores. Agronomía Tropical. 2013;63(1-2): 57-65. Available:https://n9.cl/14iow
51. Cortez A, Olivares B, Parra R, Lobo D, Rodríguez MF. y Rey JC. Description of meteorological drought events in localities of the central mountain range, Venezuela. Ciencia, Ingenieríasy Aplicaciones. 2018; I(1):22-44.
52. Olivares B, Rodríguez MF, Cortez A, Rey JC, Lobo D. Physical natural characterization of indigenous community kashaama for sustainable land management. Acta Nova. 2015;7(2):143-164. Available:https://n9.cl/6gezo
53. Olivares B, Zingaretti ML, Demey Zambrano JA, Demey JR. Typification of agricultural production systems and the perception of climatic variability in Anzoátegui, Venezuela. Revista FAVE – Ciencias Agrarias. 2016;15(2):39-50. Available:https://doi.org/10.14409/fa.v15i2.6587

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/115554