

## Stability assessment of Groundnut ABLs by AMMI and GGE biplot analysis for yield performance under multi-environmental trials (METs)

### Abstract

Eight groundnut ABLs along with two checks were examined across three environments in Karnataka during 2020-2021 in *Kharif* and *Rabi* ~~season-seasons~~ to evaluate the performance of groundnut ABLs for kernel yield and their stability across environments. The lines were arranged in a randomized complete block design (RCBD) with three replications. Pooled analysis of variance for kernel yield showed significant ( $p \leq 0.01$ ) differences among the genotypes, environments, and the genotype by environment interaction (G×E). Additive main effect and multiplicative interactions (AMMI) analysis showed highly significant ( $p \leq 0.01$ ) differences for varieties, environments, and their interaction on kernel yield. Similarly, the first and the second interaction principal component axis (IPCA1 and IPCA 2) were highly significant ( $p \leq 0.01$ ) and explained 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% variations, respectively. This indicates the existence of considerable amounts of differential response among the ABLs to changes in growing environments and the differential discriminating ability of the test environments. Based on ASV and SI, for kernel yield  $\text{plant}^{-1}$ , ABLs T65, T77, T81 and T82 were found to be stable across all ~~the~~ three environments. The stable lines identified can be used as parents in developing segregating ~~population~~ populations. AMMI model and GGE biplots were helpful methodologies and complemented each other to evaluate the adaptability and stability of groundnut genotypes in diverse environments.

**Keywords:** Groundnut, ABLs, ASV, SI, AMMI, GGE biplot, Stability analysis.

### Introduction

Groundnut (*Arachis hypogaea* L.) is a major legume crop, [that](#) ranks 12th among the food crops of the world (1). Groundnut is one of the chief [source-sources](#) of vegetable oil in the world and serves as a [store-housestorehouse](#) of protein, minerals, vitamins, and carbohydrates. The cultivated groundnut is also known as peanut. The kernel of groundnut contains 46-52% oil, 25-30% crude protein, and 12-18% carbohydrates (2). Moreover, [groundnut-groundnuts](#) can be employed in crop rotation to enhance soil fertility through nitrogen fixation through their root nodules, as it is a legume (3). According to Singh and Singh (4), groundnut is commonly produced in semiarid countries with moist weather including Africa, America, and Asia. Groundnut is cultivated worldwide on 27.9 million hectares, yielding 47 million tonnes with an average productivity of 1685 kg/ha. India contributes 22% to global production, cultivating it in 6.014 million hectares, yielding 10.02 million tonnes (1703 kg/ha). Groundnut productivity in Karnataka is currently at 720 kg/ha, which is less than half of the national average of 999 kg per ha (5). Despite [the](#) high-yielding varieties available, TMV-2, developed 82 years ago, is still preferred and in cultivation.

Despite [the](#) high-yielding varieties available, TMV-2, developed 82 years ago, is still preferred. However, the government has denotified TMV-2, leading to its unavailability in [the](#) official seed supply. Narrowing the productivity gap requires [the](#) development of new varieties with higher yield potential while maintaining TMV-2's desirable pod and kernel characteristics. Slow adoption of improved varieties and their inconsistent performance in different conditions contribute to the low productivity of groundnuts nationwide. Groundnut is affected by genotype by environment interactions (GEI) (6). The complex interplay of various traits can have positive or negative connections with yield and other characteristics.

[In order to](#) achieve the goal of increased production by increasing the yield potential of genotypes need to adapt to environmental changes temporally and geographically. Genotype-by-environment interaction (GEI) is reflected in inconsistent crop yields across environments. Unpredictable rainfall, variations in farm inputs in the resource-poor farming community, [crop-diseasescrop diseases](#), and the inherent potential of genotypes are among the major factors for low and variable crop yields. Fortunately, the possibility exists to find or develop stable and high-yielding genotypes (fit genotypes) for the mega-environments (7). Additive main effect and

multiplicative interaction (AMMI) model (8; 9), and genotype plus genotype-by-environment (GGE) biplot (10; 11; 12) are frequently applied procedures for genotype, environment, and genotype-by-environment analysis based on crop attributes. AMMI separates the genotype and environment main effects and the GEI effects (13) and provides much insight into GEI (8). The GGE biplot emphasis on genotype and genotype-by-environment interaction becomes efficient in the mega-environment analysis and genotype evaluation which includes attribute-based [genotypes-genotype](#) ranking (12).

Stability analysis identifies genotypes that can perform consistently across diverse environments (14). The interaction between genotype and environment is crucial for breeders to improve breeding programs and mitigate negative agroclimatic effects. However, the impact of environmental conditions on quantitative traits in groundnut genotypes has received limited attention. Stable genotypes adjust their phenotypic responses to maintain consistency despite environmental fluctuations (15). The present study was conducted to evaluate TMV-2 type groundnut advanced breeding lines across different locations and to identify suitable adaptable ABLs.

## Materials and Methods

Eight groundnut genotypes and two checks (Table 1) were evaluated ~~at~~ [in](#) three environments in 2021, *Kharif* and *Rabi* ~~season~~ [seasons](#). Description of groundnut varieties used as parents in the crosses and checks were given in ~~the~~ [table 2](#) The latitudes, longitudes, average temperature, and the total annual ~~rain~~ [rainfall](#) for each of the environments are presented in ~~table~~ [Table 3](#). The sowing was taken up in *Kharif* and *Rabi* ~~season~~ [seasons](#) in all ~~the~~ [three](#) locations and the design was [a](#) randomized complete block with three replications with a spacing of 30 cm and 10 cm between the rows and plants respectively. The method of sowing followed was dibbling. Necessary ~~crop~~ [crop](#) management practices were adopted except for the spray of fungicides during the crop growth period in all environments. Kernel yield and other ~~yield~~ [yield-related](#) traits were recorded.

**Table 1: List of genotypes and checks.**

Sl. No.	Genotypes	Pedigree	Sl. No.	Checks
1.	T77	TMV-2×ICGV-91114	1.	TMV-2
2.	T89	TMV-2×ICGV-91114	2.	Kadiri 6
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		

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

Varieties	Year of release	Source	Parentage	Special features
TMV-2	1940	TNAU, Coimbatore	Selection from Gudiyathambur	Old variety, wider adaptability, desirable pod, and kernel shape & size, kernel small with salmon <del>colour</del> 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 percent and SMK percent.

Kadiri6	2003	ARS,Kadiri,A nantapur	JL-24×AH-316	Early maturing and highyielding.
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**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 <sup>0</sup> 08"N	77 <sup>0</sup> 34" E	924m
AgricultureResearchStation,Balajigapa de	E2	13 <sup>0</sup> 43"N	77 <sup>0</sup> 79"E	915m
OrganicFarmingResearchStation,Mand ya	E3	12 <sup>0</sup> 37"N	76 <sup>0</sup> 66"E	678m

To detect (ABLs + parents) × season interaction (GSI) effects, data recorded from three seasons was subjected to Additive main effects and multiplicative interaction (AMMI) model (16). The additive main effects of ABLs + parents and seasons were fitted by univariate ANOVA (Table 5) followed by fitting (ABLs + parents) × season interaction by interaction principal component (IPC) analysis based on AMMI model (16). The following model was used to estimate main effects of ABLs and seasons and (ABLs + parents) × season interaction effects.

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

**Additive parameters:**  $\mu$  is the grand mean;  $g_i$  is the deviation of genotype  $g$  from the grand mean,  $e_j$  is the deviation of the environment  $e$ ;

**Multiplicative parameters:**  $\lambda_n$  is the singular value for IPCA,  $\gamma_{gn}$  is the genotype eigenvector for axis  $n$ , and  $\delta_{en}$  is the environment eigenvector;  $\varepsilon_{ger}$  is error term and  $\rho_{ge}$  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 [17 and 18].

AMMI stability value of the  $i^{\text{th}}$  genotype (ASV) was calculated for each genotype and each environment according to the relative contribution of IPCA1 to IPCA2 to the interaction SS

as follows [19]:

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

Where, SSIPC 1 and SSIPC 2 are the sum of squares (SS) attributable to the first two IPCs. Conceptually, ASV is the distance from zero in a two-dimensional scatter diagram of IPC 1 vs. IPC 2 scores (19). Since the IPC 1 score generally contributes proportionately more to GSI, it is weighted by the proportional difference between IPC 1 and IPC 2 scores in order to compensate for the relative contribution of IPC 1 and IPC 2 scores to total GSI sum of squares. Lower magnitude of estimates of ASV indicates greater stability, while higher magnitude of ASV indicates lower stability of genotypes (19).

### 3. Result and Discussion

#### 3.1 Combined Analysis of Variance

Analysis of variance showed statistically significant differences ( $P < 0.01$ ) among varieties, environments and their interaction for kernel yield (Table 4). This indicated the presence of genetic variation among varieties and possibility to select high yielding and stable variety (s), the environments are variable and the differential response of groundnut varieties across environments. Similar result was reported for groundnut varieties (20 and 21).

**Table 4: Pooled ANOVA of groundnut ABLs evaluated across three locations for yield and its attributing traits during Rabi 2021-22**

Source of variation	Degrees of freedom	Plant height (cm)	Primary branches plant <sup>-1</sup>	Days to 50% flowering	Pods plant <sup>-1</sup>	Pod yield plant <sup>-1</sup> (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 <sup>-1</sup> (g)	Shelling percent	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 atP=0.01

### 3.2. Additive Main Effects and Multiple Interaction (AMMI) Model

Combined analysis of variance revealed highly significant ( $P \leq 0.01$ ) variations among environments, genotype  $\times$  environment interaction, IPCA-1, and IPCA-2 (Table 5). This result revealed that there was a differential yield performance among groundnut varieties across testing environments and the presence of a strong genotype by environment interaction. The GEI posed a significant effect on the kernel yield of groundnuts and on other yield attributing traits (Table 4). This also indicated the existence of a considerable amount of deferential response among the varieties to changes in growing environments and the differential discriminating ability of the test environments. Except days to 50% flowering, mean squares related to locational contexts were significant for all traits, illustrating the potential of the temporal environments to distinguish the ABLs under study. Significant mean squares due to ABLs indicated that there was that there was significant variation among the ABLs for each trait.

Similar results were reported by Yayiset al., (22) and Akandeet al., (23). Substantial A substantial percentage of G  $\times$  E interaction was explained by IPCA-1 (72.72%) followed by IPCA-2 (25.00%) and therefore used to plot a two-dimensional GGE biplot. Gauch and Zobel, (26) and Amare and Tamado (20) suggested the most accurate model for AMMI can be predicted by using the first two IPCA.

**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 <sup>-1</sup> (g) (Kharif)		Kernel yield plant <sup>-1</sup> (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 $\times$ 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	0.04**	4.80
Error	48	0.003	0.61	0.81	43.72

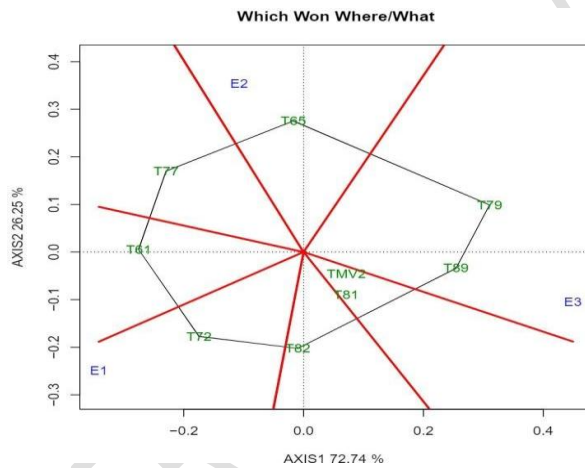
### 3.3 To identify specifically adaptable or widely adaptable TMV-

#### 2 type Groundnut Advanced Breeding Lines

#### GGE Biplot analysis of GEI patterns

The GGE bi-plot visual, which scatters ABLs according to their IPCs, can be used to qualitatively evaluate the stability and adaptation of ABLs over spatial settings. The conventional GGE bi-plot, often known as the SREG (sites regression) model, was proposed by Yan *et al.* (25). It consists of genotype (G) + genotype  $\times$  environment (GE) data. It is a multivariate analytical tool that clearly illustrates interactions among each ABL and each location environment.

According to graph during *Kharif* 2021 for Kernel yield plant<sup>-1</sup> was shown to T72 and T82 were the winning genotype in environment 1 (GKVK), T77, T65 and T61 in environment 2 (Mandya) and T89 found to be the winning genotype in environment 3 (Balajigapade) (Fig 1).



**Fig. 1.** Polygon view of GGE bi-plot based on the symmetrical scaling for “which won which won-where” pattern of ABLs and locational environments for kernel yield plant<sup>-1</sup>(g) during *Kharif* 2021

During *Rabi* 2021, as per our graph for kernel yield plant<sup>-1</sup> 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 ~~was~~ were shown to be the winning genotype in environment 3 (Fig. 2).

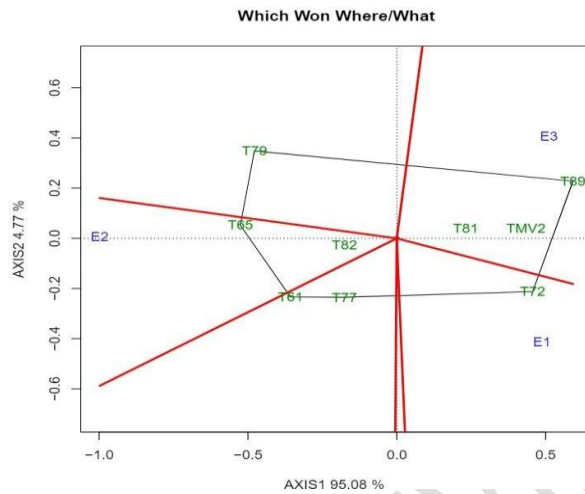


Fig. 2. Polygon view of GGE bi-plot based on the symmetrical scaling for “which won which where” pattern of ABLs and locational environments for kernel yield plant<sup>-1</sup>(g) during Rabi 2021

### 3.4 AMMI model-based stability parameters AMMI Stability value (ASV)

ASV offers an unbiased evaluation of stability, which aids in the identification of ABLs that are consistent across the three seasonal conditions. ASV is the distance from zero in a two-dimensional scatter-gram 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 of Kharif 2021 and Rabi 2021 is shown in table 6. The stable genotypes for the season 2021 Kharif and 2021 Rabi are represented in (Table 7).

Similarly, Ajay *et al* (26) carried out stability analysis in fifty two peanut genotypes for two years under two phosphorous levels. They used AMMI model to study Genotype x environment interaction (GEI).

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 <sup>-1</sup> (g) (Kharif)							Kernel yield plant <sup>-1</sup> (g) (Rabi)						
	ME AN	R Y	IPC A1	IPC A2	AS V	RA SV	SI	ME AN	R Y	IPC A1	IPC A2	AS V	RA SV	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 <sup>-1</sup>	T81, T82, T72	T82, T65, T79, TMV-2	T82
Days to 50% flowering	T81, T72, T61	T81, T72, T89	T81, T72
Pods plant <sup>-1</sup>	T65, T61, T72	T72, T82, T65, T61	T65, T61, T72
Pod yield plant <sup>-1</sup> (g)	T82, T72, T65	T82, T81, T65	T82, T65
Kernel yield plant <sup>-1</sup> (g)	T65, T77, T81, T82	T77, T81, T82, T65	T65, T77, T81, T82
Shelling percent	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

The candidate manuscript does not have a robust scientific discussion. I suggest the authors incorporate the suggested paragraphs. In this way, it would improve the scientific quality of the manuscript.

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 (Araya-Alman et al. 2020; Campos et al. 2023). 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

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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 (Hernandez et al. 2018a; 2018b; 2020).

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Soil quality plays a pivotal role in shaping crop performance and stability, as it directly influences nutrient availability (Calero et al. 2022), water retention (Olivares et al. 2022), and overall plant health (Rey et al. 2022; Olivares, 2022). 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 (Rodríguez-Yzquierdo et al. 2023a; 2023b). 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 (Hernandez and Olivares, 2020; Hernandez and Olivares, 2019).

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Furthermore, the influence of precipitation patterns and other environmental variables on groundnut performance underscores the need for climate-resilient crop varieties (Hernandez et al. 2018c; Lobo et al. 2017). As climate change continues to manifest through shifts in rainfall patterns (López and Olivares, 2019; López et al. 2019), temperature extremes, and unpredictable weather events (Montenegro et al. 2021a; 2021b), the development of genotypes capable of thriving under varying climatic conditions becomes imperative (Rodriguez et al. 2016a; 2016b). This study elucidates the differential responses of groundnut ABLs to precipitation regimes, highlighting the importance of incorporating genotype-specific adaptive traits in breeding programs (Rodriguez et al. 2013; Cortez et al. 2018). 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 (Olivares et al. 2015; Olivares et al. 2016).

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#### 4. Conclusion

G×E interaction study in multi-environment trials had been carried out by ~~well established~~well-established AMMI and biplot model. The simultaneous consideration of stability measures and yield would be more appropriate to recommend high-yielding stable groundnut ABLs. In the present study, the main advantages of AMMI and biplot ~~had~~

~~been~~ were combined to increase the reliability of ~~multi-locations~~ multi-location trials analysis. ABLs were subjected to a Pooled analysis of ~~variance~~ for variance for kernel yield showed significant ( $p \leq 0.01$ ) differences among the genotypes, environments, and the genotype by environment interaction (G×E), which indicated significant variability attributable to ABLs and their interaction with spatial environments for all the traits considered for the study. AMMI analysis was performed to detect and characterize GSI. Genotype + Genotype × environment (GGE) bi-plot ~~were~~ was also used to interpret GSI patterns of ABLs and ~~identify those~~ identify those with specific/wide adaptation. AMMI analysis showed highly significant ( $p \leq 0.01$ ) differences for varieties, environments, and their interaction on kernel yield. Similarly, the first and the second interaction principal component axis (IPCA1 and IPCA2) were highly significant ( $p \leq 0.01$ ) and explained 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% variations, respectively. This indicated the existence of considerable amounts of differential response among the ABLs to changes in growing environments and the differential discriminating ability of the test environments. AMMI Stability Value (ASV) and Stability ~~index~~ Index (SI) were estimated and were used to assess the relative stability of ABLs. Based on ASV and SI, for kernel yield plant<sup>-1</sup>, ABLs T65, T77, T81, and T82 were found to be stable across all the three ~~location~~ locations and in both ~~the~~ season. Stable lines will be checked for kernel yield potential in future years. The stable lines after validation can be released as a variety or can be used as parents in developing segregating ~~population~~ populations. AMMI model and GGE biplot were helpful methodologies and complemented each other to evaluate the adaptability and stability of groundnut genotypes in the diverse environments.

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