Stability assessment of Groundnut ABLs by AMMI and GGE biplot analysis for yield performanceundermulti-environmental trails (METs)

Abstract

Eight groundnut ABLsalong with two checks were examined across three environments in Karnataka during 2020-2021in *Kharif* and *Rabi* season to evaluate the performance of groundnut ABLs for kernel yieldand their stability across environments. The lines were arranged in 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 16.44, 81.87 and 1.68% variations, respectively. This indicates the existence of considerable amounts of deferential response among the ABLs to changes in growing environments and the deferential discriminating ability of the test environments. Based on ASV and SI, for kernel yield plant^{-1}, ABLs T65, T77, T81 and T82were found to be stable across all the three environments. The stable lines identified can be used as parentsin developing segregating population. 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 (*Arachishypogaea* L.) is a major legume crop, ranks 12th among the food crops of the world (1).Groundnut is one of the chief source of vegetable oil in the world and serves as a store house 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 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 720kg tonnes per hectare, which is less than half of the national average of 999 kg per ha (5). Despite high-yielding varieties available, TMV-2, developed 82 years ago, is still preferred and in cultivation.

Despite 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 official seed supply. Narrowing the productivity gap requires 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 reflectedin inconsistent crop yields across environments. Unpredictable rainfall, variations in farm inputs in the resource-poor farming community, crop-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 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 three environments in 2021,*Kharif*and *Rabi*season. 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 fall for each of the environments are presented in table 3**.** The sowing was taken up in *Kharif* and *Rabi* season in all the three locations and the design was 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 cop 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.

Sl. No.	Checks

Table 1: List of genotypes and 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

1.	TMV-2
2.	Kadiri 6

Table2:Salientfeaturesofgroundnutvarietiesusedasparentsinthecrossesandchecks

Varieties	Yearofrelease	Source	Parentage	Specialfeatures
TMV-2	1940	TNAU, Coimbatore	Selectionfrom Gudiyathambunch	Old variety, wider adaptability,desirable pod and kernel shape&size,kernelssmallwithsalmon colourtesta, susceptibletodroughtand foliardiseases.
ICGV-91114	2007	ICRISAT, Hyderabad	ICGV-86055 ×ICGV-86353 Bulk pedigreemethod	Earlymaturing,moderateyielding,boldseeded,tolerantto drought & LLS, good seedsize,betterdigestibilityandpalatabilityof haulms
ICGV-00350	2012	ICRISAT, Hyderabad	ICGV-87290 ×ICGV-87846 Bulk pedigreemethod	High yield and high oil content,resistanttoLLS,rustandtoleranttodroughtandstemrot.
TG-69	2011	BARC, Trombay, Mumbai	Mutantvariety	Highharvestingindex,shelling *percent*andSMK*percent.*
Kadiri6	2003	ARS,Kadiri,Anantapur	JL-24×AH-316	Early maturing and highyielding.

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
AgricultureResearchStation,Balajigapade	E2	13^{0}43”N	77^{0}79”E	915m
OrganicFarmingResearchStation,Mandya	E3	12^{0}37”N	76^{0}66”E	678m

To detect (ABLs + parents) × season interaction (GSI) effects, data recorded fromthreeseasonswassubjectedtoAdditivemaineffectsandmultiplicativeinteraction(AMMI) model (16). The additive main effects of ABLs + parentsand seasons were fitted by univariate ANOVA (Table 5) followed by fitting (ABLs +parents) × season interaction by interaction principal component (IPC) analysis based onAMMI model (16). The following model was used to estimate maineffectsof ABLs andseasons 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: μ is the grand mean; αg is the deviation of genotype g from the grand mean, βe is the deviation of the environment e;

Multiplicative parameters: 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 [17 and 18].

AMMI stability value of the i^{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]:

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

Where, SSIPC 1 and SSIPC 2 are sum of squares (SS) attributable to first twoIPCs. Conceptually, ASV is the distance from zero in a two-dimensional scatter diagramof IPC 1 *vs.* IPC 2 scores (19). Since the IPC 1 score generallycontributes proportionately more to GSI, it is weighted by the proportional differencebetween IPC 1 and IPC 2 scores in order to compensate for the relative contribution ofIPC 1 and IPC 2 scores to total GSI sum of squares. Lower magnitude of estimates ofASV indicates greater stability, while higher magnitude of ASV indicates lower stabilityofgenotypes (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).

Table4:PooledANOVA ofgroundnutABLsevaluatedacrossthree locationsforyieldanditsattributingtraitsduring*Rabi*2021-22

Sourceofvariation	Degreesoffreedom	Plantheight(cm)	Primary branchesplant^{-1}	Days to 50%flowering	Pods plant^{-1}	Podyieldplant^{-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**
Pooledерror	48	8.08	0.63	6.50	2.94	3.11

Sourceofvariation	Degreesoffreedom	Kernelyield plant^{-1}(g)	Shellingpercent	Soundmaturekernel	Testweight(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**
Poolederror	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≤0.01) variations among environments, genotype × 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 strong genotype by environment interaction. The GEI posed significant effect on the kernel yield of groundnut 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. With theexception of days to 50% flowering, mean squares related to locational contexts weresignificantforalltraits,illustratingthepotentialofthetemporalenvironmentstodistinguish the ABLs under study. Significant mean squares due to ABLs indicated thattherewas significant variation among theABLs foreach trait.

Similar results were reported by Yayis*et al.*, (22) and Akande*et al.*, (23). Substantial percentage of G x 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.

Table5:AMMIANOVAofgroundnutABLsevaluatedacrossthreelocationsforyieldanditsattributingtraitsduring*Kharif* and *Rabi* 2021-22

Sourceofvariation	Degrees offreedom	Kernelyield plant^{-1}(g) (*Kharif*)		Kernelyield plant^{-1}(g) (*Rabi*)	
		Mean sum ofsquares	%variation	Mean sum ofsquares	%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

3.3 ToidentifyspecificallyadaptableorwidelyadaptableTMV-2typeGroundnutAdvancedBreeding Lines

GGEBiplotanalysisofGEIpatterns

The GGE bi-plot visual, which scatters ABLs according to their IPCs, can be usedto qualitatively evaluate the stability and adaptation of ABLs over spatial settings.

TheconventionalGGEbi-plot,oftenknownastheSREG(sitesregression)model,wasproposed by Yan *et al.* (25).It consists of genotype (G) +genotype × environment(GE) data. It is a multivariate analytical tool that clearly illustrates interactions amongeachABLand each location environment.

According to graph during *Kharif* 2021 for Kernel yield plant^{-1}was shown toT72 and T82 were the winning genotype in environment 1 (GKVK), T77, T65 and T61 inenvironment 2 (Mandya) and T89 found to be the winning genotype in environment 3(Balajigapade)(Fig 1).

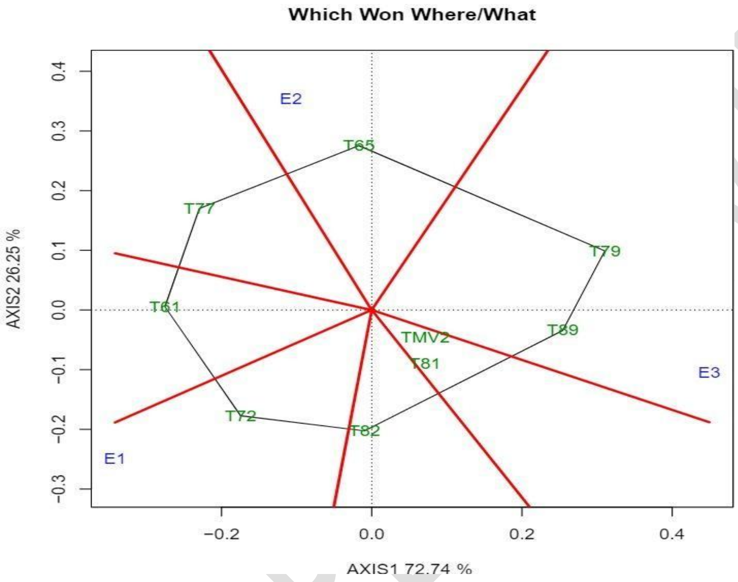

Fig. 1.Polygon view of GGE bi-plot based on the symmetrical scaling for "whichwon-where" pattern of ABLs and locational environments for kernel yield plant^{-1}(g)during *Kharif* 2021

During *Rabi* 2021, as per our graph for kernelyieldplant^{-1} T72wasfoundtobethewinninggenotypeinenvironment 1 (GKVK), T65 and T79 were discovered to be the winning genotype inenvironment 2 (Mandya), and T89 was shown to be the winning genotype in environment3 (Fig. 2).

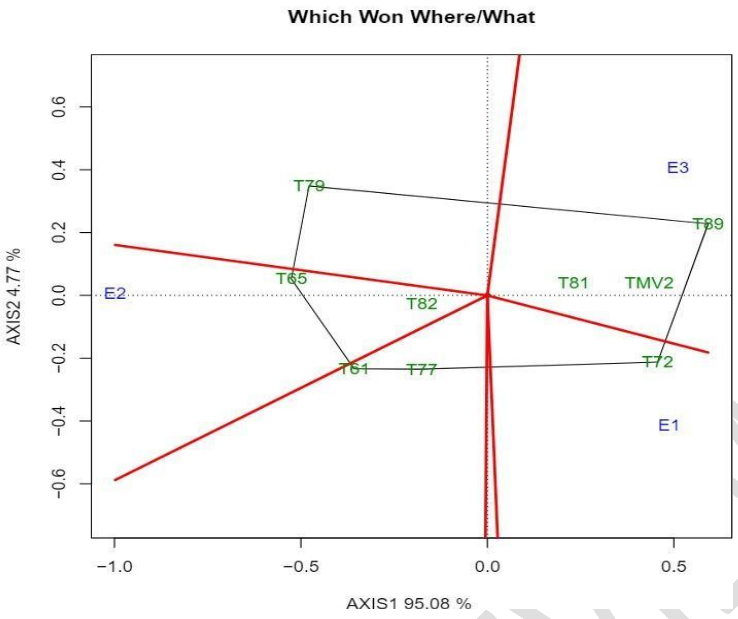

Fig. 2.Polygon view of GGE bi-plot based on the symmetrical scaling for "whichwon-where" pattern of ABLs and locational environments for kernel yield plant^{-1}(g)during *Rabi* 2021

3.4 AMMI model-based stability parameters

AMMIStability value(ASV)

ASV offers an unbiased evaluation of stability, which aids in the identification ofABLs that are consistent across the three seasonal conditions. ASV is the distance fromzero in a two-dimensional scatter-gram of IPCA 1 (InteractionPrincipal ComponentAnalysis Axis 1) scores against IPCA 2 (Interaction Principal Component Analysis Axis2) scores. TheIPC scores and ASV values of*Kharif* 2021 and *Rabi* 2021 is shown intable 6. The stable genotypes for the season 2021 *Kharif* and2021*Rabi* arepresented in (Table 7).

Similarly, Ajay *et al* (26) carried out stability analysis in fifty twopeanutgenotypes for two years under two phosphorous levels. They used AMMI model to studyGenotypex environmentinteraction (GEI).

Table6:EstimatesofASV and SItoassessstability ofgroundnutABLsacrossthreelocationsduring*Kharif* and *Rabi*2021-22

ABLs	Kernelyieldplant^{-1}(g)(*Kharif*)							Kernelyield 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

Table7:StableandadaptablegroundnutABLsacrossthreelocationsidentifiedbasedonStabilityIndexfordifferenttraitsduring*Kharif* and*Rabi*2021.

Traits	**AdaptableABLsduring*Kharif* 2021**	**AdaptableABLsduring*Rabi*2021**	**StableABLs**
Plantheight(cm)	T81, T82,T77	T61, T81, T82	T81, T82
Primarybranchesplant^{-1}	T81, T82, T72	T82,T65,T79,TMV-2	T82
Daysto 50% flowering	T81, T72, T61	T81, T72, T89	T81, T72
Podsplant^{-1}	T65, T61, T72	T72,T82, T65,T61	T65, T61, T72
Podyieldplant^{-1} (g)	T82, T72, T65	T82, T81, T65	T82, T65
Kernelyieldplant^{-1} (g)	T65,T77, T81, T82	T77,T81,T82, T65	T65,T77, T81, T82
Shellingpercent	T77,T65,TMV-2,T61	T77,T65,TMV-2,T61	T77,T65,TMV-2,T61
Soundmaturekernel	T89,T77,T82,TMV-2	T77,T61, T81, T89	T89, T77
Testweight(g)	T82, T72, T65	T81,T82, T79, T65	T82, T65

4. Conclusion

G×E interaction study in multi-environment trials had been carried out by well established AMMI and biplotmodel. 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 combined to increase the reliability of multi-locations trials analysis. ABLs were subjected to Pooled analysis of variancefor 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 andtheirinteraction withspatial environments forall the traitsconsidered forthestudy. AMMI analysis was performed to detect and characterize GSI. Genotype + Genotype ×environment (GGE) bi-plot were also used to interpret GSI patterns of ABLs and identifythose 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 16.44, 81.87 and 1.68% variations, respectively. This indicated the existence of considerable amounts of deferential response among the ABLs to changes in growing environments and the deferential 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.Based on ASV and SI, for kernel yield plant^{-1}, ABLs T65, T77, T81 and T82were found to be stable across all the three location and in both the season.Stablelines willbechecked forkernel yield potentialin futureyears. Thestablelinesaftervalidation canbe releasedasavarietyor canbeusedas parents indevelopingsegregating population. 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.

Reference

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. 2022. Genotype by environment interaction on tropical maize hybrids under normal irrigation and waterlogging conditions. Frontiers in Sustainable Food Systems. **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;Jul;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;vol. 9, pp. 56-62

20. 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;vol. 17, pp. 101-107

21. Amare, Tamado T. Genotype by environment interaction and stability of pod yield of elite breeding lines of groundnut (*Arachis hypogaea* L.) in Eastern Ethiopia. StarJournal, 2014;vol. 3, pp. 43-46

22. 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

23. 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. InternationalJournal of Sustainable Agricultural Research, 2014;vol.1, pp. 28-38

24. 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;vol. 3, pp. 127-132

25. 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; pp. 85-122

26. 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

27. Ajay BC, Bera SK, Singh AL, Kumar N, Gangadhar K, Kona P. 2020, 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