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ASSESSING YIELD AND GENOTYPE X ENVIRONMENT INTERACTION IN PEANUT (*ARACHIS HYPOGAEA*) FOR DEVELOPING CLIMATE-READY CULTIVARS

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Abstract

Peanut or groundnut (*Arachis hypogaea*) is one of the major cash crops in the arid parts of Pakistan. Moreover, the country's changing climatic conditions are hampering its production due to perpetual droughts, rising temperatures and unpredictable precipitation. Therefore, it is imperative to develop climate-adaptive stable groundnut cultivars which can perform across different agro-ecologies of the country. In the present experiment, the yield stability of seven advanced groundnut lines across six locations was examined during two Kharif seasons of the year 2018-19. The yield data were subjected to analysis of variance, stability indices and GGE biplot to determine the pattern of variation across locations. The ground nut yield across six experimental sites ranged from 1180 to 4065 with an average of 2433 kg/ha. The highest groundnut yield was recorded (4522 kg/ha) in genotype BARI--2011 at Umerkot. Whereas the genotype ICG-11855 had the minimum yield average across different locations. Location-wise, the highest average was recorded in Umerkot followed by Attock and NARC Islamabad. Genotypes exhibited significant variation for yield and stability attributes which demonstrated the potential of selection to identify zone-specific cultivars. The analysis of variance showed that most of the variation was contributed by the environment. Strong genotype x environment interaction was observed as per GGE biplot analysis. Conclusively, the analyses revealed 13CG003, 11AK011 and 10AK003 are potential candidates for approval as they exhibited stable and better yield across the locations. It is recommended that further evaluation of breeding materials should be carried out in all the agro-ecological zones of the country to determine the extent of GxE interaction as well as identify stable genotypes for the country.

Key words: Yield; Stability analysis; Genotype x environment; GGE biplot.

Introduction

Peanut or groundnut (*Arachis hypogaea*) is an important annual oilseed legume crop having good quality edible oil (40-50%) and a sufficient amount of protein contents (25%). It is cultivated in warm tropical, sub-tropical regions worldwide. The cultivation of groundnut mainly on marginal land in rain-fed regions (Nawaz *et al*., 2009) and unpredictable environmental stresses are the two major reasons for the reduction of groundnut yield and productivity in Pakistan (Mothilal *et al*., 2010).

To increase food production, enhance crop resilience, boost nutritional value, and advance sustainable agriculture, groundnut cultivars must be developed (Rehman *et al*., 2020; Ulian *et al*., 2020). It is crucial for agricultural researchers and farmers alike since it promotes food security, economic growth, and environmental sustainability (Tabe-Ojong *et al*., 2023; Khattak *et al*., 2020). Weather patterns are changing as a result of climate change, which has an effect on crop growth. For a reliable food supply, groundnut varieties that are more tolerant to heat, drought, and other climatic stresses must be developed (Olanrewaju *et al*., 2022). Higher yield potential is frequently developed into improved groundnut types. As a result, farmers can increase their production by growing more ground nuts on a given amount of land. This is essential for both economic stability and food security, particularly in areas where ground nuts are a major crop (Aragie *et al*., 2023; Ulian *et al*., 2020).

Farmers can also lower their risk of crop failure by creating groundnut varieties with predictable growth and yield patterns (Tabe-Ojong *et al*., 2023). As a result, producers may better control risk and guarantee a steady supply of food by using varieties that mature at different timings of the year or have various resistance profiles (Purwadi *et al*., 2023; Rana *et al*., 2023). In general, groundnut variety creation is a complex process with wide-ranging effects on food security, nutrition, revenue generation, and environmental sustainability. It is essential for tackling the complex issues facing our global food system and for enhancing the standard of living for millions of smallholder farmers worldwide (Siankwilimba *et al*., 2023).

Stable ground nut cultivars mature uniformly throughout the field, which facilitates harvesting and reduces the likelihood of crop losses brought on by uneven maturation (Shi *et al*., 2023). This constancy in maturity supports efficient agricultural operation planning and management. Stable groundnut cultivars maintain their quality traits, such as kernel size, shape, and oil content, across time (Yang *et al*., 2023). These characteristics are crucial for processing industries and sectors that have rigorous quality requirements. The ability of a variety to consistently produce comparable yields over a variety of seasons and settings is another definition of stability (Yu *et al*., 2023; Khattak *et al*., 2020). Low output variability varieties are viewed as steady and reliable by farmers. In a variety of locations with varying temperatures and precipitation levels, stable groundnut cultivars can flourish (Esan *et al*., 2023).

Due to unpredictable climate, adaptation and stability of groundnut remains one of the big breeding challenges to tackle. Groundnut breeders are focusing on developing biotic and abiotic stress-resistant and quality-enriched varieties of groundnut with stable performance as their main objectives (Tabe-Ojong *et al*., 2023; Begum *et al*., 2022; Ulian *et al*., 2020). Identification of groundnut genotypes displaying adaptability and performing stably for yield under different ecological zones is achieved by concentrating yield contributing traits and genetic attributes enabling crop to crop with different environmental stresses (Thaware, 2009). Yield remains one of the most environmentally controlled attributes, therefore, genotype alone cannot be a determinant of the stability across different ecological zones (Kebede & Getahun, 2017). As a quantitative trait, yield is dependent on a number of traits that may be swayed under fluctuating climatic factors. Rainfalls and intermittent drought conditions are major yield stability-disrupting abiotic factors in groundnut (Nawaz *et al*., 2009).

Drought-sensitive plants undergo yield reduction by changing several metabolic pathways, while tolerant plants have developed numerous molecular mechanisms such as excessive production of reactive oxygen species, calcium ions (Ca^{2+}), and signaling through hormones and epigenetic modifications (Mehmood *et al*., 2019). Screening for yield stability under drought stress and identification of those traits which have shown tolerance and support yield, such as root length, less transpiration rate and chlorophyll content could be proven best genetically important material. These features were observed in early maturing groundnut genotypes (Falke *et al*., 2019). Each year severe and variable behavior of environmental conditions causes a drastic reduction in yield.

In addition to soil moisture, nitrogen fixation and water use efficiency are also key factors to augment groundnut yield. Researchers have recognized genotypes for efficient use of water in different environments and plant-microbe symbiosis efficiency in two years evaluations at three locations whereas 17 peanut genotypes were verified for both the rainy and dry spells at 11 sites for two years (Frimpong *et al*., 2019). Likewise, nine genotypes were proved stable on the basis of the evaluation of genotype × environmental interaction (Suriharn *et al*., 2008).

It is suggested that certain agronomic characteristics contributing to yield under drought conditions should be targeted in breeding strategies. Breeding and selection through high throughput phenotyping and the use of molecular tools to understand the molecular mechanisms and responses under drought stress have been suggested to contribute towards the progress of achieving crop yield stability (Turner *et al*., 2014).

Groundnuts have also shown sensitivity to light and temperature (Ahmad *et al*., (2016). Salt and pH concentration in the soil affected the charge stability and kernel size in the groundnut (Hao *et al*., 2016). Different sowing dates in different ground nut growing areas also affected the pod yield. It had also been observed that number of pods, plant height and days to maturity differed significantly (Ahmed *et al*., 2016). Therefore, those varieties which remain stable on different sowing dates must be identified.

Although many agro-ecological system management and its diversification strategies have been suggested to manage yield in forthcoming changing climatic conditions (Gaudin *et al*., 2015) but breeding and evaluation of stable genotypes is possible by analyzing the behavior of different traits across different locations and also examining the role of G x E interactions (Chavan *et al*., 2009).

Stability analysis provides information that can help in the selection of genotypes depicting higher as well as stable yield performance across a wide range of agro-climatic zones, which is the basic stratagem achieved by decreasing genotype × environment collaboration (Agbaje & Oyekan, 2001; Oz, 2018; El-Harty *et al*., 2018; Jahanzaib *et al*., 2019). Moreover, stability and adaptability play key role in assessing the production efficiency of different groundnut plant varieties. A variety is considered favorable if it demonstrates strong grain production capabilities and the potential for enhancing production across diverse environmental conditions. Therefore, the assessment of adaptability and stability holds significant importance for enhancing crop yield. The GGE biplot method is a valuable tool for analyzing stability and adaptability within the context of Multi-Environment Trials (Olanrewaju *et al*., 2021).

This analysis of stability in yield performance complements the ranking of genotypes, helps to determine their adaptability and stability based on their agronomic performance across various test locations (Azrai *et al*., 2022). With stability analysis the Eberhart & Russell (1966) provided a definition of a stable genotype, characterizing it as one that exhibits a high average yield, a regression coefficient (bi) close to one, and minimal deviation from the regression line. Following this model, phenotypic stability of genotypes was assessed using three parameters: the average performance across various environments, the linear regression analysis, and the deviations from the regression function (Venkateswarlu *et al*., 2021).

It has been proposed that the stability of quality features regarding market preferences along with yield could have a chance of improvement with the approach of multiline peanut population along with their component lines (Norden *et al*., 1986). Nature and degree of genotype× environment interaction have to be identified to define the extent of stability adaptation in genotypes (Dolinassou *et al*., 2017).

Stable groundnut cultivars, characterized by uniform maturation throughout the field, facilitate efficient harvesting and minimize losses due to uneven maturation (Landoni *et al*., 2023). Consistency in maturity supports effective agricultural planning and management. Additionally, these cultivars maintain quality traits, such as kernel size, shape, and oil content, over time meeting the stringent quality requirements of processing industries and markets (Purwadi *et al*., 2023). Finally, stability in terms of yield consistency across seasons and locations reinforces the reliability and dependability of these varieties for farmers, allowing them to thrive in diverse agroecological settings with varying temperature and precipitation levels.

Material and Methods

Agro-climatic condition of the experimental sites: The current study was conducted during the kharif seasons of 2018 (sowing was done on 6th of April and harvested on 1st of October) and 2019 (sowing was done on 2nd of April and harvested on 18th of October) at 6 different ecological sites in Pakistan. Six locations selected for the experiment were the National Agricultural Research Centre (NARC), Islamabad, (33.6701° N, 73.1261° E latitude with 610 meters altitude), Chakwal (32.9311°N, 72.8551°E latitude with 498 meters altitude), Attock (33.7687°N, 72.3621°E latitude with 351meters altitude), Bahawalpur (29.9986°N, 73.2536°E latitude with 159 meters altitude), Umerkot (25.3549° N, 69.7376° E latitude with 36 meters altitude) and Quetta (30.1830°N, 66.9987°E latitude with 1679 latitude. Islamabad mainly falls in a humid subtropical zone with annual rainfall of 959 mm. While Chakwal and Attock have semi-arid climate with 521mm and 539 mm annual rainfall, respectively. The climate of Bahawalpur and Umerkot is arid with hot dry summer and the average annual rainfall is 223 mm and 84.15mm respectively. Swat falls in the temperate zone with an annual rainfall of 897 mm while Quetta has cold sami-arid conditions with 294mm annual rainfall. All of these locations had loamy sand, sandy loam and sandy clay soil.

Experimental procedure: Plant material in the present study consisted of seven National Uniform Yield Trial (NUYT) genotypes of groundnut Check cultivar BARI 2011 and six entries viz., 10AK003, ICG6590, BARI2011, ICG11855, 13CG003 and ICG2271. The experiment was conducted in a randomized complete block design (RCBD) with three replications at all experimental locations. Each genotypic entry was sown in four lines plot and each line was 4 meters long. The row-to-row distance was kept at 45 cm and plant-to-plant space was maintained at 15 cm. All the crop husbandry practices were performed along with fertilizer application at the rate of 20:50:80 NPK kg/ha. Pre-emergence weedicide S-Metolachlor and post-emergence weedicide Haloxyfop-P-methyl were used to eradicate weeds and hoeing was done at the time of pegs formation. Data for pod yield were measured in g/m^2 and converted into kg/ ha. The total yield per plant was recorded for individual plant and the entry yield was recorded per plot in all replications for all locations.

Data analysis: Analysis of Variance was performed over two years with mean data of seed yield from six locations to examine variation in sites and genotypes. Furthermore, the data were subjected to stability analysis and GGE biplot in GEA-R software to elucidate the Genotype x Environment interaction. The parameters of stability were computed following the model proposed by Eberhart & Russell 1966 (Francis' Coefficient of variance, regression coefficient, deviation from the regression), coefficient of determination, Shukla's stability variance (1972), Wrickes's ecovalence (1962) and Lin and Binns's cultivar performance measure.

Results

The two-year experimental data of groundnut yield from six locations was analyzed to assess the variation among the seven groundnut genotypes. The effect of interaction among them, with environmental factors and other components has been computed from the total variation. The results of analysis of variance (ANOVA) demonstrated that the impact of environment and year change was highly significant (p<0.01) (Table 1). The differences observed among the genotypes for grain yield were significant (p<0.05) for all the locations, while results of replication data revealed fewer risks of error showing non-significant variations over all locations. Furthermore, the variation caused by the interaction of genotypes with environment and year was non-significant.

The average grain yield of all the genotypes for 6 locations was 2650 kg/ha (Table 2). The results revealed the highest grain yield of 2984.694 kg/ha in genotype 11AK011 followed by 10AK003 and ICG6590 having 2920.722ha and 2627.722 kg/ha respectively. The lowest yield among all was partaken by genotype ICG2271 which was 2307.306 kg/ha. The highest yield was observed in Attock for genotypes 11AK011 and 10AK003 (4247 and 4177 kg/ha) showing strong adaptation of these lines to the local climate. Also, in Umerkot the yield performance of these genotypes during 2018 and 19 was higher i.e. 4074 and 4071kg/ha, respectively. The yield performance of ICG2271 was observed minimum in almost all locations among all genotypes except Umerkot.

In NARC, genotype 10AK003 outperformed all the genotypes by recording the highest yield (2943 kg/ha). While line 11AK011 was a high yielder in Chakwal (2428kg/ha), Attock (4247kg/ha), Bahawalpur (2171kg/ha) and Umerkot (4074kg/ha). In Quetta, the genotype ICG6590 produced a maximum yield (1374 kg/ha). Whereas it was observed that the genotype ICG2271 performed lowest in almost all locations i.e. 2086kg/ha at NARC, 1591kg/ha at Chakwal, 2701kg/ha at Attock, 1478kg/ha at Bahawalpur and 4155kg/ha, at Umerkot. Moreover, it outperformed ICG11855(867 kg/ha) in Quetta by giving a 1154 kg/ha seed yield.

Yield stability: Stability indices meticulously explained the extent of adaptation and stable performance across the environments (Table 3). The variability exhibited in 7 genotypes has been endorsed by the values of the Francis coefficient of variation (Fig. 1). The higher value of CV% is the indication of maximum variability and the lesser value of CV% is associated with minimum variability in genotypes across different environmental locations (Francis & Kannenberg, 1978). The average value of CV% for all the genotypes was 40.15. Minimum variability was shown by genotype 13CG003 (34.51) indicating it as the most stable genotype across all locations followed by 11AK011 (36.38) and ICG6590 (37.95), while BARI 2011 with maximum variability (48.31) was specified as the most unstable genotype across all environments.

Table 1. Analysis of Variance of two years yield data of groundnut genotypes.

Source of variation	DF	SS	MS	F	P
Gen	6	11698864	1949811	2.251731	0.039898*
Rep	2	19243.11	9621.556	0.011111	0.988951
Environment	5	2.17E+08	43464950	50.19531	1.39E-33***
Year	1	8787833	8787833	10.14859	0.001674**
Gen× Environment	30	20061455	668715.2	0.772263	0.797539
Gen× Year	6	4981343	830223.9	0.958781	0.454337
Residuals	201	1.74E+08	865916.5	NA	NA

DF= Degree of freedom, SS= Sum of square, MS= Mean sum of square

Table 2. Mean Performance and variability across locations.

Genotypes	NARC	Chakwal	Attock	Bahawalpur	Umerkot	Quetta
11AK011	2883	2428	4247	2117	4074	1351
10AK003	2943	2387	4177	2003	4071	1219
ICG6590	2845	1836	3241	1563	4104	1374
BARI2011	2374	1679	3348	1615	4522	1081
ICG11855	2797	1526	3247	2683	3877	867
13CG003	2436	2140	3406	2109	3680	1217
ICG2271	2086	1591	2701	1478	4155	1154

Table 3. Assessment of yield stable genotypes via stability analysis.

			Francis	Eberhart & Russell			Shukla	Wricke's ecovalence	Superiority measure
GEN	Mean	Sd	CV (%)	Bi	S2di	R2	ri2	Wi	Pi
10AK003	2920.722	1125.778	38.5445	1.073	-218309	0.9402	91600.31	406755.4	60772.02
11AK011	2984.694	1086.087	36.3885	1.0303	-211758	0.9313	92539.75	410110.6	43301.03
13CG003	2569.556	886.7659	34.5105	0.8532	-271750	0.9579	55253.97	276947.1	206243.2
BARI2011	2533.056	1223.832	48.3144	1.1807	-244122	0.9632	102253.7	444803.4	275514.6
ICG11855	2610.694	1052.712	40.3231	0.9401	-70986.2	0.8252	254080.5	987041.8	231091.4
ICG2271	2307.306	1038.72	45.0188	0.9713	-184869	0.9049	122517.7	517174.8	473706.6
ICG6590	2627.722	997.2843	37.9524	0.9515	-240934	0.942	61946.21	300847.9	234694.7

CV (%) = Francis' Coefficient of variance,bi = Regression coefficient, S2di= Deviation from the regression, R2 = Coefficient of determination, σ2 i = Shukla's stability variance, S2 di= Deviation from the regression, Wi= Wrickes's ecovalence, Pi= Lin and Binns's cultivar performance measure

The Francis' Coefficient of Variation was also visualized by a plot showing high-yielding and stable genotypes with minimum CV% labeled with red font (Fig. 2). It has been demonstrated that genotype 13CG003 was the most stable among all but yield performance was considerably less than genotypes 10AK003 and 11AK003 and mean value of yield. The genotypes 10AK003 and 11AK003 produced the best yield across all locations with stability.

According to Eberhart & Russell (1966), a genotype having the highest mean yield performance and regression coefficient (bi) almost equal to one and deviation from the regression (S^2di) equal to zero is the most stable genotype. The value of the regression coefficient of genotype 13CG003 is almost equal to one (0.9) with a minimum value of mean square deviation (S^2di) and better yield performance supported the adaptability of this genotype across all environments (Table 3). All the other genotypes exhibited non-significant stability according to Eberhart and Russell's descriptions (Fig. 3).

The genotypes 11AK003 and 11AK003 were lying closer to the value portraying stable genotypes with the best yield performance. The genotypes BARI2011 fell far from the stability value (1.0) with better mean yield indicating that it performed well only in a favorable environment (Fig. 3), while the genotype ICG2271 and 11855 in the graph was below the stability value (1.0) with less mean yield indicating their lower performance in the unfavorable environment (Fig. 3).

The values of the coefficient of determination ranged from 0.82 to 0.96. The genotype 13CG003 with a high value of R^2 showed stable characteristics as it maintained its yield under different environmental conditions.

Yield stability criterions: According to Shukla's (1972) yield stability standard varies for genotypes in different ecological zones, genotype 13CG003 was the most stable genotype showing a minimum value (55253.97) of variability also validated by the results of Wricke's Ecovalence accounting for lesser value (276947) of variation among all genotypes hence demonstrating negligible deviation from the grand mean. Whereas ICG11855 was found most unstable genotype according to Shukla's (1972) and Wrickes's (1962) standards showing maximum values of variability.

Lin and Binns's genotype performance measure (*Pi*) was also calculated which described the stability of a genotype across different environments exhibited by smaller values of *Pi*. Genotypes 11AK011, 10AK003 and 13CG003 were observed to be stable viz-a`-viz yield under diverse ecologies as depicted by smaller *Pi* values.

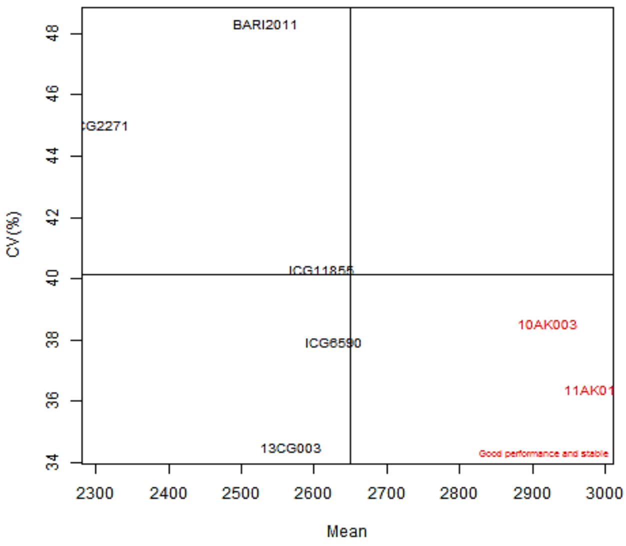

Fig. 1. Mean yield of genotypes against Francis, coefficient of variation (CV %).

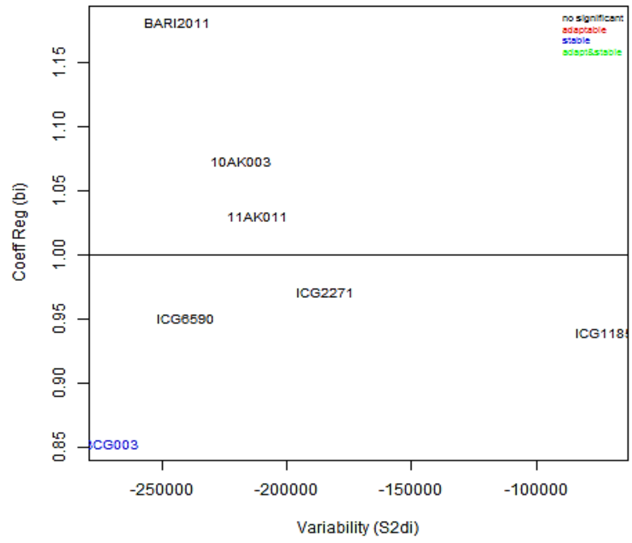

Fig. 2. Eberhart & Russell's regression-based yield stability index.

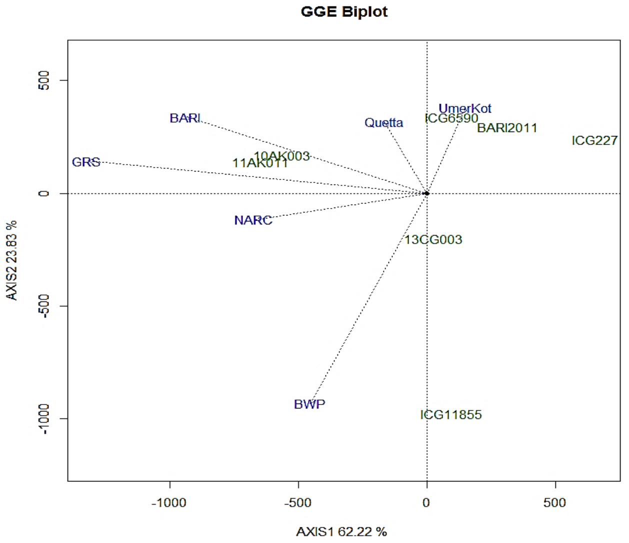

Fig. 3. Interrelationship of various environments and genotypes yield.

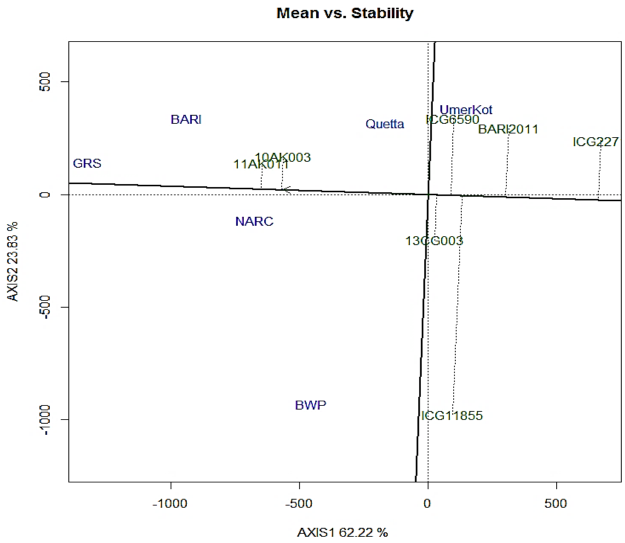

Fig. 4. Mean yield performance and genotypes stability.

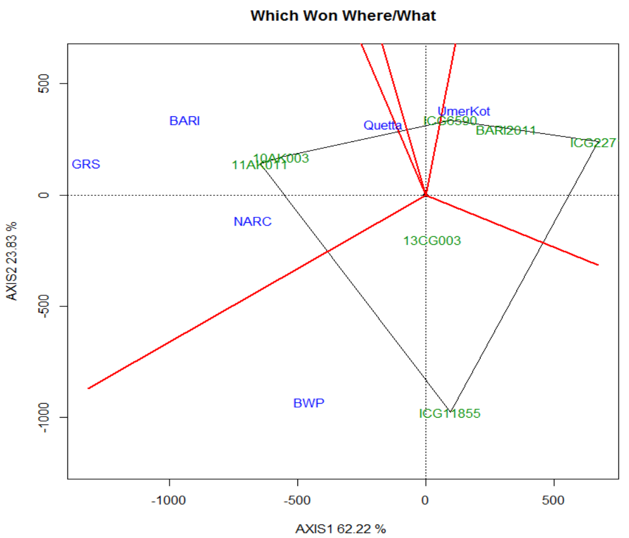

Fig. 5. Location specific best performing genotypes assessment.

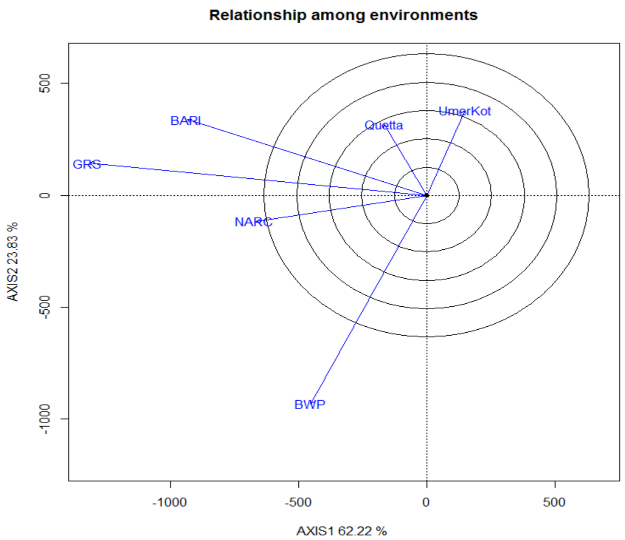

Fig. 6. Relationship among Environments viz-a`-viz groundnut seed yield.

Genotype and genotype to environment (GGE) biplot interaction: Genotype and genotype to the environment (GGE) Biplots were constructed to graphically represent variation in studied genotypes across different locations (Fig. 4). Notably, Umerkot Quetta and NARC emerged as least varied environments, whereas BWP showed with larger vector away from the origin demonstrated relatively higher dissimilarity in yield performance from other environments. The total variation observed among the genotypes was 86.05%. Genotypes 10AK003 and 11AK011 have shown variation in similar locations, these two genotypes varied greatly in GRS Attock and BARI Chakwal respectively, however, the genotypes demonstrated relatively stable yield in Quetta for both years. The genotypes ICG6590, ICG227 and BARI-2011 differed slightly in Umerkot. The genotype 13CG003 was least affected by environmental variation in studied ecological zones and showed overall stable and best performance. The genotype ICG11855 as a low-yielding entry also seemed unaffected by environmental factors.

Mean vs. stability: The line passing through the origin in the biplot represents the average environment axis (Fig. 5). The genotypes are classified on this axis according to their mean performance at different locations. The perpendicular lines representing genotypes at different locations to the environmental axis are displaying their extent of stability. The genotype 13CG003 is placed closer to the origin, not falling in any particular region, moreover it proximity to the environmental axis confirmed its overall stability and non-significant G×E interactions. The genotypes 11AK011 and 10AK003 were found to adapt to three areas closer to the origin point showing overall best mean yield performance with stability.

Suitable genotype in particular environment: In a "which won where" plot genotypes performing best at certain location were depicted showing strong affinity with that environment (Fig. 6). Biplot showed distribution of genotypes in different locations suited best to that particular environment (Fig. 6). A polygonal shape is formed connecting 6 genotypes falling in different ecological zones. Red lines dividing the environmental locations into groups specified that Quetta, BARI Chakwal, GRS Attock and NARC fell in the same group, while Bhawalure and Umerkot were marked in two separate groups. In the first group of environments, the genotypes 10AK003 and 11AK011 performed well with high yield, whereas three genotypes ICG6590, BARI2011 and ICG227 showed the best performance of yield in Umerkot only. The genotype 13CG003 inside the polygonal shape portrayed its best performance in all selected ecological environments, while ICG11855 performed poorly at almost all locations.

Relationship among environments: The relationship among selected ecological zones is displayed. The angles and patterns between locations expressed their correlation regarding similarity, site type and distance. The smallest angle existed between BARI Chakwal and GRS Attock; GRS Attock and NARC displaying closer relation are classified in group 1. Furthermore, relatively larger angles existed between BARI Chakwal and Quetta; Quetta and Umerkot forming group 2, while the largest angle was between Umerkot and BWP, categorized in group 3.

Discussion

The stable and high-yield performance of a genotype across different environments is vital for its selection in the development program. The yield stability of groundnut genotypes was greatly affected under influence of environmental changes (Raza *et al*., 2019). Genotype x environment interactions caused significant variation in the yield performance of genotypes across tested locations (Padi, 2008; Romagosa *et al*., 2009), which is discernable (Malosetti *et al*., 2013). The assessment of phenotypic values under fluctuating environmental conditions is essential to select stable and best yield-performing genotypes. It is demonstrated in studies that, inconsistent performance of a genotype across different ecological zones is caused due to significant genotype x environment interaction. Researchers have shown that such GxE interaction effect on the phenotype is additive (Oteng *et al*., 2019) and low correlation between phenotypic and genotypic values (Romagosa *et al*., 2009).

In the present study, we evaluated the yield stability of 7 groundnut genotypes at 6 locations through GGE biplot and stability indices scores. In Analysis of variance (ANOVA) total genotypic variation, variation due to environment, variation due to genotype× environmental interaction and genotype× year interaction has been computed. Moreover, performance of genotypes at different locations is highlighted from the mean values of genotypes. The stability of genotypes has been assessed under different criteria of stability analysis, such as Francis' Coefficient of variance, regression coefficient (Eberhart & Russell, 1966), deviation from the regression, coefficient of determination, Shukla's stability variance (1972), Wrickes's ecovalence (1962), Lin and Binns's cultivar performance measure.

Yield is a complex trait whose selection is associated with several contributing parameters, therefore information on the nature and degree of variation either genetic or environmental existing in the breeding population has been assessed to lead the objective (Savaliya *et al*., 2009). The Genotypes used in our experiment at different locations were carrying significant variations for yield stability offering the best chance of selection. The results of ANOVA revealed a highly significant difference among genotypes due to the environment at different locations as well as environmental change by the change in the year suggested a greater magnitude of variation contributed by environmental factors. These results were in conformity with the findings of Jahanzaib *et al*., (2019) research study and Ahmed *et al*., (2008) and Chavan *et al*., (2009).

Similarly, the mean yield performance of the genotypes across 6 different environmental locations revealed a greater variability. Dolinassou *et al*., (2016) also found significant variation in genotypes signifying distinct responses across selected experimental sites. Although significant differences existing among genotypes indicated considerable diversity among them but the prominent difference in yield across the selected locations indicated the influence of both genotype and environment. The stability analysis demonstrated genotype × environment interaction by different genotypes yield potential at different locations. Various environmental dynamics such as drought, differential rainfall, temperature and soil type interacted greatly to affect the consistency of the yield of the genotypes (Ikeogu *et al*., 2013; Khan *et al*., 2008).

Considering the stability of genotypes as well as yield performance across the locations; the two genotypes 11AK011 and 10AK003 performed well with high mean yield but their high potential was mostly observed in BARI Chakwal, GRS Attock and Quetta.

It was observed that genotypes suitable for multi-environment with the best and consistent yield performance had low Genotype x environmental interaction and genotypes varying in their performance at different locations had high Genotype x environment interaction (Gauch & Zobel, 1997). However, 13CG003 stable performance at all locations with yield performance closer to the average grain yield supported by different stability indices indicated by the low Genotype x Environmental interaction. Minimum Francis coefficient (CV %) of variance in 13CG003 among all genotypes indicated lesser variability across the locations. The value of regression coefficient (*bi*) and deviation from regression (S^2di) for genotype 13CG003 in accordance with Eberhart and Russell (1966) also suggested its stability across the locations. With minimum values of variability, genotype 13CG003 has fulfilled both Shukla's (1972) and Wricke's (1962) criteria of stability.

The GGE Biplot demonstrated high mean yield performance, adaptability and stability of genotypes across the locations. The genotype 13CG003 did not show a particular association with studied locations but demonstrated consistent yield across the selected locations considered stable with a mean yield closer to average. Whereas the genotypes 10AK003 and 11AK011 had high yield above the average value at three locations, GRS Attock, Chakwal and NARC. These two genotypes covered a large group of environments that exhibited similarity in various environmental factors. The areas including Quetta, Umerkot and BWP exhibited different behavior classified into three separate groups of environments. Three genotypes ICG590, ICG227 and BARI2011 were proved suitable for the Umerkot region but their yield was lower than average yield. Furthermore, high Genotype x Environment Interaction at Umerkot showed their adaptability for this region and selection for local adaptation is possible. These results were in conformity with Gauch & Zobel, (1997). According to Dolinassou *et al.*, (2016) genotypes depicting lowest values were considered as the most stable varieties which could be added to in crop improvement programs. The genotype ICG2271 performed lowest at almost all locations such as 2086kg/ha at NARC, 1591kg/ha at Chakwal, 2701kg/ha at Attock, 1478kg/ha at Bahawalpur and 4155kg/ha at Umerkot but in Quetta ICG2271 (1154 kg/ha) performance was better than ICG11855 (867 kg/ha), however, it maintained stability as low performing genotype in all locations.

It is further proposed that the yield performance of genotypes across different locations had an impact of differential rainfall mainly and other environmental factors like humidity and temperature. Earlier reported studies (Agbaje & Oyekan 2001) have also shown variability in groundnut yield due to variations in mean annual rainfall.

Conclusion

Groundnut is a prominent edible oilseed crop, which is a cheap source of good quality fats, minerals, vitamins and proteins for under-nourished poor countries population. Therefore, increase in groundnut production in the country can provide the best opportunities of quality oil and confectionary items for indigenous use and export also. The unpredictable environmental stresses are the major reasons for reduction of groundnut yield and productivity. Adaptation and stability of groundnut in fluctuating climatic conditions in different ecological zones can be achieved by concentrating on stability characteristics and genetics of stress related attributes. Information provided by different stability credentials guides' the successful evaluation of stable genotypes for the promotion in breeding programs. A greater magnitude of Genotype x Environment interaction across all locations greatly swayed the yield of genotypes. Therefore, genotype 13CG003 was overall stable giving the yield closer to average value. The genotypes 11AK011 and 10AK003 also have a potential of adaptability and yield over wide range of environmental group such as Attock, Chakwal, NARC and Quetta.

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