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Full Length Article

Estimating Genotype x Environment Interaction for Groundnut Seed Yield across Different Ecological Zones

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Abstract

Information regarding combined effect of genotype and environment is crucial for breeders to mitigate undesirable effects of agro–climatic conditions and simultaneously enhance efficiency of a breeding program. In groundnut, seed yield, as important quantitative trait remains under considerable influence of genotype x environment interaction. In the present study, eight groundnut genotypes were evaluated for grain yield under six different environments for two years, 2013–2014. Among these genotypes, PG–1162 had maximum yield (1.91 tons ha^{-1}) followed by PG–1135 (1.90 tons ha^{-1}) at all experimental sites. ANOVA of mean data revealed 69% of total variability in groundnut seed yield was contributed by agroecological variation while year–on–year variation accounted for 12% variation in the yield. Univariate stability indices *i.e.* CV_i (%), b_i, S^2_{di}, σ^2_i, β_i, W_i, P_i, and mean absolute rank differences S_1 and S_2 revealed that genotype PG–1162, PG–1167 and PG–1169 were stable with consistent seed yield across different environments. Multivariate approach of GGE biplot dissected 70% of the total yield variability in first two PCs and graphically represented best performing genotypes viz–a–viz environments. Results revealed that PG–1162 and PG–1167 as adaptable to wide range of environments. Moreover, environment specific cultivation of suitable genotypes is recommended for higher yield. © 2019 Friends Science Publishers

Key words: Genotype x environment interaction; GGE biplot; Groundnut; Stability analysis

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Introduction

Groundnut (*Arachis hypogea* L.) is an annual oilseed crop mainly grown for its nutritious seeds. It is native to South America but planted on 24.6 million hectares of tropical and temperate regions (Chavan *et al.*, 2009; Dolinassou *et al.*, 2016). Its seed contains 40–50% of edible oil and 25% protein. Worldwide production of groundnut was estimated at nearly 27 million tons representing 5% of the ten major oilseed crops. China is the largest producer with 11 million tons shelled basis followed by India and Nigeria with 3.40 and 2.12 million tons, respectively (Anonymous, 2015). There is enormous potential to elevate crop productivity by focusing on biotic and abiotic stresses, yield related traits and adaptable genotypes showing stable performance in different agronomic zones (Thaware, 2009). Increasing seed yield, introgression of pest resistance and quality enhancement are some of the key objectives of groundnut breeders. In Pakistan, groundnut is considered as rainfed crop grown on marginal lands with limited cultivation in irrigated plains (Nawaz *et al.*, 2009). This in turn reduces overall production and yield of the groundnut unlike other major crops. Besides, highly variable agro–climatic conditions remain the major limiting factors of groundnut production in the country (Mothilal *et al.*, 2010). Among these climatic features, the abrupt pattern of precipitation is one of the primary causes of unstable groundnut yield in the country (Nawaz *et al.*, 2009). This necessitates development of new groundnut varieties demonstrating stable yield across wide range of agro–ecologies. However, information regarding genotype x environment interaction is crucial for breeders to mitigate undesirable effects of agro–climatic conditions and simultaneously enhance efficiency of a breeding program. Varieties responsiveness to different environmental stimuli prompts breeders not to rely only on yield as a selection criterion but also include stability analysis of genotypes under multiple environments. This strategy focuses on reducing genotype x environment interaction by discriminating cultivars adapted to favorable and unfavorable environments (Agbaje and Oyekan, 2001). Consistent performing genotypes with modest yield across variable environments are considered more relevant as compared to high yielding but inconsistent performing cultivars (Sahay and Sarma, 2005; El–Harty *et al.*, 2018; Oz, 2018).

There are different methodologies to estimate stability and adaptability as well biometric procedures for measuring GE interaction. Traditionally, the environmental component of G x E interaction is simplified by examining average yield

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performance of the genotype in respective locality. These methodologies are based on simple linear regression or multiple linear regression, nonlinear models and multivariate methods (Dolinassou *et al.*, 2016). One such method is Finlay–Wilkinson regression (Finlay and Wilkinson, 1963) which evaluates yield response to favorable environments for different genotypes. This linear regression–based adaptability study model is efficient tool to select consistent performing cultivars in a given environment (Agbaje and Oyekan, 2001). However, there are short comings associated with this technique whereas it describes average response of each genotype to environment but does not identify the main relationship causing G x E interaction (Santos *et al.*, 2012).

Other approaches *i.e.* Francis and Kannenberg (1978) CV%, Eberhart and Russel (1966), Shukla (1972), Perkins and Jinks (1968), Wricke (1962) eco–valence, absolute rank method of Nassar and Huhn (1987) and additive main effects and multiplicative model (AMMI) are preferable choices while studying response of genotypes viz a` viz multiple variables such as climatic or pedological data over a wide range of environments (Gauch and Zobel, 1996; Sanchez–Garcia *et al.*, 2012). Eberhart and Russel (1966) joint regression model of using phenotypic values or environmental interaction indices is popular for studying adaptation and stability of crops at different locations. These methods not only explain a larger portion of the genotype x environment interaction but also simplify the results by representing the products of the environmental and genotypic sensitivity scores in a biplot (Bassi and Sanchez–Garcia, 2017). Besides, these approaches not only enable plant breeders to quantify G x E analysis but allow characterizing genotypes as "widely adapted" or as "specifically adapted" to a single environment or multiple environments (De Oliveira and Godoy, 2006). Recently, a GGE biplot method has been proposed which combine some of these methods to graphically represent genetics and G x E interaction (Yan *et al.*, 2000). Plant curators have used GGE biplot technique to evaluate varieties of different crops in diverse ecologies (Yan and Hunt, 2001; Crossa *et al.*, 2002; Ma *et al.*, 2004; Butron *et al.*, 2004; Dehghani *et al.*, 2006; Kaya *et al.*, 2006). In the present study, an attempt has been made to screen eight groundnut genotypes for higher grain yield across six ecologically diverse locations and to estimate their genotypic stability and role of G x E interaction.

Materials and Methods

The experiment was conducted in six ecologically diverse locations for two years in 2013–2014 during kharif seasons (Table 1). Eight candidate lines collected from the gene bank of Plant Genetic Resources Institute (NARC, Islamabad) *viz*., 10CG001, BARD–479, GOLDEN, PG–1135, PG–1162, PG–1167, PG–1169 and PG–1190 were sown in randomized complete block design in three replications with each genotype having a plot of 4 rows of 5 meter length in a replication. Plant and row spacing were maintained at 10 and 45 cm, respectively. Fertilizer was incorporated @20:50:80 NPK kg/ha to a well–prepared soil. Recommended agronomic practices were performed to achieve vigorous growth. Hoeing was performed at the time of emergence and peg formation and post emergence weedicide was used to eradicate the weeds. Data for pod yield were measured from dried pods (g/m^2) and converted into kg/ha. The total grain yield per plant was recorded for individual plant while entry yield was recorded per plot in each replication for all environments.

Data Analysis

The two years mean data of seed yield from twelve environments (i.e., 6 locations x 2 years) of all eight groundnut genotypes were subjected to Analysis of Variance to explain components of the G x E interaction using STATISTIX 8.1 (Analytical software, USA). The responses of the groundnut varieties to changes in environment were quantified with linear regression models according to Eberhart and Russel (1966) and Perkin and Jinks (1968) where each genotype yield was regressed on environmental index. Other parameters for stability i.e. Francis and Kannenberg's, (1978) Coefficient of variance (CV_i), Shukla's (1972) stability variance (σ^2_i), Wricke's (1962) ecovalence (W_i), Lin and Binns' (1988) cultivar performance measure (P_i) and Nassar and Huhn's (1987) mean absolute rank difference (S1, S2) were computed using GEA–R (Genotype x Environment Analysis with R) for Windows Version 4.0 developed by International Maize and Wheat Improvement Center (CIMMYT). GGE Biplot was constructed to graphically interpret the genotype x environment interaction.

Results

Analysis of Variance of GE Interaction

Combined analysis of variance for grain yield of eight groundnut genotypes in six locations revealed significant variation ($P \leq 0.05$) (Table 2). Total variation was partitioned into its components to quantify role of genotype (G), environment (E) and their interaction (G x E) (Table 2). Analysis revealed that environment was major contributor of variation with 69% and genotype represented only 1% of variation. The year wise environment effect contributed 12% of variation in grain yield; however, the genotypes were stable showing only 0.7% of variability. Mean groundnut grain yield for all the 8 genotypes at 6 locations was 1.8 tons ha^{-1}. Genotype PG–1162 produced highest number of grain (3.15 tons ha^{-1}) at Chakwal followed by 10CG001 (3.05 tons ha^{-1}) at same location. PG–1167 had the minimum grain yield (0.36 tons ha^{-1}) at district Karak.

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Table 1: Environmental and soil data of locations of groundnut yield trials

Location	Coordinates	Elevation (m)	Climate (Koppen-Geiger)	Annual Rainfall (mm)	Soil Type
Islamabad	33.7294° N, 73.0931° E	610	Humid subtropical/Cwa	959	Loamy Sand
Chakwal	32.9311° N, 72.8551° E	498	Semi-Arid/ BsH	512	Sandy Loam
Attock	33.7687° N, 72.3621° E	351	Semi-Arid/ BsH	539	Sandy Loam
Karak	33.1105° N, 71.0914° E	586	Hot Semi-arid/ BsH	359	Sandy Clay
Swat	35.4920° N, 72.5205° E	984	Temperate/ Cfa	897	Sandy Loam
Quetta	30.1830° N, 66.9987° E	1679	Cold Semi-arid/ BsK	244	Sandy Clay,SiltLoam

Table 2: ANOVA

Sources	DF	SS	MS	F	P
Year	1	0.445	0.4454		
Location	5	145.389	29.0777		
Year x Location	5	25.526	5.1052		
Genotype	7	2.203	0.3147	2.32	0.0264*
Replication	2	0.075	0.0373	0.27	0.7603
Gen. x Rep.	14	1.603	0.1145	0.84	0.6226
Error	253	34.387	0.1359		
Total	287	209.627			

Table 3: Comparison of stability indices for eight groundnut genotypes grain yield

GENOTYPE	Mean	St. Dev.	CV_i(%)	b_i	S^2d_i	R^2	σ^2_i	β_i	S^2d_i	W_i	P_i	S1	S2
10CG001	1.77	0.77	43.71	1.01	0.01	0.96	0.03	0.01	0.03	0.13	0.07	1.07	4.6
BARD-479	1.89	0.63	48.85	0.83	-0.01	0.97	0.03	-0.17	0.01	0.13	0.04	0.73	4.2
GOLDEN	1.85	0.69	37.56	0.90	0.02	0.94	0.04	-0.10	0.04	0.18	0.05	0.93	4.4
PG-1135	1.91	0.86	44.87	1.14	-0.01	0.99	0.02	0.14	0.01	0.10	0.02	0.73	3
PG-1162	1.91	0.78	40.56	1.02	0.01	0.95	0.03	0.02	0.03	0.14	0.02	1	6.6
PG-1167	1.67	0.82	33.38	1.08	0.01	0.97	0.03	0.08	0.03	0.13	0.11	0.87	6.6
PG-1169	1.74	0.72	41.34	0.95	0.00	0.97	0.02	-0.05	0.02	0.08	0.07	1	5.8
PG-1190	1.89	0.81	42.85	1.06	0.02	0.95	0.04	0.06	0.04	0.19	0.04	1.27	7.6

CV_i (%)= Francis' Coefficient of variance, b_i=regression coefficient, S^2d_i=deviation from the regression, R^2=coefficient of determination, σ^2_i=Shukla's stability variance, β_i=Perkins and Jinks' linear regression coefficient,S^2d_i=deviation from the regression, W_i=Wrickes's ecovalence, P_i=Lin and Binns's cultivar performance measure,S1, S2Nassar and Hühn (1987) mean absolute rank difference

Analysis of Yield Stability

The yield data for all 8 genotypes in 6 locations was represented on graph against CV_i values to measure stability and performance of genotypes concurrently (Fig. 1; Table 3). Average CV_i for all genotypes was 41.6. PG–1167 showed minimum variability (CV_i =33.38) followed by PG–1169 (CV_i= 37.56) while BARD–479 exhibited maximum variability of grain yield across environments (CV_i=48.85). As the trend line indicates the genotypes with above average yield i.e. PG–1167 and PG–1169 were comparatively stable in different environments.

The linear regression procedure was used to check yield of each groundnut genotype on the basis of mean yield of locations. According to this procedure, a genotype with higher mean yield, regression coefficient b=1.0 and deviation S^2_{di} =0 is considered stable. Genotype 10CG001, PG–1162, PG–1167 and PG–1169 were stable with minimum S^2_{di} and regression coefficient b value near to unity (Table 3). A comparison plot of these values was generated to interpolate these genotypes on an XY plane (Fig. 2). All genotypes were classified as adaptable except for BARD–479 which remained highly responsive to environment. The graph also depicted PG–1169 and PG–1167 closer to ideal values of stable genotypes. However, PG–1190 and PG–1135 were found to be highly unstable with divergent yield at different locations. Values of other stability indices are given in Table 3.

Analysis of Genotype x Environment Interaction

A GGE biplot was constructed for first two principal components PC1 and PC2 showing 38.25% and 32.17% variation, respectively. GGE results are explained in three sections *i.e.* "which won where/what", "relationship among environments and "mean vs stability".

Which Won Where/What

Which won where/what identify the best suited genotype (s) for each environment or group of environments (Fig. 3). Polygons are formed by connecting markers for 5 of the genotypes while 3 genotypes are inside the shape. Red rays are drawn perpendicular to the sides of polygon marking a specific environment/ location or their group. In this case, 5 rays divide this biplot into 5 different sections where 6 of our locations fall into 4 of these sections. The vertex genotypes for each quadrant are the ones with the highest yield for that location and fall within that quadrant. Plot indicated that genotype PG–1190 performed well at NARC and PG–1135

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was high yielding at Attock district. Similarly, PG–1162 in Karak, BARD–479 in Swat, Golden in Chakwal and PG–1169 in Quetta gave highest grain yield. Interestingly 10CG001 did not perform well in all environments.

Relationship between Environments

Summary of the relationship between different experimental location is given in Fig. 4. The lines connecting origin of the plot and markers of the locations represents environment vectors. The cosine angle of the environment vectors is proportioned according to the correlation coeffecient between them. In this plot, smallest angle is between environmental vectors of Attok and Karak, Karak and Swat, hence can be placed in a single group. Largest angle is between environmental vectors of NARC and Swat; NARC and Quetta. This pattern of arrangment of different environments coincides with geographic distance and site type.

Mean Yield vs. Stability

The ranking of all eight genotypes according to their grain yiled at six locations has been represented in Fig. 5. The arrowed line starting from upper left corner and passing through plot origin is called average environmet axis as defined by first two principal components. Closeness to a circle located on this axis indicates higher mean yield. A line perpendicular to axis of environment shows stability and moving away from it in either direction means lower stability and higher GxE interaction. It indicates that PG–1162 and PG–1169 are stable genotypes.

Comparison of Grain Yield Stability Indices

A summary of different stability parameters with mean grain yield for all genotype is given in the Table 3. According to stability variance ($\sigma^2 i$) value PG–1169, PG–1135 and PG–1167 were stable genotypes whereas Golden and PG1190 were prone to environmental stimuli. Perkins and Jinks (1968) regression coefficient β_i accounts for all or most of the GE interaction. A genotype with average sensitivity to the environment has a (1+β_i) value of 1 and β_i value of zero. This genotype is considered as non–responsive to GE interaction. A genotype responsive to GE has (1+β_i) value greater than 1 hence has an β_i value greater than zero. However, a stable genotype which is indifferent to environmental variation has value (1+β_i) less than 1 and hence have a significantly negative β_i value. Therefore, PG–1169 was stable genotype with β_i = –0.05 and 1+β_i <1. Wricke's (1962) ecovalence (W_i) or the stability of the i^{th} genotype is its interaction with environments, summed and squared for all environments. Thereby a genotype with less ecovalence has fewer fluctuations under different environments and considered as stable. PG–1169 has minimum ecovalence (W_i =0.08) followed by PG–1135

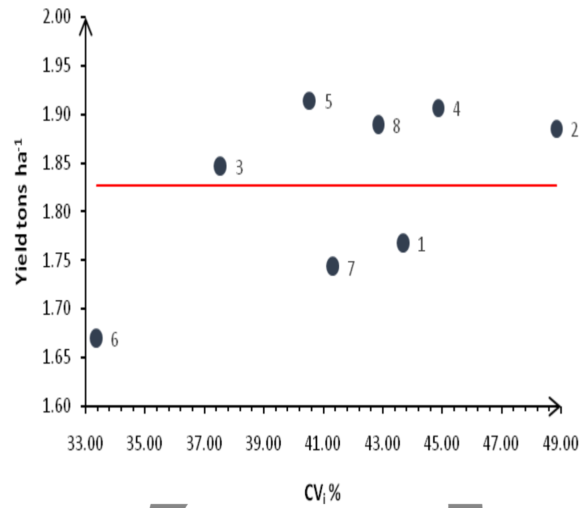

Fig. 1: Yield of 8 genotypes vs. Francis' Coefficient of variation

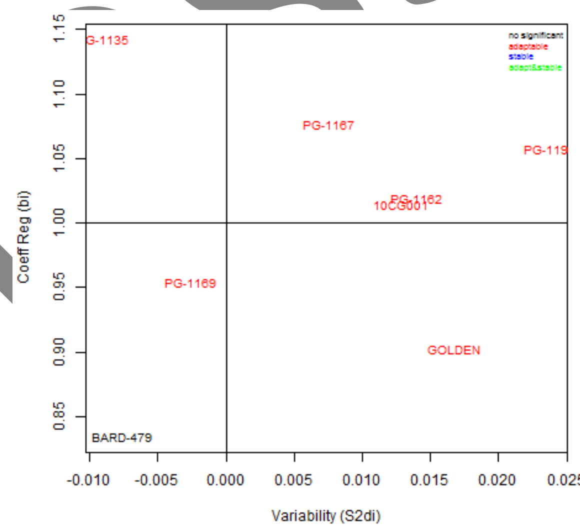

Fig. 2: Eberhard and Russel (1966) stability plot for coefficient of yield

(W_i =0.10) and PG–1167 (W_i =0.13). On the contrary, genotype PG–1190 (W_i =0.19) and Golden (W_i =0.18) had higher ecovalence hence their yield was relatively more prone to environmental variation. The non–parametric mean absolute rank difference (*S1*) was also calculated for stability analysis. The *S1* represents all possible pairwise rank differences for each genotype across locations while *S2* values are variances for ranks for all genotypes in all locations. Smaller *S2* values are associated with stable genotypes however *S1* is preferred parameter to rank genotypes according to stability. Genotypes PG–1135, BARD–479 and PG–1167 were ranked higher for grain yield variation among different environments. PG–1190 and 10CG001 were ranked as more sensitive to environmental fluctuations. The superiority measure (*Pi*) is calculated by squared differences between a genotype and the maximum

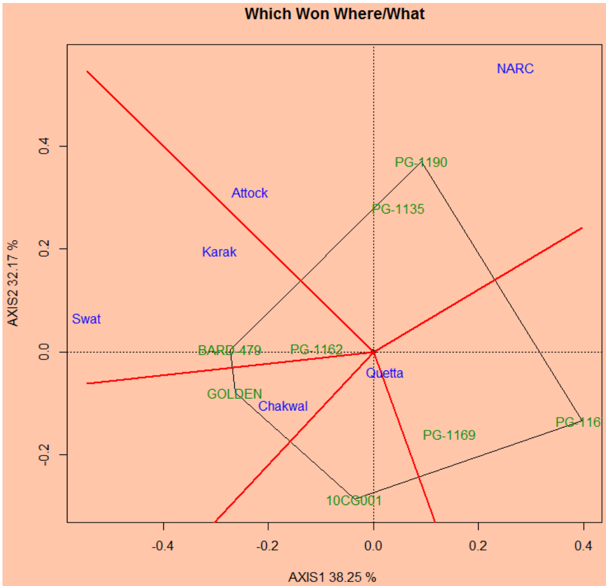

Fig. 3: Performance of 8 genotypes in 6 different locations for grain yield

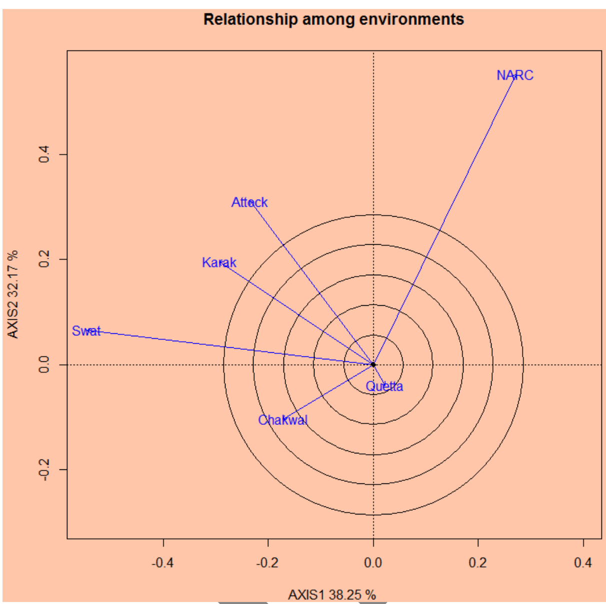

Fig. 4: Interrelationship between 6 different locations/ environments

mean of a genotype's yield at a given location, summed and divided by two times the number of locations. Genotype with lower values of *Pi* is considered as stable. Genotype PG–1162 and PG–1135 had the lowest *Pi* values (0.02) and hence considered as relatively stable.

Discussion

Several researchers studied the environment and genotype relationship and its effect on groundnut yield

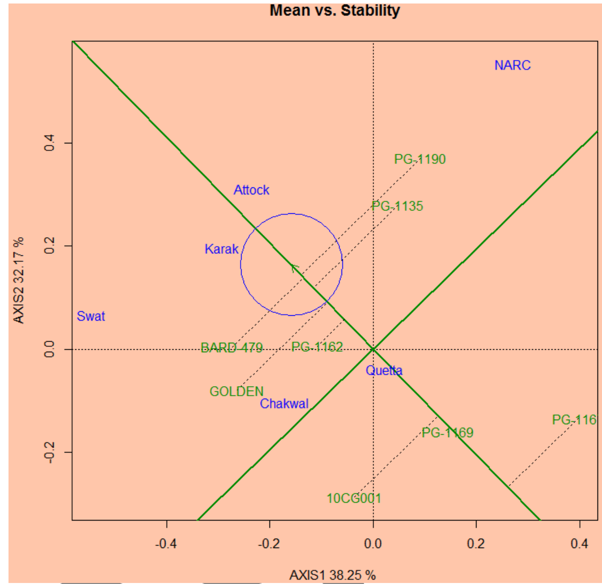

Fig. 5: Genotypes' stability and GE interaction at different locations

stability (Sahay and Sarma, 2005; Nawaz *et al.*, 2009; Mothilal *et al.*, 2010; Santos *et al.*, 2012; Dolinassou *et al.*, 2016). In present study, eight important groundnut genotypes were analyzed for stability analysis at six different locations. Important G x E factors i.e. yield stability analysis, combined analysis of variance for grain yield, analyses of genotype x environment interaction, the fit genotype of a specific environment, relationship among the environment, mean yield influenced by environments, and comparison of stability indices were studied. Significant variation was noted among genotypes at different locations for different stability factors, the environmental effect, genotype and environment relationship. Temesgen *et al.* (2015) evaluated sixteen diverse *Faba bean* genotypes at 13 different environmental condition of Ethiopia and observed different grain yield of genotypes associated with multiple environments. Our results were supported by findings of Temesgen *et al.* (2015) as principal amount of variation (69%) for yield of 8 studied genotypes was contributed by environments, up from Mingora in the north to southern part of Pakistan. These were in conformity with the findings of Santos *et al.* (2012) who also found most of the variation for yield in 7 groundnut genotypes at 6 different locations in northeast Brazil. It is proposed that differential rainfall in our studied environment had largest contribution to overall yield performance across environments. Previous study of Agbaje and Oyekan (2001) also observed impact of rainfall on groundnut yield and reported significant variability response viz a viz mean annual precipitation.

Temesgen *et al.* (2015) observed that no single variety performed better under studied environmental conditions, however, a genotype EK01024–1–2 was comparatively high yielding and stable in response at multiple locations.

They recommended the genotypic superiority index (P_i) for screening of stable and high yielding genotypes. In the present study, no elite genotype performing across all the environments was found. Moreover, PG1169 were stable genotypes having above average grain yield at multiple locations and had second least Francis Variability. On the contrary, PG–1167 demonstrated type 1 static stability albeit with below average performance over all locations. For variety release scenarios Type 2 or "dynamic stability" are used as criteria as stable genotypes having higher yield are preferred choice for wider adoption. Kilic *et al*. (2010) studied the stability pattern of high and low yielding durum wheat germplasm. They noted that average yielding genotypes showed maximum stability than other high yielding genotypes. According to Becker and Leon (1988), not necessarily all genotypes should give similar response at different environments due to the fact that different genotypes give different response at varying environmental conditions. Sabah *et al.* (2007) and Jarsso and Degago (1997) found significant variations in phenotypic traits like yield among *Faba bean* genotypes with different genotype and environment interaction levels.

The regression coefficient b_i of PG–1167 was almost equal to 1 and S^2d_i=0 followed by PG–1162 and 10CG001 with similar index values. Becker and Leon (1988) reported that genotypes showing b_i values of unity gave average performance to different environmental conditions. Eberhart and Russell (1966) and Finlay and Wilkinson (1963) described that genotypes having a regression coefficient of unity (b_i= 1), and deviation as zero (S^2d_i = 0), gave excellent mean performance. These genotypes also acclimatized better across different environments.

GGE biplot is useful tool to visualize adaptable, stable and high performing genotypes across multiple locations. The GGE biplot visualizes genotype main effect in addition to GE interaction which is not represented by additive main effects and multiplicative interaction. Particularly it visualizes any crossover G x E interaction (Ding *et al.*, 2008). Yan and Wu (2008) recorded 216 different families in GGE plot in *Pinus radiate* genotypes grown at five different locations. Ali *et al.* (2017) identified adaptive and stable cotton cultivars across six environments using GGE biplot analysis. In the present study, mean grain yield data of all 8 genotypes for 6 environments were used to construct GE biplot. The "Which–won–where" plot represented higher mean performance of PG–1190 at NARC and PG–1135 as high yielding at Attock district. Similarly, PG–1162 yielded higher seed in Karak, and BARD–479, Golden and PG1190 performed well in Swat, Chakwal and Quetta, respectively.

Yan and Hunt (2001) described "which– won– where" patterns of polygon based interaction of GGE for screening and identification of elite genotypes at single or multiple environments. This model has also been used by Ding *et al.* (2008) and Ali *et al.* (2017) to screen best performing monetery pine and cotton genotypes in different environments, respectively. Environmental comparison plot indicated resemblance between environments i.e. Karak and Attock which corroborated with geographical proximity as well as their climatic conditions.

Conclusion

In Pakistan, groundnut is a marginal crop and mostly grown in rainfed areas unlike wheat, rice sugarcane and cotton which are widely grown in irrigated plains of Punjab and Sindh. Due to drastic changes in climate and unpredictable rainfall pattern, groundnut yield has been immensely influenced leading to fluctuated production. Besides, the diverse agro–ecologies of the country does not allow growers to rely on existing environment–responsive varieties. For breeding new groundnut cultivars, adaptation and yield stability must be accounted as important trait. Therefore, we represented results from univariate and multivariate approaches quantifying genotype by environment interactions on seed yield. Genotypes *i.e.* PG–1162, PG–167 and PG–1169 produced both above average yield and relatively remain consistent at different locations. These genotypes showed dynamic stability from Northern sub humid environs of the Mingora to arid cool climate of Quetta. It denotes presence of adaptable loci in these genotypes for adjusting photoperiodism and phenology according to the agroecological conditions. Local plant breeders can develop new cultivars by further improving these genotypes for yield and other economically important traits.

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References

Agbaje, G. and P. Oyekan, 2001. Yield and stability of groundnut (*Arachis hypogaea* L.) varieties in the derived savanna areas of South–western Nigeria. *Ghana. J. Agric. Sci.,* 34: 15–20

Ali, I., N.U. Khan, F. Mohammad, M.A. Iqbal, A. Abbas, Farhatullah, Z. Bibi, S. Ali, I.A. Khalil, S. Ahmad and M.U. Rahman, 2017. Genotype by environment and GGE–biplot analyses for seed cotton yield in upland cotton. *Pak. J. Bot.,* 49: 2273–2283

Anonymous, 2015. *edible Nuts – groundnuts*. Quarterly Bulletin International Trade Centre (ITC)

Bassi, F. and M. Sanchez–Garcia, 2017. Adaptation and stability analysis of ICARDA durum wheat elites across 18 countries. *Crop Sci.,* 57: 2419–2430

Becker, H. and J. Leon, 1988. Stability analysis in plant breeding. *Plant Breed.,* 101: 1–23

Butron, A., P. Velasco, A. Ordás and R. Malvar, 2004. Yield evaluation of maize cultivars across environments with different levels of pink stem borer infestation. *Crop Sci.,* 44: 741–747

Chavan, R., V. Toprope, P. Jagtap and B. Aglave, 2009. Stability analysis in groundnut for pod yield and its component traits. *Intl. J. Plant Sci.,* 4: 531–534

Crossa, J., P.L. Cornelius and W. Yan, 2002. Biplots of linear–bilinear models for studying crossover genotype × environment interaction. *Crop Sci.,* 42: 619–633

In Press

De Oliveira, EJ. and I.J. De Godoy, 2006. Pod yield stability analysis of runner peanut lines using AMMI. *Crop Breed. Appl. Biotechnol.,* 6: 310–317

Dehghani, H., A. Ebadi and A. Yousefi, 2006. Biplot analysis of genotype by environment interaction for barley yield in Iran. *Agron. J.,* 98: 388–393

Dolinassou, S., T. Noubissié, A. Djirantal and Y. Njintang, 2016. Genotype x environment interaction and kernel yield–stability of groundnut (*Arachis hypogaea* L.) in northern Cameroon. *J. Appl. Biol. Biotechnol.*, 4: 1–7

Eberhart, S.T. and W. Russell, 1966. Stability parameters for comparing varieties. *Crop Sci.,* 6: 36–40

El–Harty, E.H., S.S. Alghamdi, M.A. Khan, H.M. Migdadi and M. Farooq, 2018. Adaptability and stability analysis of different soybean genotypes using biplot model. *Intl. J. Agric. Biol*., 20: 2196–2202

Finlay, K. and G. Wilkinson, 1963. The analysis of adaptation in a plant–breeding programme. *Aus. J. Agric. Res.,* 14: 742–754

Francis, T. and L. Kannenberg, 1978. Yield stability studies in short–season maize. A descriptive method for grouping genotypes. *Can. J. Plant Sci.,* 58: 1029–1034

Gauch, H. and R. Zobel, 1996. AMMI analysis of yield trials. *In*: *Genotype by Environment Interaction*, pp: 85–122. Kang, M.S. and H.G. Gauch (eds.). CRC Press: Boca Raton, FL

Jarsso, M. and Y. Degago, 1997. Genotype x Environment interaction and grain yield stability in Faba bean. *In*: *Proceedings of the eight annual conference of the crop science society of Ethiopia, Sebil*, pp: 16–25. 26-27 February 1997, Addis Ababa, Ethiopia

Kaya, Y., M. Akçura and S. Taner, 2006. GGE–biplot analysis of multi–environment yield trials in bread wheat. *Turk. J. Agric. Fores.,* 30: 325–337

Kilic, H., M. Akçura and H. Aktas, 2010. Assessment of parametric and non–parametric methods for selecting stable and adapted durum wheat genotypes in multi–environments. *Notulae Bot. Hort. Agrobotan. Cluj–Napoca.,* 38: 271–277

Ma, B., W. Yan, L. Dwyer, J. Fregeau–Reid, H. Voldeng, Y. Dion and H. Nass, 2004. Graphic analysis of genotype, environment, nitrogen fertilizer, and their interactions on spring wheat yield. *Agron. J.,* 96: 169–180

Mothilal, A., P. Vindhiyavarman and N. Manivannan, 2010. Stability analysis of foliar disease resistant groundnut genotypes (*Arachis hypogaea* L.). *Elect. J. Plant Breed.,* 1: 1021–1023

Mussa, J.K.G., A. Belay, T. Wuletaw, M. Wendafrash and T. Tadele. 2001. Performance of elite faba bean genotypes for grain yield under waterlogged vertisols of the ethiopian highlands. *Paper Presented at 10th Annual Conference of the Crop Science Society of Ethiopia*; June, Addis Ababa, Ethiopia

Nassar, R. and M. Huehn, 1987. Studies on estimation of phenotypic stability: Tests of significance for nonparametric measures of phenotypic stability. *Biometrics,* 45–53

Nawaz, M.S., N. Nawaz, M. Yousuf, M.A. Khan, M.Y. Mirza, A.S. Mohmand, M.A. Sher and A. Masood, 2009. Stability performance for pod yield in groundnut. *Pak. J. Agric. Res.,* 22: 116–119

Oz, M., 2018. Yield and stability analysis of some sesame (*Sesamum indicum*) genotypes in Turkey. *Int. J. Agric. Biol*., 20: 821−825

Perkins, J.M. and J. Jinks, 1968. Environmental and genotype–environmental components of variability. *Heredity,* 23: 339–356

Sabah, M., M. El–Hady, A. El–Taweel and E. El–Harty, 2007. Stability statistics of some *Faba bean* genotypes. *Ann. Agric. Sci. Moshtohor.,* 45: 525–544

Sahay, G. and B. Sarma, 2005. Yield stability of some groundnut (*Arachis hypogea*) genotypes in meghalaya. *Ind. J. Agric. Res.,* 39: 221–224

Sanchez–Garcia, M., F. Álvaro, J.A. Martín–Sánchez, J.C. Sillero, J. Escribano and C. Royo, 2012. Breeding effects on the genotype × environment interaction for yield of bread wheat grown in Spain during the 20th century. *Field Crops Res.,* 126: 79–86

Santos, R.C., A.F. Silva, T.M.S. Gondim, J.L. Oliveira Júnior, R.B.D. Araújo Neto, E. Sagrilo and J.L.D. Silva Filho, 2012. Stability and adaptability of runner peanut genotypes based on nonlinear regression and AMMI analysis. *Pesqui Agropecuaria Bras.,* 47: 1118–1124

Shukla, G. 1972. Some statistical aspects of partitioning genotype environmental components of variability. *Heredity,* 29: 237–245

Temesgen, T., G. Keneni, T. Sefera and M. Jarso, 2015. Yield stability and relationships among stability parameters in faba bean (*Vicia faba* L.) genotypes. *Crop J.,* 3: 258–268

Thaware, B. 2009. Stability analysis for dry pod yield in Spanish bunch groundnut. *Agric. Sci. Digest.,* 29: 221–223

Wricke, G. 1962. Uber eine Methode zur Erfassung der okologischen Streubreite in Feldversuchen. Zeitschrift Fur Pflanzenzuchtung. *J. Plant Breed.,* 47: 92–98

Yan, W. 2002. Singular–value partitioning in biplot analysis of multienvironment trial data. *Agron. J.,* 94: 990–996

Yan, W. and L. Hunt, 2001. Interpretation of genotype × environment interaction for winter wheat yield in Ontario. *Crop Sci.,* 41: 19–25

Yan, W., L. Hunt, Q. Sheng and Z. Szlavnics, 2000. Cultivar evaluation and mega–environment investigation based on the GGE biplot. *Crop Sci.,* 40: 597–605

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