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Stability analysis of bread wheat [*Triticum aestivum* (L.) Em. Thell] using different models: A review

Vijeta Gupta, Mukesh Kumar, Vikram Singh and Lakshmi Chaudhary

Abstract

Wheat (*Triticum aestivum* L.) has been defined as the 'King of cereals' because of the acreage it occupies, high productivity and the prominent position it holds in the international food grain trade. It is an important human food crop, ranks on top three cereals in the world because of its adaptability, nutritional value and high yield potential which is mainly used for bread and biscuits purpose satisfying hunger globally. High temperature and drought are major abiotic stresses which affects the yield of wheat. For development of stable varieties having consistent performance in all the environments, there must be a presence of large genetic diversity in populations under study. From such populations one can identify genotypes showing wide stability under different environmental conditions. This is performed by understanding the interaction of genotype to the environment. Genotype × Environment Interaction (GEI) is a phenomenon related to the inconsistent performance under diverse environmental conditions and it plays an important role in performance of genotypes under different environment. To reveal patterns of GxE Interaction several methods such as Stability Factor, regression-based approach (Perkins & Jinks, 1968; Eberhart and Russell, 1966; Finlay & Wilkinson, 1963; Freeman and Perkins, 1971), AMMI model (Gauch, 1988) and GGE biplot analysis have been developed. So for the breeders to develop a variety suitable for different environments, the analysis of stability of genotypes is the most important tool.

Keywords: AMMI, Eberhart and Russell model, stability, wheat

Introduction

Wheat (*Triticum aestivum* L.) is a chief human dietary component and it is the most significant source of carbohydrates, proteins, minerals and vitamins for humans (El- Beltagi *et al*., 2021) [15]. The increasing demand of wheat products, due to a rapid increase in human population and changes in dietary preferences, have moved wheat into non-traditional areas formerly thought unacceptable for its production (Grote *et al*., 2021) [19]. That's why wheat is being grown in new environments. To adapt new crop varieties to multienvironments havimg elevated temperature and moisture deficit conditions and to address the needs of diverse wheat growing areas we need to develop a stable variety. Stability is suitability of a variety over a wide range of environments while adaptability is the better survival of a genotype over any specific environment. Therefore, it is essential to select the genotypes based on yield stability evaluation. Selection of genotypes for stability and adaptability is required prior to recommendation in crops which are grown in wide range of environments. Effects of genotype, environment and genotype x environment (G X E) interaction determine the phenotypic performance and its general and specific adaptation to different environments. There are several statistical procedures to analyze the stability and G X E interaction as joint regression (Eberhart and Russell 1966) [14] and additive main effects and multiplicative interaction, AMMI (Gauch 1992) [18]. Eberhart and Russell (1966) [14] suggested that the regression coefficient (b_i) and deviation from the regression coefficient (S^2d) might predict stable genotype. The Additive Main Effects and Multiplicative Interaction (AMMI) model is more popular among breeders now a days. This model quantifies the G X E interaction through PCA and graphical representation and has widely been used in multi-environment cultivar trials. (Balakrishnan *et al*., 2016) [6]. A large number of investigations on this aspect have been conducted over last three decades and the relevant literature pertaining to the present investigation entitled "Stability analysis of yield and yield attributing characters of promising bread wheat [*Triticum aestivum* (L) Em. Thell] genotypes" is reviewed under following heads:

- Effect on morpho-physiological traits in relation to rainfed (water deficit) and late sown conditions (heat stress) of wheat

- Analysis of variance for morpho-physiological parameters
- Estimates of GE interaction and Stability analysis in wheat by using AMMI biplot and Eberhart and Russell model

Effect on morpho-physiological traits in relation to rainfed (water deficit) and late sown conditions (heat stress) of wheat

Dhanda and Munjal (2012) [11] studied 28 wheat genotypes under two environments *viz.* timely and late sown conditions. They found that variety WH 1021 had a desirable combination of grain yield and heat tolerance potential, while WH 730 had a combination of cellular thermo-tolerance (TTC and chlorophyll fluorescence), heat tolerance (HRI) and high grain yield under heat stress conditions. Sareen *et al.* (2014) [38] evaluated twenty-five wheat genotypes in irrigated timely, rainfed timely and irrigated late sown conditions for 2 year using 10 agronomic traits for their response to drought and heat stress and four stress indices (stress susceptibility index, stress tolerance index, mean productivity, and stress tolerance) were calculated. Grain yield, plant height and productive tillers were found more sensitive and test grain weight was tolerant under drought. Under heat stress grain yield, grain weight and test grain weight were observed to be more sensitive. Genotypes CPAN 4079 and NEPAL 38 stable over all environments and can be used for introgression of the stress tolerance in elite cultivars. Mahrookashani *et al*. (2017) [27] studied combined effects of heat and drought on the physiological and yield traits. Single grain weight was reduced under drought stress by 13%–27% and under combined heat and drought stress by 43%–83%. Heat stress significantly decreased grain number by 14%–28%, grain yield by 16%–25% and straw yield by 15%–25% and concluded that cultivar responses were similar for heat but different for drought and combined heat and drought treatments. Dwivedi *et al.* (2018) [13] found that heat stress at terminal stages leads to severe reduction in 1000-grain weight, grain number /head, grain filling duration and grain yield. Furthermore, the high temperature results in disturbance in the transport of photosynthate from source (green foliage) to sink (tissues) and it leads to events such as high mortality of pollen grain and hence grain yield gets decreased. Fábián *et al.* (2019) [16] reported that heat stress affected plant physiology by altering availability of several chemicals and antioxidant compounds which play key role in metabolism. The changes induced alterations in the morphology and anatomy of female reproductive organs and shortened the duration of gametogenesis and grain filling. Dependent on floret position and tolerance to the heat stress, there was reduced fertility and plant production to an extent.

Kizilgeci *et al.* (2019) [23] evaluated fourteen bread wheat genotypes of Australian and Turkish origin for grain yield, quality and physiological parameters under Turkey environmental conditions and observed that NDVI, SPAD, LAI and canopy temperature of fourteen bread wheat genotypes were changed according to cultivars under the ecological conditions of Diyarbakir-Turkey. Qaseem *et al.* (2019) [32] exposed one hundred and eight elite diverse wheat genotypes to heat (H), drought (D) and combined stresses (HD) from heading till maturity. Grain yield was reduced by 56.47%, 53.05% and 44.66% under (HD), (H) and (D) treatment, respectively. The HD treatment affects the grain yield by reducing metabolism and mobilization of reserves to developing grains and leaves. They concluded that disintegration of membrane structure, chlorophyll and protein molecules was higher under heat stress than drought stress while water status of genotypes and sink strength was more affected by drought than heat stress. A pot study was done by Sattar *et al.* (2020) [39] using homogenous lot of wheat seeds variety ‘Faisalabad-2008’ to assess the influence of drought and combined (drought and heat) stress on wheat seedlings and found more reduction in yield and yield components of wheat where combined stress (drought and heat) was applied. A significant reduction in growth duration, grain growth rate, 100 grain weight, chlorophyll contents was observed after drought and heat stress treatment. Quality traits of wheat grains were significantly affected under drought, heat and drought +heat stress conditions and concluded that effect of simultaneously applied drought and heat stress was more severe as compared to individual effect of drought and heat stress.

Terminal heat stress in late sown wheat is one of the major constraints studied by Youldash *et al.* (2020) [45] by planting fifty-eight wheat genotypes of diverse origin at optimal and late sowing times at the Agricultural Research Area, Cukurova University, Adana, Turkey. Wheat sown at optimal time had better growth and yield-related traits, which lead to better grain yield. In late sown (heat stress conditions) crop, grain yield of all tested genotypes was significantly decreased. Aberkane *et al.* (2021) [1] assessed sixty-seven lines of durum wheat varieties with accessions of *Triticum aegilopoides*, *T. dicoccoides Koern*, *T. urartu* and *Aegilops speltoides* for drought and heat tolerance. The trials were conducted during two seasons (2016−2017 and 2017–2018) at Tessaout, Morocco, under full irrigation (optimal conditions) and rainfed conditions (drought stressed) and at Wed Medani, Sudan, under full irrigation combined with heat stress. Drought reduced the grain yield by 62%. High variation was found for agronomic traits, with heading time delineating 16% of grain yield under drought, while thousand kernel weight considering for 18% of the yield under heat. The data from the experiments by Boussakouran *et al.* (2021) [9] revealed that grain yield and associated traits were essentially affected by water regime and growing season in wheat and concluded that the nonirrigated plots had 30% lower grain yield than irrigated ones. The number of spikes per m^2 was the yield component most affected by drought conditions. Singh *et al.* (2021) used 16 Indian wheat lines in his study. Timely sowing and late sowing of wheat was carried out dated 15th November and 12th December 2016, respectively. Grain of TSW and DSW trials were accomplished dated 20th April, and 25th April 2017, respectively. Timely sown wheat (TSW) and delayed sown wheat (DSW) were compared to see the effects of heat stress (HS). Delayed sowing decreased grain yield and diameter while increased protein and all categories of gliadins and high molecular weight glutenins. Yashavanthakumar *et al.* (2021) [44] evaluated 36 genotypes for yield traits, phenological traits, plant architectural traits, physiological traits and stress index under drought, heat and combined stress environments. The combination of high temperature and water deficit asserted highest yield losses (55.96%) when compared to control followed by drought (41.11%) and least affected by heat alone (4.77%).

Analysis of variance for morpho-physiological parameters

Analysis of variance (ANOVA) is a collection of statistical models and their associated estimation procedures (such as the "variation" among and between groups) used to analyze the differences among means. ANOVA was developed by the statistician Ronald Fisher (Cleophas and Zwinderman, 2021) [10]. The ANOVA is based on the law of total variance, where the observed variance in a particular variable is partitioned into components attributable to different sources of variation. In its simplest form, ANOVA provides a statistical test of whether two or more population means are equal, and therefore generalizes the *t*-test beyond two means.

Tambe *et al.* (2013) [41] studied variability for yield and its attributing traits in 28 genotypes of durum wheat. The results of analysis of variance (ANOVA) indicated that there were significant differences between the genotypes for all the traits under study. It indicated the presence of considerable genetic variability among all the genotypes under study for various traits.

Thapa *et al*. (2019) [42] revealed the mean squares due to treatments for all the traits in both the environment (normal and heat stress) were highly significant, thereby suggesting the presence of considerable amount of variability among the one hundred ninety (190) wheat genotypes with respect to traits studied under present study. Mekonnen *et al*. (2020) [28] evaluated ten released durum wheat varieties during 2016 and 2017 at five districts representing various agro-ecologies of northwestern Ethiopia using Randomized Complete Block Design, replicated three times. Grain yield and protein contents (%) of entries were scored and the ANOVAs were performed for the traits under study. Analysis of variance revealed a significant difference among the tested varieties for the grain yield in all tested locations. The results of analysis of variance by Roy *et al*., 2021 [34] revealed that mean sum of squares for all the characters were highly significant ($P \leq 0.05$) and it was highest for biological yield per plant (376.385) followed by number of grains per spike (86.169) and grain yield per plant (81.302) indicating significant variability existing among all the genotypes for all the characters studied.

Estimates of GE interaction and Stability analysis in wheat using AMMI biplot and Eberehart & Russell model

Identification of high yielding and stable genotypes across variable environments has been a continued challenge to plant breeders worldwide. The characterization of stable genotypes is often complicated by the frequent occurrence of genotype-by-environment interactions (GEI) (Alwala *et al*., 2010) [3]. Environmental conditions strongly influence agricultural production, leading to considerable variations in yield. Such influence is discriminated when yield experiments are performed in various locations and in different years (Neisse *et al*., 2018) [31]. Such influence is termed genotype-environment interaction (GEI). In the case of multi-environment trial (MET) data, GEI is frequently present and the presence of genotype-environment interaction (GEI) influences production making the selection of cultivars in a complex process. The two most used methods to analyze GEI and evaluate genotypes are AMMI and Eberhart & Russell joint regression method that are widely used to identify high yielding and stable genotypes. Eberhart & Russell (1966) [14] suggested that regression coefficient ‘b’ and deviation from regression coefficient ‘S^2d’ might predict stable genotype. A cultivar with $b = 1$ and $S^2d = 0$ might be stable across divergent environmental conditions (Anwar *et al*., 2011) [4]. In addition, additive main effects and multiplicative interaction (AMMI) analysis is another approach, which combines both the ANOVA (with additive parameters) and Principal Component Analysis (with multiplicative parameters) into a single analysis (Gauch and Zobel, 1988) [17]. It is also an effective tool to diagnose genotype environment interaction patterns graphically (Kumar *et al*., 2018) [13] and is a powerful tool for effective analysis and interpretation of multienvironment data structure in breeding programs.

Mahmodi *et al*. (2011) [26] determined stable bread wheat genotypes with high grain yield *via* a single parameter, field experiments were conducted with 14 genotypes for 3 consecutive years (2008-2011) under two different conditions (irrigated and rainfed) in a complete randomized block design with three replications in each environment. Combined analysis of variance showed highly significant differences for the GE (genotype-environment) interaction indicating the possibility of selection for stable entries. The results of AMMI (additive main effect and multiplicative interaction) analysis indicated that the first four AMMI (AMMI1–AMMI4) were highly significant ($P< 0.01$). The partitioning of TSS (total sum of squares) exhibited that the environmental effect was a predominant source of variation followed by GE interaction and genotype effect. The GE interaction was ~5 times higher than that of the genotype effect, suggesting the possible existence of different environment groups. AMMI stability value discriminated genotypes 10 and 6 as the stable accessions, respectively.

Mladenov *et al.* (2012) [29] determined influence of genotype, environment and their interaction on yield to evaluate stability through AMMI model. Grain samples were obtained from ten winter wheat cultivars grown in 2009/10 and 2010/11 at three locations in Serbia, Novi Sad, Sremska Mitrovica and Pančevo. Yield of different cultivars were investigated and statistically analysed *via* AMMI model which shows significant differences between genotypes at various locations. Best performer was Simonida with average yield 8.22 $t \cdot ha^{-1}$.

Sareen *et al*. (2012) [37] evaluated wheat genotypes developed for stress and normal environments by different research centers across 7 locations representing varied agroclimatic zones during 2007–08 and 2008–09 to study their adaptability for heat stress and non-stress environments. The additive main effects and multiplicative interaction analysis for G × E interactions revealed differences amongst locations to phenology and grain yield. Genotype RAJ 4083 developed for cultivation under late sown conditions in peninsular zone was also found adaptable to timely sown conditions. Similarly, HD 2733 a cultivar of NEPZ timely sown conditions and PBW 574 an advanced breeding line of NWPZ late sown conditions was found adapted to Peninsular zone. The cultivar RAJ 3765 showed specific adaptability to Pantnagar in NWPZ. Genotype NW 3069 developed for NEPZ timely sown conditions have shown adaptability to number of locations; timely sown conditions at Karnal and Hisar in NWPZ and Niphad in PZ. Likewise, WH 1022 developed for NEPZ late sown conditions exhibited specific adaptability to all timely sown locations in NWPZ.

Ten bread wheat genotypes were evaluated by Hagos *et al.* (2013) [20] at five wheat growing locations of Tigray region in the year 2011. Yield data was analyzed using the additive main effect and multiplication interaction model (AMMI) and GGE biplot. The AMMI analysis of variance for grain yield detected significant effects for genotype, location and genotype by location interaction. Location effect was responsible for the greatest part of the variation, followed by genotype and genotype by location interaction effects. Based on AMMI stability value, G4, G10, G8 and G9 were the most stable genotypes, while G1, G2, and G3 were found to be the most responsive genotypes.

Bavandpori *et al*. (2014) [7] conducted experiments with 20 genotypes for 3 consecutive years (2011-2013) under two different conditions (irrigated and rainfed) in a randomized complete block design with three replications in each environment. Combined analysis of variance showed highly significant differences for the GE (genotype-environment) interaction indicating the possibility of selecting stable entries. The results of AMMI (additive main effect and multiplicative interaction) analysis indicated that the first two AMMI (AMMI1–AMMI2) were highly significant ($P< 0.01$). The partitioning of total sum of squares exhibited that the environment effect was a predominant source of variation followed by GE interaction and genotype effect. The GE interaction was three times higher than that of the genotype effect, suggesting the possible existence of different environment groups. AMMI stability value (ASV) discriminated genotypes G12, G18, G13, G14 and G11as the stable genotypes, respectively.

Heidari *et al.* (2016) [21] investigated yield stability and adaptability of 17 advanced durum wheat genotypes (G) in four environments over two crop years (2011-12 and 2012-13) under rainfed and supplementary irrigation (IRR) conditions. Combined analysis of variance showed that environmental factor and GEI explained 70% and 10.71% of total sum of squares, respectively. The AMMI and GGE biplot model were used to study the nature of GEI on the grain yield. First and second component of AMMI model totally explained 90.73% of GEI variations. The results indicated that AMMI and GGE biplot are facilitated visual comparison and informative methods to detect genotypes stability and in the preferential genotypes recommendations.

Alam *et al.* (2017) [2] evaluated eight promising wheat genotypes against two standard checks across five locations under terminal heat stress condition. The experimental design was an RCBD with three replications in one year. AMMI analyses exhibited significant ($p< 0.01$) variation in genotype, location and genotype by location interaction with respect to grain yield. The ASV value revealed that GEN4, GEN9 and GEN8 were stable, while GEN5, GEN1 and GEN6 were the most sensitive genotypes. The genotype GEN7 (BAW 1202) was released as BARI Gom 32. Considering all analysis, GEN3 (BAW 1194), GEN7 (BAW 1202) and GEN8 (BAW 1203) demonstrated more stable genotypes with high mean yield, resistant to BpLB and leaf rust.

Jeberson *et al.* (2017) [22] evaluated the eleven wheat genotypes under eight locations representing typical rainfed conditions of the North Hill Zone. The study based on AMMI and GGE biplot analysis methods to highlight the G×E interaction in multi-location trials and stratification of genotypes as per their adaptability for rainfed conditions of the northern hill zone. Combined ANOVA analysis showed highly significant differences ($p< 0.001$) of 11 genotypes under rainfed conditions of North Hill Zone. Highly significant environments, genotypes and G×E interaction explained 81.4%, 2.3% and 15.7% of the total sum of squares, respectively. The significant GE interaction sum of squares is further portioned into seven significant Interaction Principal Components Axes (IPCAs) and a residual term.

Rasul *et al.* (2017) [33] assessed an International Collection (IC) of 18 spring wheat genotypes and another set of 15 spring wheat cultivars adapted to South Dakota (SD), USA to characterize the genetic component of LMAA over 5 and 13 environments, respectively. The data were analysed using a GGE model with a mixed linear model approach and stability analysis was presented using an AMMI biplot on R software. All estimated variance components and their proportions to the total phenotypic variance were highly significant for both sets of genotypes, which were validated by the AMMI model analysis. Significant genetic effects and stability analyses showed some genotypes, e.g. ‘Lancer’, ‘Chester’ and ‘LoSprout’ from IC, and ‘Alsen’, ‘Traverse’ and ‘Forefront’ from SD cultivars could be used as parents to develop new cultivars expressing low levels of LMAA. Stability analysis using an AMMI bi-plot revealed that ‘Chester’, ‘Lancer’ and ‘Advance’ were the most stable across environments, while in contrast, ‘Kinsman’, ‘Lerma52’ and ‘Traverse’ exhibited the lowest stability for LMAA across environments.

Kumar *et al*. (2018) [13] evaluated a set of 177 genotypes from East Gangetic Plain Sown Nursery (EGPSN) for 11 different morpho-physiological traits *viz*., germination percentage, seedling survival, days to heading, number of productive tillers, plant height and days to maturity, spike length, number of spikelets per spike, number of grains per spike, thousand grain weight and grain yield per m^2 under irrigated and nonirrigated conditions consecutively for two years 2007-08 and 2008-09. Field screening was done in multi-environment for four years for identifying stable drought tolerant wheat genotypes. Stability analysis and AMMI biplot was performed to analyze the stable performance of genotypes across the environments and years. Based on physiological parameters and molecular analysis, the genotypes namely, ET127225, ET127230, EC531185, ET127236, ET127267 and ET127269 were found to be potential genetic resources for drought tolerance, which can be further used in wheat improvement programme.

Mohammadi *et al.* (2018) [30] assessed genotype × environment (GE) interaction for grain yield in rainfed durum wheat and analysed the relationships of GE interaction with genotypic/meteorological variables by the additive main effects and multiplicative interaction (AMMI) model. Grain yield and some related traits were evaluated in 25 durum wheat genotypes in 12 rainfed environments differing in winter air temperature. The AMMI analysis of variance indicated that the environment had highest contribution (84.3% of total variation) to the variation in grain yield. The first interaction principal component axis (IPCA1) explained 77.5% of GE interaction sum of squares (SS), and its effect was 5.5 times greater than the genotype effect, indicating that the IPCA1 contributed remarkably to the total GE interaction. Large GE interaction for grain yield was detected, indicating specific adaptation of genotypes.

A panel of 30 advanced lines with two checks (Anaj17 and Ujala16) was grown by Zulkiffal *et al.* (2018) [46] under normal, drought and heat prone environments. The data of 9 different traits were subjected to multivariate technique and stability analysis. For stability imagining, biplots were constructed to partition the genotypes and genotype by environment effects for 6 stress adaptive traits. All three environments were far from the biplot origin for exclusively CTBT, ND*VIA*N for normal, GRW for heat, CTAN for drought and heat. Biplot exhibited that normal environment is comparatively high contributor to the stability of genotypes for yield.

Sardouei-Nasab *et al*. (2019) [36] evaluated two recombinant inbred line (RIL) populations bred from crosses between a drought-tolerant landrace 'Roshan' and the cultivars 'Sabalan' and 'Falat' in the field under both well-watered and water-stressed conditions. The drought stress was imposed by stopping irrigation at the flowering stage. The additive main effects and multiplicative interaction (AMMI) model was employed to determine the yield stability of the RILs. Finally, set of 10 drought-tolerant lines with consistent performance were screened across the test environments. The results of the AMMI and REMEL analysis showed that environment was the major source of variability (69.98%) followed by GEI (12%). The two AMMI biplots revealed that a set of three RILs yielded stably in all environments with the high mean yield response.

Dhiwar *et al*. (2020) [12] conducted experiment with twelve genotypes of wheat using Eberhart and Russell (1966) [14] model for days to heading, days to maturity (days), plant height (cm), spike length (cm), spikelets per spike, effective tillers per plant, grains per spike, 1000 grain weight (g), grain yield per hectare (q), biological yield per hectare (q) and harvest index in three date of sowing during Rabi- 2019-20. The variances due to genotypes was found significant revealed the presence of genetic variability for all the characters under study. Differences due to Genotype × Environment were also found highly significant for all the study traits, indicates that genotypes interacted considerably to environmental conditions in different environments. Only the genotype CG-1029 having high mean performance, non-significant regression coefficient deviation from unity (bi=1) and non-significant deviation from zero ($S^2d=0$) in term of grain yield per hectare. Hence, in term of grain yield per hectare CG-1029 can be considered the most stable and adopted to all environments compared to other stable genotypes.

Said *et al*. (2020) [35] selected wheat stable cultivars with high productivity across various environments using the models of Eberhart & Russell (1966) [14] and Tai (1971). Five wheat cultivars *viz*, Shandwell 1, Sids 1, Sids 12, Giza 168 and Misr 2 were grown in a randomized complete block design with four replications under sixteen environmental conditions (2 years x 2 locations x 4 sowing dates) on yield and yield components during two successive seasons of 2017/2018 and 2018/2019. Pooled analysis of variance for grain yield and its components revealed significant variance due to genotypes, environments and their interactions. According to Eberhart & Russell and Tai, the cultivar Shandwell 1 and Sids 12 was genetically stable across various environments because it showed high mean performance for grain yield over these environments when compared with grand mean beside acceptable stability parameters.

Thirty wheat genotypes were tested by Suresh *et al*., 2020 [40] for yield stability under two dates of sowing i.e. late and very late for two consecutive years. Stability was measured based on regression (bi) and stability parameter (S2di) according to stability model of Eberhart and Russell. Significant differences for grain yield among genotypes and environments were present. The mean square for GXE interaction was highly significant for grain yield ($P< 0.01$) which revealed that different genotypes ranked differently among these environments. Further linear interaction of GXE was also significant, indicating differences among the regression coefficients With these parameters, four varieties (HD 3059, WH 1105, HTW 66 and WH 1124) for late sown conditions whereas three varieties (HTW 11, WH 730 and BWL 5186) for very late sown conditions were found promising with their yield stability under late and very late sown environment. Four genotypes namely, HD 3059, WH 1105, HTW 66 and WH 1124 with bi significantly greater than 1 and higher average productivity than overall mean are suitable for late sown condition.

Verma and Singh (2020) [43] conducted field trials using sixteen advanced wheat genotypes at eight locations and sixteen genotypes at nine locations at of northern hills zone during 2018-19 and 2019-20 cropping seasons, respectively in randomized complete block designs with four replications. Highly significant effects of environment (E), GxE interaction and genotypes (G) observed by AMMI analysis during 2018-19 and 2019-20 studied years. Environment explained about significantly 53% of the total sum of squares due to treatments indicating that diverse environments caused most of the variations in genotypes yield. Significant proportion of GxE interaction deserves the stability estimation of genotypes over environments. Genotypes explained only 5.4% of total sum of squares, whereas GxE interaction accounted for 30.5% of treatment variations in yield. More of GxE interaction sum of squares as compared to genotypes indicated the presence of genotypic differences across environments and complex GxE interaction for wheat yield.

Attia *et al*. (2021) [5] evaluated the productivity of bread wheat cultivars under rainfed conditions of different locations in the NWCZ of Egypt. AMMI analysis revealed that the environment was responsible for most of the cultivars yields variation also AMMI2 bi-plot revealed that East Barrani in the first season was the most favorable environment for all cultivars, and Sakha 94 was the superior cultivar in this environment. According to the Eberhart and Russel Sakha 94 was the most stable cultivar followed by Misr 1. Sakha 93 cultivar is considered as the most stable high yielding genotypes under both moderate and severe drought conditions.

Bishwas *et al*. (2021) [8] conducted field experiment using 18 elite wheat lines and 2 check varieties in alpha lattice design (2 replication and 5 blocks per replication) in two different environment *viz*. irrigated and terminal heat stress. The AMMI Model with GGE bi-plots were used for analyzing the yield stability of elite lines in the heat stress and irrigated environment using GEAR. The analysis of variance revealed that genotype, environment and their interaction had highly significant effect on the yield. Similarly, Mean-versus-stability study indicated that elite line BL-4407, NL-1368, BL-4919, NL-1350 and NL-1420 had above average yield and higher stability whereas elite lines Gautam, NL-1412, NL-1376, NL-1387, NL-1404 and N-1381 had below average yield and lower stability.

Kumar *et al*. (2021) [24] conducted experiment using forty wheat genotypes and evaluated them for two years (2017-19) with different dates of sowing. Pooled analysis of variance showed highly significant variations for genotypes, environments and genotypes x environments (G X E).

Stability analysis for grain yield revealed that the genotypes LOK-1, NI-5439 and HUW-468 has a high mean value and non-significant regression coefficient (bi) and non-significant deviation from regression and found more stable across the four environments.

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