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Review on Effect of Genotype x Environment Interaction and Yield Stability Among Sorghum (*Sorghum bicolor (L.)* Moench.) Genotypes

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Abstract: Sorghum is a prominent cereal crop, particularly in the world's semi-arid tropics. It is grown in over 105 countries across Africa, Asia, Oceania, and the Americas on 40 million hectares. Sorghum is an important indigenous food crop, second only to teff in terms of production of injera (leavened native flat bread). The majority of sorghum varieties are recommended for various agro ecological zones (AEZs), and no single variety is appropriate for all of Ethiopia's circumstances (GxE). GxE affects grain yield, nutritional quality and content, as well as physicochemical and malting quality. The interaction of an organism's genetic composition with its environment results in phenotype, which is a physical trait. The presence of GEI complicates the selection of yield and yield-related traits. GEI can inhibit progress in the selection process and is a key driver of genotype-to-genotype yield stability differences. Plant breeders should investigate GEI in order to better understand crop development in relation to biophysical conditions. In different agro-ecologies, locales, and seasons, genotypes will respond differently. Agronomic/dynamic stability refers to a genotype's ability to adapt to changes in the environment. Breeders should encourage the development of varieties/hybrids that can adapt to a wide range of environments. Crossover and non-crossover gene x environment interactions (GEI) are the two forms of GEI. When there is a disparity in genotypic performance between individuals. Statistical analysis of yield studies can help agronomists, breeders, and other agricultural specialists make faster progress. G x E Interaction and Stability Analysis permits genotypes' relative performance and stability for yield and yield-related variables to be assessed. Therefore the objective of this review study is to assess the role of G x E on yield stability of sorghum.

Keywords: Sorghum, Yield, Genotype, Stability

1. Introduction

Sorghum (*Sorghum bicolor (L.)* Moench) is a major cereal crop, especially in the semi-arid tropics of the world. After wheat, rice, maize, and barley, it is the world's fifth most important cereal [27]. Sorghum is grown on 40 million hectares in over 105 countries across Africa, Asia, Oceania, and the Americas [38], with 60 percent of this land in Africa, where it continues to play an important role in food security [47]. Sorghum is a tropical crop classified as C4 and belongs to the Gramineae family [31]. Sorghum is a naturally self-pollinated plant with up to 20% spontaneous cross pollination under some situations, based on panicle types (Endalamaw and Semahegn, 2020). Ethiopia is the birthplace and diversification hub for sorghum [15]. It is the most significant grain crop in Ethiopia's lowlands and is extensively distributed throughout the country because of its drought tolerance [34].

Sorghum [*Sorghum bicolor* (L.) Moench] is the sixth most widely grown crop in the world, with 63.9 million metric tons produced and 58 million hectares harvested [26]. Sorghum is grown in practically every region of Ethiopia, ranking third in terms of area coverage behind tef and maize, and has a national average production of 2.71 tons/ha [9]. It is the most important crop in Ethiopia's arid lowlands, accounting for 66 percent of the country's total farmed land, and its national average production is 2.5 tons per hectare. However, research has shown that improved varieties and agricultural strategies can boost Sorghum yield from 3 to 6 tons per hectare [71]. However, a number of obstacles have stood in the way of sorghum production.

Lack of early maturing varieties that can withstand drought, poor soil fertility, poor stand establishment due to reduced emergence in characteristically crusty soils, insect pests such as spotted stalk borers (Chilopartellus), and birds are among the major problems of sorghum production in the country's dry land areas [29]. A variety of open pollinated sorghum cultivars have been introduced by national and regional sorghum improvement initiatives for Ethiopia's moisture shortage arid lowland areas. For decades, pure line selections and pedigree breeding have been the primary breeding activities aimed at the three major agro ecologies. Several open pollinated sorghum varieties have been released for production using these approaches [29]. However, one of the biggest constraints for sorghum production and productivity in Ethiopia's moisture-stressed areas is a lack of extensively adapted and stable high yielding varieties.

Sorghum is a major indigenous food crop that ranks second only to teff in terms of injera (leavened native flat bread) production. Porridge, "injera," "Kitta," "Nifro," infant food, syrup, and native beverages like "Tella" and "Areke" are all made from sorghum grain [45]. With 70-80 percent carbohydrate, 11- 13 percent protein, 2-5 percent fat, 1-3 percent fiber, and 1-2 percent ash, sorghum grain has a significant nutritional value. Sorghum protein is gluten-free, making it a specialist diet for celiac disease (gluten intolerance) sufferers, including diabetics, and a viable substitute for cereal grains including wheat, barley, and rye [13].

It possesses extraordinary genetic variety because it is native to Ethiopia, as proven by various landrace collections conducted in the country. It is highly adaptable to a wide range of semi-arid African climatic conditions. It is mostly produced in Ethiopia's middle and lowlands. It can endure hot and dry conditions better than most Ethiopian crops. Sorghum is farmed for its grain, which is used in food and local beverages; however, the stalk is now used as animal feed and fuel [3].

Because of the effects of genotype-environment interaction, most sorghum varieties are indicated for specific agro ecological zones (AEZs), and no variety is suitable to all of Ethiopia's conditions (GxE). GxE has an impact on grain yield, nutritional quality and content, physicochemical qualities and malting quality, and total soluble solids in sorghum [3, 4, 48]. GGE biplots, which graphically portray genotype by environment interaction in a two-dimensional space, provide a visual representation of the interactions between genotypes and environments, can be used to assess genotype by environment interaction [43].

One of the issues researchers/breeders have in generating broadly adapted cultivars with larger yields is yield stability [4]. For a long time, the notions of GxE and yield stability have been a hindrance to breeders. A significant GxE for a quantitative trait is known to limit the genotype means' utility in screening out and moving superior genotypes to the next stage of selection across all environments [51]. If GxE didn't exist, selection would be much easier because the 'best' genotype in one environment would also be the 'best' genotype in all target settings [5]. As a result, the goal of this review study is to evaluate the yield and stability of sorghum genotypes across locations.

2. Literature Review

2.1. Sorghum Origin and Domestication

Sorghum's geographic genesis and early domestication occurred in Africa. Sorghum [Sorghum bicolor (L.) Moench] is thought to have originated and been domesticated in Ethiopia [64]. The early domestication of farmed sorghum [Sorghum bicolor (L.) Moench] is thought to have occurred in north-eastern Africa. Due to the great variety of the crop, Vavilov proposed Ethiopia as a site of origin for sorghum in 195 [64]). Some scholars think that the crop should have many origins. Stemler et al. [61] found no indication that sorghum was domesticated or originated in Ethiopia, based on biogeographic, morphological, historical, or evolutionary evidence. Some writers believe sorghum originated in India, whereas others believe sorghum originated and was domesticated in southern and northern China. All views about sorghum's genesis and domestication were founded on archaeological evidence. However, the time and location are not necessarily accurate [36].

2.2. Sorghum Research Strategy in Ethiopia

Ethiopian farmers have traditionally chosen landrace genotypes with good quality attributes such as greater grain size and diverse colors for various end applications, as well as good plant biomass, tailored to certain environments and management strategies such as intercropping [30, 44]. Since the 1970s, the EIB (Ethiopian Institute of Biodiversity) and the national sorghum improvement program in Melkassa agricultural center have been collecting and conserving a large number of sorghum landraces. To date, more than ten thousand sorghum collections have been maintained in the EIB (Ethiopian Institute of Biodiversity) and the national sorghum improvement program in Melkassa agricultural center [35].

Ethiopia is also a major contributor to ICRISAT and the US National Plant Germplasm System's global sorghum collections [12]. High yielding, photoperiod insensitive, abiotic and biotic stress resistant cultivars for adaptability to a variety of agroclimatic environments have been the focus of breeding efforts. The identification of dwarfing genes in sorghum has resulted in the production of a number of short-statured sorghum hybrids that respond well to high-input farming [37].

Sorghum breeding in Ethiopia began in the early 1950s. Improved varieties lack farmers' favored features such as plant height, grain size, and so on, which is one of the main reasons for low acceptance [44]. Introduced lines were used to generate 85% of the improved varieties released for lowland and intermediate conditions, and their traits include short plant stature, early maturity, and smaller grain size [4], [44]. All of the varieties released for the highland environment, on the other hand, were pure lines selected from highland landrace collections; however, these improved varieties only have a small yield advantage over farmers' selected varieties or landraces, which is one of the reasons for their lower adoption rate by farmers [44].

The Ethiopian Institute of Agricultural Research (EIAR), formerly the Institute of Agricultural Research (IAR), took over the sorghum research program in 1982, and Melkassa Agricultural Research Centre (MARC) has been managing the research statewide since then. The study concentrated on four sorghum-growing environments: dry and hot-humid lowlands, as well as mid- and high-altitude regions. More than 52 improved sorghum varieties, along with agronomic and crop protection recommendations, have been published for production in various agro-ecologies, despite a low rate of acceptance of these released varieties and agronomic and crop protection recommendations [18].

According to [18], the sorghum sub-sector anticipates a steady demand for varieties with better, more stable yields and acceptable quality in the next years. To meet this demand, much of the attention will be on breeding new varieties that are high yielding, adaptable to a variety of habitats, and tolerant to many stresses including climate change, the appearance of new pests and diseases, and other biotic and abiotic factors. The plan will aim to speed up crop improvement by combining traditional and modern methods and technology that allow for the handling of vast amounts of genetic material and more precise selection. This will necessitate a greater integration of traditional plant breeding methods with current biotechnology tools and methods.

2.3. Sorghum Production and Importance

After wheat, maize, rice, and barley, sorghum is the world's fifth most important cereal crop, with an area of 42.70 million ha and a total yield of 62.3 million tons. Sorghum is grown on around 26.14 million hectares in Africa, with total production and average yields of 42.35 million tons and 1.62 ton/ha, respectively [25]. Ethiopia is the second-largest sorghum producer in Eastern Africa, after Sudan, and ranks third in terms of area coverage behind teff and maize, as well as second in terms of productivity (2.7 t/ha) [11].

Because of its wider adaptation to drought-prone locations, sorghum is grown globally for food and feed in dry land agriculture [55]. Sorghum is a favoured cereal in dry and semi-arid locations because of its short growth time and drought tolerance. Sorghum is used in the manufacture of biofuels, beer, and silage. Sorghum is given special attention as a food-grade grain because it is gluten-free and high in health-promoting phytonutrients. Sorghum is largely used as a food crop in underdeveloped nations, and grain yields have been greatly enhanced. Sorghum is the primary food supply for more than 500 million people in poor countries.

Sorghum is grown for human consumption and animal feed in Asia and Africa [62]. It has been exploited as a source for bioethanol production in recent years, particularly with sweet sorghum varieties with high sugar content on their stalks [52]. After maize, barley, and oats, sorghum is the fourth most important crop for biofuel generation [65]. Because sorghum cultivars have easily available fermentable sugars within the culm, using sorghum as a source of bio-fuel will reduce the cost of enzymatic conversion of starch to sugar [65, 62]. In comparison to other crops used for bioethanol production, such as sugarcane and maize, sorghum is drought and salt resistant, making it a good choice for biofuel generation in factories [62].

2.4. Genotype and Phenotype by Environment Interaction and Its Importance in Plant Breeding

Becker [7] defines genotype as any of the following: pure-line variety, Clone, inbred-line, hybrid variety, open-pollinated variety, composite variety, synthetic variety, elite breeding lines, and others on which the breeder collects performance and trait data. Phenotype, on the other hand, is a physical trait that arises from the interaction of an organism's genetic composition with its environment. The term "environment" refers to a combination of physical characteristics of a location, as well as climatic and other seasonal characteristics (such as soil type, fertility, topography, temperature, rainfall, and pest/disease challenge) that influence plant growth and productivity during the growing season [20]. Environments with similar "biotic and abiotic stressors, cropping system requirements, customer preferences, and volume of production" were first classified as mega-environments.

In agricultural research, genotype by environment interaction (GEI) is a typical occurrence. Differences in genotypic values may rise or fall from one environment to the next, causing genotypes to rank differently in different contexts [54]. The GEI investigations are challenging because they require integrated methodologies that include a variety of disciplines such as agriculture, biology, statistics, computer science, and genetics. The genotype, the environment, and the interaction of the genotype and the environment are all significant components of phenotypic diversity, as shown by the GEI study [7, 2].

There are two sorts of interactions, according to Beker [8]. There are two types: cross-over and non-cross-over. Cross-over (qualitative) interaction refers to changes in genotype ranks from one environment to the next, indicating that the environments are not perfectly correlated. It is critical for precise recommendations for a limited number of contexts. On the other side, the non-cross over interaction (quantitative) refers to heterogeneity of genotype differences without a change in genotype rank across contexts, implying that a genotype will be the best or worst in all test conditions. As a result, for broader adaptability, a single genotype can be recommended. The crossover type, which affects top-yielding genotypes, is the most important GEI effect for cultivar targeting [8, 46].

Plant breeders should research GEI because interactions can stifle progress in the selection process and because it is a fundamental driver of yield stability discrepancies across genotypes. Crop breeders and farmers prefer varieties with low GEI and high consistent yields since this suggests that the environment has less of an impact on them and that their greater yields are mostly due to their genetic composition. When selecting well-adapted genotypes and the optimum planting date, it is critical to select and understand crop development in connection to biophysical circumstances and seasonal fluctuations [40, 69, 66].

The presence of GEI makes yield and yield-related trait selection more difficult. Plant breeding efforts to analyze and enhance crops rely heavily on yield trials done in many sites and years [57]. Microenvironment error variances and GEI variances are assumed to be homogeneous across environments and genotypes in most trials [17]. Because the presence of a cross-over interaction has such a big impact on breeding for certain adaptations, it's crucial to figure out how common they are. There are two basic ways to GEI in general. The first strategy is to create high-yielding genotypes with low GEI interaction, or genotypes that can adapt to a wide range of mega environments. The second strategy is to use GEI to breed genotypes for optimal yield and stability in mega environments [69].

In most situations, however, breeders seek a variety with good average performance across a wide range of settings (METs). Such an approach makes sense if there is no genotype by environment interaction, however seed yield is a quantitative trait that is heavily influenced by genotype, environment, and their interactions, and thus has a low heritability. As a result, unless environmental variation is well controlled, direct seed yield selection may be unexpected [49]. Statistical models can be used to describe and understand genotype by environment interaction, which is a significant limiting factor in the estimation of variance components and the efficacy of selection programs [10].

2.5. Genotype x Environment Interaction

Plant breeders are still working on developing sorghum genotypes with high yield potential, resistance to major pests and sub-heading diseases, greater grain size, and improved nutritional value. Furthermore, the new variety should have a consistent performance and be adaptable to a variety of settings. For a long time, however, the characteristic of yield stability has posed a significant obstacle to sorghum breeding initiatives. Stability study is a crucial technique for cultivar development in a variety of settings or for a single area [56]. Stability can be categorized into three types, according to Lin et al. [39]: Type-1, Type-2, and Type-3. Type 1 (biological or static stability) genotypes are non-responsive to changes in input levels and so are stable across sites with minimal environmental differences. A genotype's ability to adjust to changes in the environment is referred to as agronomic/dynamic stability [41].

Genotypes will behave differently in different agro-ecologies, locations, and seasons. Genotypes that are stable perform consistently in a variety of situations [4]. Significant G X E effects, according to Sharma et al. [58], lower the correlation between an individual's genotype and phenotype, making it difficult to assess a genotype's genetic potential, which complicates the selection process. As a result, testing genotypes for stability and adaption is critical for choosing superior genotypes. Breeders should embrace the development of varieties/hybrids with broad and specialized adaptation in order to attain substantial genetic gains [59].

There are two types of genotype x environment interaction (GEI): cross over and non-cross over. When there is a difference in genotypic performance in different contexts, the cross over GEI is displayed [14]. Non-cross over GEI indicates that a genotype performs consistently in different settings. As a result, multi-environment trials have been established to aid in the selection of genotypes for target production agro-ecologies [68]. During the release of new varieties and hybrids, information obtained from stability studies is equally significant in distinctiveness, uniformity, and stability (DUS) testing and national performance trials (NPT). For stability and genotype by environment analysis, a lot of statistical approaches have been developed [59]. These include: Combined ANOVA [33], coefficient of determination (r^2) by bi-plot models using Additive Main Effects and Multiplicative Interactions (AMMI), and coefficient of determination (r^2) by the bi-plot models using Additive Main Effects and Multiplicative Interactions (AMMI) [28] & GGE (Genotype-Genotype-Environment Interaction) [68].

2.6. Stability

Stability refers to a genotype's ability to adapt to a variety of situations and is used to choose stable genotypes. The term "stability" is used to describe a genotype that produces a relatively consistent yield regardless of environmental changes. As a result of this concept, genotypes with a low variance in yield across diverse conditions are thought to be stable [1]. The interaction of genotype and environment has an impact on yield stability. The broad incidence of G x E is the reason of variances in yield stability between genotypes. When grown in a range of conditions, a variety or genotype is regarded more adaptable or stable if it has a high mean yield but a low degree of volatility in yielding ability.

The biological or static notion and the agronomic or dynamic idea are two types of phenotypic stability concepts. The biological idea of stability relates to a genotype's consistent functioning in a variety of situations. According to Becker and Leon [6], biological stability means that a genotype's performance remains constant independent of environmental changes, meaning that its variance among environments is zero. Dynamic stability, also known as the agronomical notion of stability, states that a stable genotype should always deliver a high yield expected at the level of productivity of the various settings, implying that a variety with the lowest GXE feasible is preferred [7].

All stability approaches based on quantifying GXE effects, according to Becker and Leon [6], pertain to the dynamic stability concept. This includes Wricke's ecovalence and Shukla's (1972) stability of variance partitioning procedures, as well as regression-based procedures proposed by Finlay and Wilkinson [24, 16] and non-parametric stability statistics.

Lin et al. [39] established three types of stability: type one is a stable genotype that maintains its performance despite changes in environmental variables. The genotypic variations across settings and the coefficient of variability utilized as a stability metric for each genotype are the parameters used for this form of stability. This stability was dubbed a biological concept of stability by Becker and Leon [6]. Type two stability notions identify a genotype as stable if it has no deviations from the general response to environments and so allows for a predictable response to those settings. This form of stability can be measured using a regression coefficient developed by Finlay and Wilkinson [24] and a stability variance developed by Shukla [60]. The agronomic notion of stability was coined by Becker and Leon [6]. The idea of type three stability relates to a genotype with a low mean deviation. As a result, if the residual mean square from the regression model on the environmental index is modest, a genotype is considered stable. When breeding for broad adaptability, the stability analysis technique must be interpreted and approached differently than when breeding for specific adaptability. This is part of the agronomic stability idea, according to Becker and Leon [6].

2.7. Statistical Methods to Measure G x E Interaction and Stability

The investigation of genotype-by-environment (GE) interactions is a necessary step before recommending novel selections for large-scale production. Because the performance of tested genotypes is impacted by genotype, environment, and G E interaction, it permits assessment of the relative performance and stability of genotypes for yield and yield-related variables [32].

Agronomists, breeders, and other agricultural experts can benefit from statistical analysis of yield experiments to achieve faster progress. One of the most prevalent activities in agricultural research is yield trials, which involve testing a variety of varieties in a variety of settings. Because the most stable genotype(s) may not be the highest yielding, approaches for selecting superior genotypes that combine yield performance and stability become significant. To establish whether cultivars tested in MET are stable, a variety of stability statistics have been used [63].

If relative performances of cultivars grown in different range of environments are different, the G X E interaction becomes a major challenging factor to crop breeding programs. Several statistical methods have been widely adapted to analyze and interpret G × E data to reveal patterns of GEI, such as joint regression [24]; Eberhart and Russell [16], sum of squared deviations from regression [16], stability variance [60], stability ecovalence (Wi2) proposed by [67]; combined analysis of variance (ANOVA) to quantify G X E interactions that describe the main effects Genotype (G) and environment (E) but this did not provide enough information to explain the interaction effect.

2.7.1. Wricke's Stability

Ecovalence was defined by Wricke as the contribution of each genotype to the GEI sum of squares. The interaction of the ith genotype with the environments, squared and summed across environments, is its ecovalence (Wi) or stability. Low-Wi genotypes exhibit less variations from the overall mean across environments and are hence more stable. The steady genotype has a low ecovalence, according to the definition of ecovalence.

2.7.2. Shukla's Stability Variance

Another similar measure of phenotypic stability developed by Shukla is the variance component of each genotype across contexts. After controlling for environmental main effects, Shukla defined stability variance as an unbiased estimate of genotype i's variance across environments. Because the genotype main effect is constant, the stability variance in a two-way classification is based on the residual (GEij+ eij) matrix. If the stability variance (2i) of a genotype equals the environmental variance (2o), the genotype is stable. As a result, a relatively high value of (2i) indicates more genotype I instability. Because the stability variance is the difference between the two sums of squares, it can be negative, although in variance component problems, negative estimate of variance is not unusual. Purchase [53] considers a negative estimate of (2i) to be equal to zero.

2.7.3. Eberhart and Russell's Joint Regression Model

According to the joint linear regression model which was developed by Finlay and Wilkinson [24] and modified by Eberhart and Russell [16], a stable genotype is one with a high mean yield, regression coefficient equals to one (bi=1) and deviation from regression equals to zero (S^2di=0). A genotype with a bi value of less than 1.0 has more stability and is more adaptable to low-performing settings. A genotype with a bi value greater than 1 has less stability and is more adaptive to high temperatures. A genotype with a bi value of 1 has average stability in performing contexts. Thus, depending on whether the mean is high or low, is well or poorly adaptive to all conditions [24]. According to Eberhart and Russell [16], the most relevant stability parameters appeared to be the deviation from linear regression mean square because this statistic included all types of gene action. When the data set contains only a few high or low yielding locations, regression analysis should be performed with caution [10].

2.7.4. Cultivar Superiority Measure (Pi)

The closer the genotype is to the maximum yield, the smaller the Pi values are; this indicates that the genotype is superior. Pi values were calculated based on the whole location mean; they indicate superiority in terms of general adaptability or wide adaption [10]. As a result, the ideal genotype is the one with the lowest Pi value and the smallest genotype by environment interaction contribution.

2.7.5. AMMI Stability Value

Another method is the AMMI stability value (ASV), which is calculated using the AMMI model's first and second interaction principal component axis (IPCA) scores for each genotype. In a two-dimensional scatter map of IPCA2 against IPCA1 scores, ASV quantifies the distance from the genotype coordinate point to the origin. The shortest projection from the biplot origin identifies the genotypes with the lowest ASV values, which are regarded the most stable. A genotype with the lowest ASV score is the most stable across diverse environments in the additive main effect and multiplicative interaction stability analysis (ASV) method, and the higher the ASV value (either negative or positive), the more specifically adapted a genotype is to specific environments [53]. The AMMI stability value (ASV) as described by Purchase (1997) was calculated as follow

$$ASV = \sqrt{[\frac{IPCA1_{sumofsquare}}{IPCA2_{sumofsquare}}(IPCA1_{Score})]^2 + (IPCA2_{Score})^2}$$

2.7.6. Yield Stability Index

As a measure of stability, Farshadfar et al. [21] created yield stability index (YSI), which is comparable to genotype selection index developed by Farshadfar et al. [22]. The YSI is determined by adding the rank of mean seed yield across environments and the rank of genotype AMMI stability value. The lowest AMMI stability value receives rank one, while the highest yield mean receives rank one, and the rankings are then added together to form a single simultaneous yield and yield stability selection index. This parameter's lowest value indicates preferred genotypes with high mean yield and stability.

2.7.7. Additive Main Effects and Multiplicative Interaction (AMMI)

The data will be subjected to multivariate analysis utilizing the additive main effects and multiplicative interaction (AMMI) model to determine the interaction effects [69]. It's useful for analyzing METs [10]. AMMI is a bi-linear (multiplicative effects) and linear (additive effects) model that combines two statistical procedures, analysis of variance and principal component analysis. AMMI analysis can help identify the most stable and productive genotype, promote region-specific cultivars, provide more precise estimates of genotypic responses, and make biplot graph comprehension easier.

The AMMI approach has three main applications. The first is model diagnostics; AMMI is better for initial statistical analysis of yield trials because it gives an analytical tool for identifying other models as sub cases when they are better for certain data sets. Second, AMMI explains the GEI and highlights genotype and environment patterns and interactions. The third application is to increase yield estimation accuracy. Gains in yield estimate accuracy comparable to increasing the number of repetitions by a factor of two to five have been reported [10].

The AMMI model's combination of analysis of variance and principal components analysis, as well as prediction assessment, is a useful tool for better understanding GEI and estimating yields. The interaction is depicted in the form of a bi-plot display, in which PCA scores are plotted against each other and the GEI components are visually inspected and interpreted. Integrating bi-plot and genotypic displays. Genotypes can be grouped using stability statistics depending on how well they behave in different situations. The figure makes it easy to see the average productivity of genotypes, environments, and their interactions for all genotype-environment combinations. In the AMMI study, genotype IPCA scores indicate environmental stability or adaptation [10, 28].

2.7.8. Genotype Main Effect and Genotype by Environment Interaction (GGE) Bi-plot

The genotypic main effect (G) and genotype by environment interaction (GEI) bi-plot graphically presents the genotypic main effect (G) and genotype by environment interaction (GEI) of the multi environment trial (MET) data, making visual evaluation of both genotypes and environments easier [69]. To completely explore MET data, it is an effective method based on principal component analysis (PCA). A bi-plot is a scatter plot that shows a point for each genotype and environment graphically. The best genotype with the maximum yield in a quadrant including identical locations (Mega-Environments), genotype average performance and stability, optimal genotype and ideal site to maximize yield, and specific location may all be seen on a GGE bi-plot.

GGE bi-plot is an effective tool for: 1) mega-environment identification (e.g. "which-won-where" pattern), where specific genotypes can be recommended to specific mega environments [70]; 2) genotype evaluation, where the estimation of yield and stability of genotypes was done using the average environment (tester) coordinate (AEC) methods in GGE bi-plot methodology. The average environment (tester) coordinate (AEC) is a line that passes through the biplot origin and is defined by the average PC1 and PC2 scores for all environments [70]. (3) Examination of the test environment, with a closer proximity to the concentric circle indicating a greater mean yield.

In agriculture, GGE bi-plot analysis is increasingly being employed in GEI data processing. However, there has been a small amount of information about GGE application. The environmental vectors are the lines that connect the environment to the bi-origin plot's (EV). The length of environmental vectors is proportional to their standard deviation, which is a measure of a given environment's capacity to discriminate [68].

When compared to AMMI graphs of mega environments, the GGE biplot is more accurate and practical since it describes an intermediate proportion of the sum of squares of genotypes and genotypes by environments (G + GE) [42]. Ezzat et al. [19] found significant interactions between genotypes, localities, and dates for all the traits evaluated in a study on the agronomic performance and stability of 25 sorghum F1 hybrids and their 10 parents. However, grain yield stability studies revealed that F1 hybrids had higher grain yields than their parents, but that the parents were more stable. Figueiredo et al. [23] observed substantial GxE interactions for all traits in another investigation on the GxE influence of 25 sorghum genotypes examined in nine locations. In a study on sweet sorghums, significant genotype by environment interaction was discovered for the majority of the attributes [50]. Rono et al. [56] found that the environment (E) and genotype by environment interaction (GEI) have significant effects on sweet sorghum yield.

3. Conclusion

The majority of sorghum varieties are recommended for various agro ecological zones (AEZs), and no single variety is appropriate for all of Ethiopia's circumstances (GxE). GxE affects grain yield, nutritional quality and content, as well as physicochemical and malting quality. Ethiopia has made significant contributions to the global sorghum collections of ICRISAT and the US National Plant Germplasm System. For various end applications, Ethiopian farmers have traditionally chosen landrace genotypes with superior quality traits such as larger grain size and diverse colors. One of the main causes for low acceptability is that improved varieties lack farmers' preferred traits such as plant height, grain size, and etc.

The interaction of an organism's genetic composition with its environment results in phenotype, which is a physical trait. The presence of GEI complicates the selection of yield and yield-related traits. GEI can inhibit progress in the selection process and is a key driver of genotype-to-genotype yield stability differences. Plant breeders should investigate GEI in order to better understand crop development in relation to biophysical conditions.

References

[1] Abiy Legesse and Firew Mekbib. (2016). Genotype X Environment Interaction and Stability of Early Maturing Sorghum [*Sorghum bicolor* (L.) Moench] Genotypes in Ethiopia. M.Sc. Thesis, Alemaya University of Agriculture, Ethiopia: 2016-01-04T05: 19: 25Z.

[2] Acquaah, G. (2012). Principles of plant genetics and breeding 2nd ed. First published by John Wiley & Sons, Ltd. 740p.

[3] Admas, S., &Tesfaye, K. (2017). Genotype-by-environment interaction and yield stability analysis in sorghum (Sorghum bicolor (L.) Moench) genotypes in North Shewa, Ethiopia. Agriculture and Environment, 9, 82–94. https://doi.org/10.1515ausae-2017-0008

[4] Adugna, A. (2007). Assessment of yield stability in sorghum. African Crop Science Journal, 15 (2), 83–92. http://dx.doi.org/10.4314/acsj.v15i2.54421

[5] Basford, K. E. and Cooper, M. (1998). Genotype x environment interactions and some considerations of their implications for wheat breeding in Australia. *Australian Journal of Agricultural Research* 49: 153-174.

[6] Becker, H. C. and Léon, L., (1988). Stability analysis in plant breeding. Plant Breeding, 101: 123.

[7] Beker, R. J. 1988. Tests for crossover genotype by environmental interactions. Can.j. plant sci 48: 405-410.

[8] Braun, H. J., Rajaram, S. and Ginel, M. V. (1996). CIMMYT's approach to breeding for wide adaptation. Euphytica, 92: 175-183.

[9] Central Statistical Agency, CSA. (2017). Report on area and production of crops (Statistical Bulletin 584, Volume I). Addis Abeba, Ethiopia.

[10] Crossa, J. (1990). Statistical analyses of multi-location trials. Advances in agronomy 44: 55-85.

[11] CSA (Central Statistical Agency). 2018. Agricultural Sample Survey report on Area and Production of Major Crops (Private Peasant Holdings 'Meher' Season): Statistical Bulletin 585. Addis Ababa, Ethiopia.

[12] Dahlberg JA, Burke JJ, Rosenow DT. (2004). Development of a sorghum core collection: refinement and evaluation of a subset from Sudan. Econ Bot 58: 556-567.

[13] Dial, H. L. (2012). Plant guide for sorghum (Sorghum bicolor L.). USDA-Natural Resources Conservation Service, Tucson Plant Materials Center, Tucson, AZ.

[14] Ding, M., Tier, B. and Yan, W. (2007). Application of GGE biplot analysis to evaluate genotype (G), environment (E) and GxE interaction on P. radiata: case study. Pages 132-142 in Australasian Forest Genetics Conference, 11th- 14th April 2007, the Old Woolstore, Hobart, Tasmania, Australia.

[15] Doggett, H. (1988) Sorghum. 2nd ed. Longman, London.

[16] Eberhart S. A., and Russell W. A. (1966). Stability Parameters for Comparing Varieties. Iowa State University, Crop Science. 6: 36-40.

[17] Edwards, J. W. and Jannink, J. L., (2006). Bayesian modeling of heterogeneous error and genotype by environment interaction variances. Crop Science 46 (2): 820-833.

[18] Ethiopian Institute of Agricultural Research (EIAR), 2014. Ethiopian strategy for sorghum. Country strategy document.

[19] Ezzat, E. M., Ali, M. A. and Mahmoud, A. M. (2010). Agronomic performance, genotype x environment interactions and stability analysis of grain sorghum (Sorghum bicolor L. Moench). Asian Journal of Crop Science, 2: 250-260.

[20] Falconer, D. S. and Mackay, T. F. C. (1996). Introduction to quantitative genetics. 4th edition, Longman, New York P. 132-133.

[21] Farshadfar, E., Rasoli, V., Teixeira da Silva, J. A. and Farshadfar, M., (2011). Inheritance of drought tolerance indicators in bread wheat (Triticum aestivum L.) using a diallel technique. *Australian Journal of Crop Science,* 5 (7): 870-878.

[22] Farshadfar, E., Sabaghpour, S. H. and Khaksar, N., (2008). Inheritance of drought tolerance in chickpea (Cicer arietinum L.) using joint scaling test. *Journal of. Applied. Science,* (8): 3931-3937.

[23] Figueiredo, U. J., Nunes J. A. R., da C. Parrella R. A., Souza E. D., da Silva A. R., Emygdio B. M., Machado J. R. A. and Tardin F. D. (2015). Adaptability and stability of genotypes of sweet sorghum by GGE Biplot and Toler methods. Genetics and Molecular Research, 14 (3): 11211-11221.

[24] Finlay, K. W. and Wilkinson, G. N. (1963). The analysis of adaptation in a plant breeding program. *Australian Journal of Agricultural Research,* 14: 742-754.

[25] Food and Agriculture Organization (FAO) (2017). Food and Agriculture Organization of the United Nations, Rome, Italy.

[26] Food and Agriculture Organization (FAO) (2018) Food and agriculture data. Available at: http://www.fao.org/faostat/en/#data/QC. (Accessed 14 January 2018).

[27] Food, C. (2020) 'of wag lasta, north eastern Ethiopia Evaluation of sorghum (Sorghum bicolor (L.) Moench) variety performance in the lowlands area of wag lasta, north eastern Ethiopia'. doi: 10.1080/23311932.2020.1778603.

[28] Gauch H. G. and Zobel. R. W. (1992). Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. Crop Science 30: 493–500.

[29] Gebeyehu Geremew, Asfaw Adugna, Taye Tadesse, Tesefaye Tesso, Ketema Belete, Hailemichael H. (2004). Development of sorghum varieties and hybrids for dry land areas of Ethiopia. Uga J Agri Sci., 9: 594-605.

[30] Georgis K, Abebe A, Negasi A et al. (1990). Cereal-legume intercropping research in Ethiopia. In: Waddington SR, Palmer AFE, Edje OT (eds) Research methods for cereal legume intercropping. Proc. Workshop on Research Methods for Cereal/Legume Intercropping in Eastern and Southern Africa. CIMMYT. P167-175.

[31] Harlan, J. R. & J. M. J. de Wet, (1972). A simplified classification of sorghum. Crop Science 12: 172–176.

[32] Horn L., Shimelis H., Sarsu F., Mwadzingeni L., and Laing M. D. 2017. Genotype-by- environment interaction for grain yield among novel cowpea (Vigna unguiculata L.) selections derived by gamma irradiation. *The Crop Journal*, 6 (3): 306–313.

[33] Kandus, M., Almorza D., Ronceros R. B. and Salerno J. C. (2010). Statistical models for evaluating the genotype-environment interaction in maize (Zea mays L.). *International Journal of Experimental Botany,* 79: 39-46.

[34] Kebede, Y. (1991). The role of Ethiopian sorghum germ- plasm resources in the national breeding pro- gramme. In J. M. Engels, J. G. Hawkes, & M. Worede (Eds.), Plant genetic resources of Ethiopia (pp. 315– 322). *Cambridge University Press.*

[35] Kimber CT, Dahlberg JA, Kresovich S. (2013). The Gene Pool of Sorghum bicolor and Its Improvement. In: Paterson A. H. (ed.) Genomics of the Saccharinae, Plant Genetics and Genomics: Crops and Model. 23-41, Springer Science, Media New York.

[36] Kimber, C. T. (2000). Classification origin of domesticated sorghum and its early diffusion to India and China. p. 3–98. In: Smith W. C. and Frederiksen, R. A. (Eds.). Sorghum Origin, History, Technology and Production. Wiley & Sons, New York.

[37] Kinfe H. Yield performance and adoption of released sorghum varieties in ethiopia (2018) Edelweiss Appli Sci Tech 2: 46-55.

[38] Kumar, A. A, Reddy, B. V. S. Sharma, H. C. Hash, C. T. Rao, P. S. Ramaiah, B. and Reddy, P. S. (2011). Recent Advances in Sorghum Genetic Enhancement Research at ICRISAT. *American Journal of Plant Sciences*, 2: 589-600.

[39] Lin, C. S., Bains, M. R., and Lefkovitch, L. P. (1986). Stability Analysis: Where Do We Stand? Crop Science 26: 894-900.

[40] Linnemann, A. R., Westphal, E. and Wessel, M. (1995). Photoperiod regulation of development and growth in bambara groundnut (Vignasubterranea). Field Crops Research 40 (1): 39-47.

[41] Makanda I. (2009). Combining ability and heterosis for stem sugar traits and grain yield components in dual purpose sorghum (Sorghum bicolor [L.] Moench) germplasm. PhD Thesis, University of Kwazul Natal, South Africa.

[42] Marcio, B., de Souza J. C., Von P. R. G., de Oliveira R. L., and Valente Paes J. M. (2009). Yield stability and adaptability of maize hybrids based on GGE biplot analysis characteristics. Crop Breeding and Applied Biotechnology, 9: 219-228.

[43] Massaoudou, H. *et al.* (2018) 'Identification of stable genotypes and genotype by environment interaction for grain yield in sorghum (Sorghum bicolor L. Moench)', (November). doi: 10.1017/S1479262118000382.

[44] Mekbib, F. (2006). Farmer and formal breeding of sorghum (Sorghum bicolor (L.) Moench) and the implications for integrated plant breeding. Euphytica, 152 (2), 163–176. https://doi.org/10.1007/s10681-006-9191-7

[45] MoANR (Ministry of Agriculture and Natural Resource). 2016. Plant and Animal Health Regulatory Directorate. Crop variety register issue No. 20. Addis Ababa, Ethiopia.

[46] Muir, W., Nyquist, W. E. and Xu, S. (1992). Alternative partitioning of the genotype by environment interaction. Theor. Appl. Genetics 84: 193-200.

[47] Mutegi, E., Signard, F., Semagn, K., Deu, M., Muraya, M., Kanyenji, B., De Villiers, S., Kiambi, D., Herselman, L., &Labuschagne, M. (2011). Genetic structure and relationship within and between cultivated and wild sorghum (Sorghum bicolor (L.) Moench) in Kenya as revealed by microsatellite markers. Theoretical and Applied Genetics, 122 (5), 989–1004. https://doi.org/10.1007/s00122-010-1504-5

[48] Nida, H., Seyoum, A., &Gebreyohannes, A. (2016). Evaluation of yield performance of intermediate altitude sorghum (Sorghum bicolor (L.) Moench) genotypes using genotype x environment interaction analysis and GGE biplot in Ethiopia. International Journal of Trends in Research and Development, 3 (2), 2394–9333. http://www.ijtrd.com/papers/IJTRD3499.pdf

[49] Ofori, I. (1996). Correlation and Path coefficient analysis of components of seed yield in Bambara groundnut (VignaSubterranea). Euphytica 92: 103-107.

[50] Olweny, C. (2015). Studies on genetic diversity, genotype by environment interaction, combining ability and farmers' perception on sweet sorghum (Sorghum bicolor [L.] Moench). PhD Thesis. Makerere University, Uganda.

[51] Pham, H. N. and Kang, M. S. (1988). Interrelationships among and repeatability of several stability statistics estimated from international maize trials. Crop Science 28: 925-928.

[52] Prasad, P. V. V. and Staggenborg, S. A. (2010). Growth and production of sorghum and millets. In soils, plant growth and crop production –Volume II. In: Encyclopedia of Life Support Systems, Eolss Publishers, and Oxford, UK. http:// www.eolss.net. Access data.

[53] Purchase, J. L, (1997). Parametric analysis to describe genotype by environment interaction and stability in winter wheat. PhD. thesis. Department of Agronomy, Faculty of Agriculture, University of the Orange Free State, Bloemfonten, South Africa.

[54] Rao P. S., Reddy P. S., Rathore A., Reddy B. V. S. and Panwar S. (2011). Application GGE biplot and AMMI model to evaluate sweet sorghum (Sorghum bicolor) hybrids for genotype × environment interaction and seasonal adaptation. Indian Journal of Agricultural Sciences, 81 (5): 438–444.

[55] Reddy VG, Rao NK, Reddy BS, Prasada Rao KE. (2002). Geographic distribution of Basic and Intermediate races in the World Collection of Sorghum Germplasm. Int Sorghum Millets Newsl 43: 15-16.

[56] Rono, J. K., Cheruiyot E. K., and Othira J. O. (2016). Adaptability and Stability Study of Selected Sweet Sorghum Genotypes for Ethanol Production under Different Environments Using AMMI Analysis and GGE Biplots. The Scientific World Journal, 14: 1-14. https://doi.org/10.1155/2016/4060857.

[57] Seyoum, A., Semahegn, Z. and Gebreyohannes, A. (2019) 'nal of Agricultural Science and Research AMMI and GGE bipolt analysis of Genotype x Environ- ment Interaction and Yield Stability of Pearl Millet Geno- types [Pennisetum glaucum (L.) R. Br.] in Moisture Stressed Areas of Ethiopia', 7 (May). doi: 10.14662/ARJASR2019.038.

[58] Sharma, R. C., Smith E. L., and Mc New R. W. (1987). Stability of harvest index and grain yield in winter wheat. Crop Science, 27: 104-108.

[59] Showemimo, F. A. (2007). Grain yield response and stability indices in sorghum (Sorghum bicolor (L.) Moench). Commununications in Biometry and Crop Science, 2 (1), 68–73.

[60] Shukla, G. K. (1972). Some statistical aspects of partitioning genotype-environmental components of variability. Heredity, 29: 237-24.

[61] Stemler, A. B., Harlan, J. R., and Dewet, J. M. (1975). Evolutionary history of cultivated sorghum [Sorghum bicolour (L.) Moench] of Ethiopia. Bulletin of the Torrey Botanical Club 325-333.

[62] Taylor, J. R. N. (2003). Overview importance of sorghum in Africa [Online]. Available from: http: WWw.sciencedirect/science

[63] Tewodros Mulualem and Zelalem Bekeko (2017). Current advances in G x E analysis models and their interpretations, an implication for genotype selection for multiple environments. Crop. Science. (2): 64–72.

[64] Vavilov, N. I. 1951. The origin, variation, immunity and breeding of cultivated plants. p. 366. Translated by Chester K. S. Ronald Press, New York.

[65] Wilhelm, W. W., Johnson, J. M. F. Hatfield, J. L., Voorhees W. B. and Linden, D. R (2004). Crop and soil productivity response to corn residue removal. Agron. J. 96: 1-17.

[66] Worede, F. *et al.* (2020) 'areas of Northeast Ethiopia Yield stability and adaptability of lowland sorghum (Sorghum bicolor (L.) Moench) in moisture-deficit areas of Northeast Ethiopia', 1932. doi: 10.1080/23311932.2020.1736865.

[67] Wricke G. (1962). On a method of understanding the biological diversity in field Research. Z. Pfl. Zücht 47: 92–146.

[68] Yan, W. and Tinker, N. A. (2006). Biplot analysis of multi-environment trial data: Principles and applications. Canadian Journal of Plant Science, 86: 623–645.

[69] Yan, W., Hunt, L. A., Sheng Q., and Szlavnics Z. (2000). Cultivar evaluation and mega- environment investigation based on the GGE biplot. Crop Science 40: 597-605.

[70] Yan, W., Kang M. S., Maa B., Woods S., and Cornelius P. L. (2007). GGE Biplot vs. AMMI Analysis of Genotype-by-Environment Data. Crop Science, 47: 641- 653.

[71] Yitayeh, Z. S., Mindaye, T. T. and Bisetegn, K. B. (2019) 'AMMI and GGE Analysis of GxE and Yield Stability of Early Maturing Sorghum [Sorghum bicolor (L.) Moench] Genotypes in Dry Lowland Areas of Ethiopia', 5 (1), pp. 1–10. doi: 10.4172/2329-8863.1000425.