The Role of Genotype by Environmental Interaction in Plant Breeding

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Abstract

A genotype x environment interaction is a change in the relative performance of a character of two or more genotypes measured into two or more environments. Living organisms are made up of genes whose expressions are subject to modification by environment; therefore, genotypic expression of a phenotype is environmentally dependent. This is because genotypes exhibit different level of phenotypic expression under different environmental conditions resulting in cross over performances. In genotype x environment interaction, the magnitude of the observed genetic variation changes from one environment to another and tends to be larger in better environments than poor environments. Genotype x environment interaction is a fundamental component in understanding complex trait variation and the most challenging factor in identification of genetic variation. Interaction involves a change in rank order for genotypes between environments and the relative magnitude of genetic, environmental and phenotypic variance between environments. Genotype x environmental interaction can lead to differences in performance of genotypes over environments. The relationship between selection environments and target production environment had been a major problem because many of the selected activities performed by the conventional approach. Genotype x environment interaction analysis can be used to analyze the stability of genotypes and the value of test locations. Genotypes by environment interactions are almost unanimously considered to be among the major factors limiting response to selection and, in general, the efficiency of breeding programs. Exploitation of genetic variability is the most important tool in plant breeding and this has to be inferred by phenotypic expression. The consequences of the phenotypic variation depend largely on the environment. This variation is further complicated by the fact that not all genotypes react in similar ways to change in environment and no two environments are exactly the same. If relative performance of genotypes grown in different environments is different, then genotype x environment interaction becomes a major challenging factor to crop breeding programs. Genotype x environment interaction is one of the main challenge in the selection of broad adaptation and stable genotypes in most breeding programs. The varietal stability could be challenged not only due to the change in the test environment but also due to change in growing season per environment. Some environmental variations are predictable (soil type, soil fertility, plant density) whereas others also may be unpredictable (rainfall, temperature, humidity).Generally, genotype x environment interaction is the most critical in plant breeding to make selection of genotypes based on their adaptability and stability for desirable traits.
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1. INTRODUCTION

Genotype by environment interaction (GxE) refers to the differential responses of genotypes across environments (Bavandpori *et al*., 2015). Living organisms are identified neither by their genes nor by their environment; they are the result of the interaction of genes and environment (Suzuki *et al*., 1981). A genotype x environment interaction is a change in the relative performance of two or more genotypes tested in two or more environments. Interactions may involve change in rank order for genotypes between environments and change in the absolute and relative magnitude of the genetic, environmental and phenotypic variances between environments (Bowman, 1972). In general, genotype by environment interactions happen when two or more genotypes perform differently in several environments, and are selected as differential genotypic sensitivities to environments (Sarah and Maria, 2011) and GxEs are also considered as a challenge to crop improvement in a target region (Kang, 1998). Genotype by environment interactions (GxE) is important factor to be studied in plant breeding. The genotypes by environment interaction and yield stability have been challenges to the breeders and biometricians for many years. A significant genotype by environment interaction is used to diminish the genotype means across environments for choosing and advancing high yielder genotypes to the next stage of selection (Pham and Kang, 1988, Asfaw, 2007). A non-significant genotype by environment interaction simplified the selection because the 'best' genotype in one environment would also be the 'best' genotype for all target environments (Basford and Cooper, 1998, Asfaw, 2007). The phenotype of an individual is determined by the effects of its genotypes, the environment, and the interaction between the genotype of the individual and the environment (Yan and Tinker; 2005, Abiy and Firew, 2016). The genotype by environment interaction results in non-stable performances between the genotypes across environments. Thus, significant GxE results from the changes in the degree of differences between genotypes in diverse environments or changes in the relative ranking of the performance of the genotypes (Falconer, 1952) and

(Fernandez, 1991). According to Baker (1990) and Cornelius *et al*. (1996) GxEs have been categorized in to crossover and non-crossover interactions.

When the same genotype is subjected to different environments, it can produce a wide range of phenotypes. These phenotypic variations are attributable to the effect of the environment on the expression and function of genes influencing the trait. Changes in the relative performance of genotypes across different environments are referred to as genotype- environment interactions. The repeatable genotypes by environment interaction resulted, change the ranking of genotypes across environments, and are meaningful for the specific breeding strategy (Sabaghnia *et al*., 2008). Genotypes by environment interactions are common for most quantitative traits such as yield, plant height, weight and others economic important traits. Genotype x environment (GxE) interaction and yield-stability analysis has continued to be important in measuring varietal stability and suitability for cultivation across seasons and ecological zones. The analyses of genotype x environment has focused on the identification of stable genotypes for cultivation. According to (cooper, 2001) the magnitude of genotype by environmental interaction is higher where there is wide variation between environments in incidence of the same stress such as climate, soil, biotic and management factors. Environmental factors can be micro or macro, non-organic or organic, and internal or external. Plant growth and yield are affected by both intercellular and external environments.

Plant breeding identifies causes of genotype by environment interaction towards predictability, separate predictable from unpredictable, GxE Separate into G and E components of the GxE Structured models. Several statistical models have been used to understand interactions of different crops for identifying suitable genotypes (Bose *et al*., 2014). A GxE is important to minimize the usefulness of the genotype means across locations or environments for selecting and advancing superior genotypes to the next stage of selection (Pham and Kang, 1988, Natalia de Leon *et al*., 2016). Plant breeders have managed these interactions throughout the history of crop domestication, crop improvement, and dispersal, and within recent history through the formalized procedures of plant breeding. The applied breeder now has the ability to manipulate genes identified as mechanistically involved in GxE. Likewise, interactions that are understood at morphological and physiological levels can be predicted using crop growth models (CGM), leading to target ideotypes defined phenotypically, as promoted for many years (Donald, 1968, cited by Natalia de Leon *et al*., 2016), or genetically as in new approaches (Technow *et al*., 2015, Natalia de Leon *et al*., 2016). Plant breeding is primarily depends on presence of substantial genetic variation to address the maximum genetic yield potential of the crops and exploitation of this variation through effective selection for improvement. The selection of plants from a population is almost always based on their phenotype and the phenotype has both heritable and non-heritable components.

The most important issue in plant breeding is creating genetic diversity and manipulating genetic variability. Phenotypic variation is positively associated with genetic diversity, yet also depends on environmental factors and the interactions between genotype and environment (Buckler *et al*., 2006). Genotypes x environment (GxE) interactions are important in the development and evaluation of plant varieties because they reduce the genotypic-stability values under diverse environments (Hebert *et al*., 1995). Significant achievement in crop production may be possible by breeding varieties for their stability for yield and yield components (Singh *et al*., 2009; Lal *et al*., 2010). Statistically, G x E interactions are detected as a significantly different pattern of responses among the genotype across environments and biologically, this will occur when the contributions (level of expression) of the genes regulating the trait differ among environments (Basford and Cooper, 1998).

A conceptual GxE interaction is commonly depicted as the slope of the line when genotype performance is plotted against an environmental gradient. Non-parallel, but non-intersecting lines indicate that the rank of cultivar performance stays the same across environments. Lines that intersect indicate that there is a change in rank of cultivars across environments, and the optimum cultivar will be location specific. GxE affects virtually every aspect of the decision making process involved in plant breeding programs including identification of the most relevant testing environments, allocation of resources within a breeding program, and choice of germplasm and breeding strategy (Natalia de Leon *et al*., 2016). Genotype x environment interaction is one of the main challenges in the selection of wide adaptation in most breeding programs. The phenotype effect of an individual is determined by the combined effect of the environment, the genotype and the interaction. Several studies have revealed that both environmental and genetic factors are the cause for the interaction, but in some studies have shown that the large difference of genotypes or environments has been the real cause of the interaction (Sewagegne *et al*., 2013; Abiy and Firew, 2016; Kinde, 2016). The objective of the paper was to understand the role of genotype by environment interactions in crop improvement for desirable traits.

2. IMPACTS OF GENOTYPE BY ENVIRONMENTAL INTERACTION IN CROP IMPROVEMENT
2.1 Concept of Genotype by Environment Interaction
Genotype x environmental interaction (GxE) refers to the modification of genetic factors by environmental factors, and to the role of genetic factors in determining the performance of genotypes in different environments. GxE can occur for quantitative traits of economic importance and is often studied in plant and animal breeding, genetic epidemiology, pharmacogenomics and conservational biology research. The traits include reproductive fitness,

longevity, height, weight, yield, and disease resistance. Selection of superior genotypes in target environments is an important objective of plant breeding programs. A target environment is a production environment used by growers (Dia, M *et al*., 2009). In order to identify superior genotypes across multiple environments, plant breeders conduct trials across locations and years, especially during the final stages of cultivar development. GxE is said to exist when genotype performance differs over environments. Performance of genotype can vary greatly across environment because of the effect of environment on trait expression. Cultivars with high and stable performance are difficult to identify, but are of great value (Dia, M *et al*., 2012).

Genotype x environmental interaction has significant impact in crop improvement and it is crucial for plant breeders to identify adaptable and stable high yielding genotypes with other desirable traits under different environmental conditions prior to release as a variety (Showemimo *et al*., 2000; Mustapha *et al*., 2001). Adaptability is the result of GxE interaction and generally falls into two classes: (1) the ability to perform at an acceptable level in a range of environments or general adaptability and (2) the ability to perform well only in desirable environments or specific adaptability (Farshadfar and Sutka, 2006). A genotype x environment interaction is a change in the relative performance of a character of two or more genotypes measured into two or more environments. Interaction involves a change in rank order for genotypes between environments and the relative magnitude of genetic, environmental and phenotypic variance between environments.

Genotypes x environment (GxE) interactions are important in the development and evaluation of plant varieties because they reduce the genotypic-stability values under diverse environments (Hebert *et al*., 1995). GxE used as a measurement of the plasticity of genotypes in terms of the expression of specific phenotypes in the difference (variable) environmental influence. The scientific field concerned with phenotypic plasticity, team researchers across disciplines: the ability of genotypes to express different phenotypes when influenced by different environment (Phenotypic plasticity is the ability of an organism to express different phenotypes depending on the biotic or abiotic environment). The divide comes from the focus that different groups of researchers have taken to study this phenomenon (Natalia de Leon *et al*., 2016). Crop performance depends on the genotype, environment and the interaction between genotype and environment (Mehdi Mohebodin *et al*., 2016). To test broadly adapted and stable genotypes, information dealing with adaptation of variety and stability over environments (locations and years) is important. Identification of stable genotypes which show the least G×E interaction is important consideration in sites where environmental fluctuations are noticeable. G×E interaction occurs when the performance of the genotypes is not consistent from one environment to another that complicates the selection and recommendation of genotypes. Quantitative characters are considerably affected by environment.

The main result of this effect is that the relationship between genotype and phenotype is partially or completely hidden i.e. the phenotype does not reveal the genotype. For example, phenotype = genotype + environment. If environment is zero, then phenotype is equivalent to genotype. However the effect of environment is seldom zero. So, phenotype is the joint action of genotype and environment. In crop improvement, the breeder selects plants on the basis of their phenotype and the effectiveness of selection depends on the proportion of phenotype due to the genotype. Therefore, it is important to know the extent to which environment influences different quantitative characters (Fisher, Immer & Tedin, 1932). To estimate the effect of environment on a character, large numbers of genotypes are grown in a replicated trial and the data is subjected to analysis of variance as per the experimental design used. The genotype x environmental interaction signifies that the relative performance of various genotype in effected by the environment. For example: performance of genotype 'A' may be superior to the genotype 'B' in one environment but in another environment inferior to that of 'B'. If GxE interaction is absent, genotype 'A' will be superior 'B' in all the environments (Tabrey, 2008).

2.2 Stability and Adaptability

Stability refers to the adaptation or suitability of genotypes to diverse sets of environments and used to select stable genotypes in which genotypes unaffected by environmental changes while adaptability is the better survival of a genotype over any specific environment (MOORTHY *et al*., 2012, Chandrakanth N *et al*., 2016). The term stability is used to characterize a genotype, which shows a relatively consistent yield, independent of change in environmental conditions. Due to this idea, genotypes with a minimal variance for yield across different environments are considered to be stable (Sabaghnia *et al*., 2006). Yield stability affected by genotype x environments interaction. The cause of differences between genotypes in their yield stability is the wide occurrence of GxE. A variety or genotype is considered to be more adaptive or stable if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments. Two basic phenotypic stability concepts are distinguished as the biological or static concept, and the agronomic or dynamic concept. The biological concept of stability refers to the constant performance of a genotype over a wide range of environments.

According to Becker and Leon (1988), in biological stability, a genotype possesses unchanged performance regardless of variation of the environments, thus, implying that its variance among environments is zero. On the other hand, dynamic stability, also termed as agronomical concept of stability, implies that a stable genotype should always give high yield expected at the level of productivity of the respective environments, which means that a

variety with GxE as small as possible (Becker, 1981). Becker and Leon (1988) stated that all stability procedures based on quantifying GxE effects belong to the dynamic stability concept. The knowledge of stability is important for the selection of crop varieties as well as for breeding programs. Yield stability is an interesting feature of today's plant breeding programs, owing to the high annual variation in mean yield, especially in the arid and semi-arid areas (Mohammadi *et al*., 2012). A variety or genotype is considered to be more adaptive or stable if it has a high mean yield but a low degree of fluctuation in yielding ability when grown over diverse environments. Since it is impossible to test genotypes in all target environments, plant breeders do indirect selection using their own multiple-environment trials, or test environments.

Genotype x environmental interaction reduces the predictability of the performance of genotypes in target environments based on genotype performance in test environments (Kumar, R *et al*., 2013). An important factor in plant breeding is the selection of suitable test locations, since it accounts for GxE and maximizes gain from selection (Yan, W *et al*., 2011). An efficient test location is discriminating, and is representative of the target environments for the cultivars to be released. Discriminating locations can detect differences among genotypes with few replications. Representative locations make it likely that genotypes selected will perform well in target environments (Yan, W *et al*., 2011). The concept of stability has been estimated in biometrical methods including univariate and multivariate ones that have been developed to assess stability (Chandrakanth N *et al*., 2016).The most widely used one is the regression method, based on regressing the mean value of each genotype on the environmental index or marginal means of environments (Chandrakanth N *et al*., 2016).

In breeding programs aimed at increasing the yielding ability, the selection criterion may be yield per se or one or more of the morphological components of yield. Therefore, it is also necessary to have a good knowledge of those characters that have significant association with yield because the characters can be used as indirect selection criteria to enhance the mean performance of varieties in a new population (OJO *et al*., 2006, Chandrakanth N *et al*., 2016). Any attempt to improve these characters needs an understanding of their relationship of the desired traits with other traits. The interrelationships among yield and other traits can be analyzed by different statistical techniques such as correlation, regression, path, factor and cluster analyses (Leilah and Al-Khateeb, 2005, Chandrakanth N *et al*., 2016). Among them, correlation estimates are helpful in determining the components of a complex trait, such as yield, but they do not provide an exact picture of the relative importance of direct and indirect influences of each of the component characters towards desired trait (Maurya *et al*., 2015, Chandrakanth N *et al*., 2016). Path coefficient analysis is simply a standardized partial regression analysis and appears to be useful in partitioning the correlation coefficients into direct and indirect effects (Amjad *et al*., 2009, Chandrakanth N *et al*., 2016). It is a multivariate analysis that resembles to the principal component method with construction of multiplicative model for the trait of primary interest (Darvishzadeh *et al*., 2011; Khazaie *et al*., 2011, Chandrakanth N *et al*., 2016).

As grain yield is a complex quantitative trait, with high environmental interaction; selection of genotypes based on performance in single environment is not effective for varietal identification (Shrestha *et al*., 2012, Divya *et al*., 2016). It is essential to carry out selection based on yield stability evaluation than average performance in multiple environment conditions (Kang, 1993; Tariku *et al*., 2013; Islam *et al*., 2015, Divya *et al*., 2016). Selection of genotypes for stability and adaptability is required prior to recommendation in case of a crop such as rice which is grown in diverse ecologies. Several statistical methods have been proposed for stability analysis. These methods are based on univariate and multivariate models. Among several methods, the AMMI method is widely used in stability and adaptability analyses because it i) provides an initial diagnosis of the model and is well-suited for data analysis with many environmental influences, ii) allows greater unfolding of the G×E interaction and summarizes the patterns and relationships between genotypes and environments, and iii) improves the accuracy of trait estimates (Gauch, 1988; Zobel *et al*., 1988; Crossa *et al*., 1990). The statistical perspective on GxE focuses on the detection of statistical interactions in general and GxE specifically, which strictly refers to modeling the effect of GxE as the product of two variables each with their own main effects.

2.3 Importance of Studying Genotype by Environment Interaction

Genotype x environment (GxE) interactions is among major factors limiting response to selection and affects the efficiency of breeding programs (Hebert *et al*., 1995). Genotype x environment (GxE) interactions complicates the interpretation of plant breeding experiments and makes predictions difficult. It is difficult where genotypes have to be selected in one environment and used in another environment. Genotype x environment (GxE) interactions occurs at both micro- and macro environmental levels and due to the confounding of its effects with those of the genetic sources, it is usually cumbersome to analyze (Singh *et al*., 2009). A major task of quantitative genetics is to determine the ways in which genes interact with the environment to contribute to the formation of a given quantitative trait variation (Mehdi Mohebodin *et al*., 2016). Genotype x environment (GxE) interactions becomes more important when the rank of varieties changes in different environment (Natalia de Leon *et al*., 2016). These have a -ve impact on the success of breeding programs, because breeders search for a few widely adapted cultivars, targeted to favorable environments. Genotype x environment (GxE) interactions determines choice of selection

environments and determines whether the breeding strategy, i.e. breed for wide vs. specific adaptation; genetic uniformity vs. genetic diversity/heterogeneity.

Genotypes x environment (GxE) interactions effects are considered a hindrance to crop improvement in a target region and contribute to the temporal and spatial instability of crop yields. Temporal instability, in particular, has a negative effect on farmers' income and, in the case of staple crops, contributes to food insecurity at national and household level. The environmental component could be partitioned into locations and years when the experiment is conducted at many locations for a number of seasons, leading to higher orders of genotype-environment interactions (Hebert *et al*., 1995). Crop performance depends on the genotype, environment and the interaction between genotype and environment (Mehdi Mohebodin *et al*., 2016). To test broadly adapted and stable genotypes, information dealing with adaptation of variety and stability over environments (locations and years) is important. Identification of stable genotypes which show the least G×E interaction is important consideration in sites where environmental fluctuations are noticeable. A (GxE) interaction occurs when the performance of the genotypes is not consistent from one environment to another that complicates the selection and/or recommendation of genotypes.
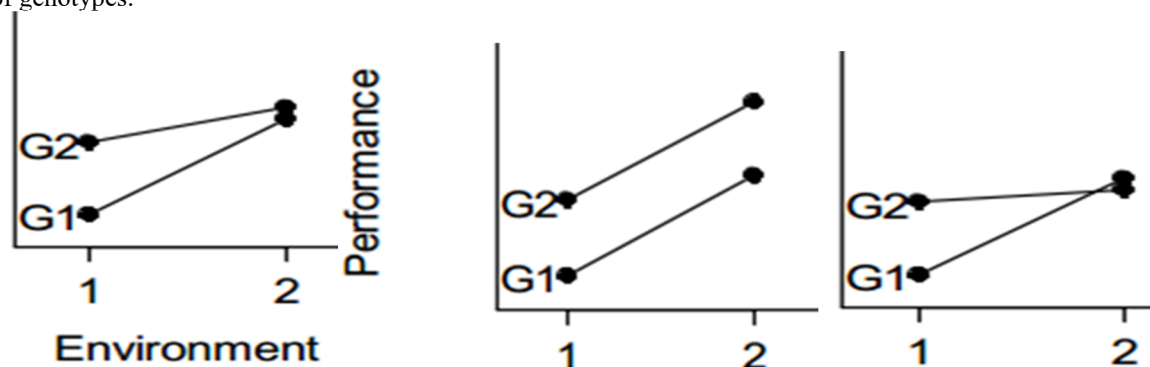

Figure 1: Examples of different types of interaction between two genotypes and two environments.
Source: Rice Coe (r.coe@cgiar.org), Statistical Services Centre, University of Reading, UK and World Agroforestry Centre, Kenya, 5 April 2012.

The above figure-1 shows two genotypes and two environments. In the first graph there is no interaction which means, the difference between G_1 and G_2 is the same in both environments and the lines are parallel. In the middle graph, there is an interaction which means, the difference between G_2 and G_1 is much larger in environment 1 than 2, though G_2 still performs best in both environments. The lines are no longer parallel. In the third graph the interaction is stronger still, and we have G_2 best in environment 1 but G_1 best in environment $_2$, something described as a 'cross-over interaction. As the number of genotypes and environments increases, the possible patterns of interaction rapidly become complex and we use a range of tricks to try to understand them.

2.4 Types of Variation in Genotypes x environment (GxE) interactions and Its Components
Variation is any observable difference among individuals of the same population caused either genetic differences, environmental differences and phonotypical differences. A variation is classified into the following types.

2.4.1 Genotypic Variation
Genotypic variation caused because of differences in the genetic constitution of the individual present in the population. Plant breeding is primarily depends on presence of substantial genetic variation to address the maximum genetic yield potential of the crops and exploitation of this variation through effective selection for improvement. Plant breeders improve crops by identifying sources of genetic variation for the characteristics of interest. In plant breeding, the rates of genetic gain rely on the genetic diversity for a given trait in the breeding population (Hallauer and Miranda, 1981, Kai Luo *et al*., 2016). The magnitude of genetic variation for plants programs will enhance the development of appropriate breeding strategies to achieve maximum genetic gain (Moll and Stuber, 1974, Kai Luo *et al*., 2016). There are three components of genetic variation: 1. Additive genetic (genes which are 100% transmitted from parent to offspring), 2. Dominant gene action and 3. Epistatic gene components (when one gene masks the effect of another gene). These three components are used for variety development. $V_P = V_{G} + V_{E} = V_D + V_{H} + VI + V_E$, where $_{VP}$ = Total phenotypic variance, V_{G} = Genotypic variance, V_{D} = Additive gene, V_{H} = Dominance gene and V_I = Epistatic, V_I = i, j and l.

2.4.2 Phenotypic Variation
Phenotype is the external appearance of an individual or plant which distinguishes it from other species or plant. The phenotype is determined by the genetic constitution of the plant, its environment and interaction between its genetic constitution and the environment. A plant phenotype is the result of the interaction between genotypic traits and environmental conditions. This process is summarized by term GxE interaction (Genotype x Environment). The plant phenotype is not only determined by the plant genetic composition and environmental

factors, but also their interaction (GxE), usually described by the linear model P=G+E+GxE (Visscher, P.M. *et al*., 2008, Mohamed El-Soda *et al*., 2014). Therefore, variety trials in a breeding program are usually conducted in several environments, to minimize the risk of discarding genotypes that potentially perform well in some, but not in all environments (Mohamed El-Soda *et al*., 2014). In general, to predict the genotypic response to selection across environments, the narrow sense heritability of a trait is estimated based on main effects. Evaluating genotypes in multiple environments is essential to gain insight into the extent of GxE (Van Eeuwijk, F.A. *et al*., 2010, Mohamed El-Soda *et al*., 2014) and this is of great interest for crop breeders to assess how much of the selection progress achieved in one environment can be carried over to other environments (Mohamed El-Soda *et al*., 2014).

2.4.3 Environmental Variation

Environmental variation is a variation which caused due to environmental effects and varies under different environmental conditions. Environmental caused variations may result from one factor or the combined effects of several factors, such as climate, food supply and actions of other organisms. This uncontrolled variation is measured in terms of error mean variance. It is non-heritable and observes environmental variation we grow genetically uniform genotype in different environment (Bernardo R, 2008).

2.5 Heritability

Heritability is the proportion of observed variability which is due to hereditary, the remainder being due to environmental factors. It is the proportion of the total variance that is attributable to the average effects of genes. There are two types of heritability: 1. Broad sense heritability is the proportion of phenotypic variance due to genotypic variance i. e $h^2 = VG/VP \times 100$ 2. Narrow sense heritability is the proportion phenotypic variance due to additive genetic variance i. e $h^2 = V_D/V_P \times 100$ (Bnejdi Fethi and El Gazzeh Mohamed, 2012).

2.6 Phenotyping Plasticity

The ability of a genotype (the same genotype) to produce distinct phenotypes in different environments. A plant cannot migrate when challenged by fluctuations in environmental conditions, which means that it has to cope with environmental heterogeneity by adapting to the new or fluctuating environment. It can do so via changing the phenotypic expression, a phenomenon also called phenotypic plasticity (Mohamed El-Soda *et al*., 2014). Plasticity often involves altering gene expression and plant physiology in response to environmental causes (Juenger, T.E, 2013). The differential effect of the environment on different plant genotypes has been known for a long time and has been considered in crop-breeding programs. Technological advances in genotyping approaches have resulted in a shift in the focus of plant-breeding research from the generation of molecular markers, which is no longer issue, to high-throughput, automated phenotyping. With these advances, it should become increasingly easy to determine what effect the environment has on the phenotype (Mohamed El-Soda *et al*., 2014).

2.7 Challenges of Genotype by Environmental Interaction

Genotypes x environmental interaction and yield stability have been challenge to the breeders and biometricians for a long of time, because it complicates the selection of superior genotypes by reducing the genetic progress. The phenomenon of genotypes x environmental interaction refers to the differential performance of genotypes in different environment that affect the efficiency of selection in breeding program. Genotype x environmental interaction arises due to the differences in the sensitivies of genotypes to the different environmental conditions. In order to mitigate the effect of genotypes x environmental interaction, crops need to be tested in several environments to assess their specific and broad adaptation (Dagnachew *et al*., 2014). A genotypes x environmental interaction is important to minimize the usefulness of the genotype means across locations or environments for selecting and advancing superior genotypes to the next stage of selection (Natalia de Leon *et al*., 2016). Plant breeders have managed these interactions throughout the history of crop domestication, crop improvement, and dispersal, and within recent history through the formalized procedures of plant breeding. The varietal stability could be challenged not only due to the change in the test environment but also due to change in growing season per environment (Dagnachew *et al*., 2014). Some environmental variations are predictable (soil type, soil fertility, plant density) while, others also may be unpredictable (rainfall, temperature, humidity).

3. CONCLUSION

The phenotype of an individual is determined by the effects of its genotypes, the environment, and the interaction between the genotype of the individual and the environment. Genotype x environmental interaction is a prerequisite for crop plant improvement and evaluates the improved genotypes across multiple environments (locations and years), before they are promoted for release and commercialization. The genotype by environment interaction results in non-stable performances between the genotypes across environments. Thus, significant GxE results from the changes in the degree of differences between genotypes in diverse environments or changes in the relative ranking of the performance of the genotypes. In order to obtain information on the performance of the

genotypes in terms of adaptability and stability, an analysis of genotype x environmental interaction is very relevant. The objective of most plant breeders is to develop new varieties that perform consistently well across multiple environments. Environmental factors such as soil, moisture, temperature, light intensity, humidity, rainfall, photoperiod and agronomic practices play important role in the expression of the genes controlling the trait of interest. This results in different phenotypic expression among locations. For these reasons, genotype x environmental interaction effect complicates the selection of suitable and superior varieties because elite varieties developed for one location may not perform the same in different locations. Stability analysis is performed to estimate the performance of genotypes as linear function of the level of productivity in each environment.

To maintain high agricultural productivity, the development of varieties with high yield potential is the ultimate goal of plant breeders in a crop improvement program. In addition to high yield potential, a new cultivar should have stable performance and broad adaptation over a wide range of environments. However, the presence of genotype by environment (G x E) interaction is a major concern to plant breeders, since large interactions can reduce gains from selection and complicate identification of superior cultivars. Genotype x environmental interaction is major importance for crop breeders, given that phenotypic response to change in environment is different among genotypes. However, phenotypic response is not always the same in different location as it is affected by biotic and abiotic factors environmental factors. Genotype x environmental interaction is very important to reduce the genotype means across different environments. It is a continues task of plant breeders because of the environmental fluctuation across different location and through years and it is used as a measurement of plasticity of genotypes to the expression of specific phenotypes in different environments.

In multi-environment trial, the combined analysis of variance is vital for estimating variance components related to different sources of variation, including genotypes, environment and GxE. The main purpose of multi-environment trials is to observe stability and adaptability of genotypes across the environments, to identify the superior genotypes and the location that best represents the target environment for production. The major area of focus in plant breeding in the future is genotype x environmental interaction to develop adequate varieties for climate change and many others biotic and abiotic stresses. Eventually, Genotype x environment interaction is one of the main challenge in the selection of broad adaptation and stable genotypes in most breeding programs. Therefore, evaluation of genotypes for adaptation and stability is the key prerequisite to proceed to another improvement programs.

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