WENDE ABERA

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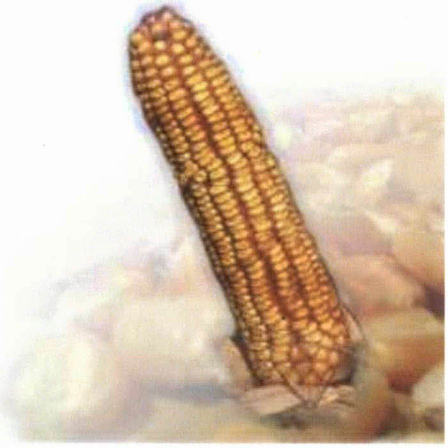

ESTIMATION OF GENOTYPE X ENVIRONMENT INTERACTION FOR YIELD IN ETHIOPIAN MAIZE (ZEA MAYS L.)

BY

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CHAPTER 1

INTRODUCTION

Maize (*Zea mays L.*) is widely grown in most parts of the world over a wide range of environmental conditions, ranging between 50° latitude North and South of the equator. It is also grown from sea-level to over 3000 meters above sea-level elevation (Singh, 1987; Dowswell *et al.*, 1996). It is believed that the crop originated from Mexico and that it was introduced to West Africa during the early 1500's by Portuguese traders. Maize is used as human food, feed for livestock and for industrial purposes (Dowswell *et al.*, 1996).

Breeding of maize in Ethiopia started almost 50 years ago (Benti, 1988). During the late 1960s and early 1970s, several promising hybrid and composite varieties of East African origin were introduced and evaluated at different locations. These resulted in the recommendation of several maize varieties for the maize producing regions of the country (Benti, 1988; Benti *et al.*, 1997). However, most of these varieties have been replaced by locally developed and better performing varieties and hybrids (Mosisa *et al.*, 1994). The superiority of the average performance of these varieties has already been demonstrated (Benti *et al.*, 1997; Gemechu & Fekede, 1998). However, the interaction of these varieties and other promising maize genotypes with variable environmental conditions, still needs systematic investigation.

Crop breeders have been striving to develop improved genotypes that are superior in grain yield, quality and other desirable agronomic characteristics over a wide range of environmental conditions. However, due to the wide occurrence of genotype x environment (G X E) interactions, stable and high yielding genotypes are not as easily available as required. The interactions of genotypes with environments were partly ascribed (Becker & Leon, 1988) differential reactions to environmental stresses, such as drought, extreme temperatures, diseases and other factors. In fact, the function of experimental design and statistical analysis of multi-location trials is to minimize and eliminate this unexplained and unpredictable extraneous variability, which was termed as noise (Gauch 1988; Crossa, 1990). Consequently, many plant breeders use estimates of various stability parameters to assist them in identifying superior genotypes in the presence of G X E interactions.

Ethiopia is a country of great environmental variation (EMA, 1988). When environmental differences are greater, it may be expected that the interaction of G X E will also be higher. As a result it is not only average performance that is important in genotype evaluation programs, but also the magnitude of the interactions, i.e., one cultivar may have the highest yield in some environments while a second cultivar may excel in others (Fehr, 1991; Gauch & Zobel, 1997).

Performance tests over a series of environments give information on G x E interactions at population level, but from a practical point of view, it is important to measure the stability of the performance of individual genotypes (Eberhart & Russell, 1966). Variation in genotypic yield response in different environments (location and/or years) in multi-environment yield trials is known as G X E interaction: the effects of genotypes and environments are statistically non-additive, which means that differences between genotypes depend on the environment. For data sets with more than two genotypes and more than two environments, the G X E interactions are commonly calculated by analyses of variance (ANOVA) techniques, leading to an estimated variance component for G X E interactions. Different parametric statistical approaches have been developed over the years to analyze G X E interaction and specially yield stability over environments.

The objective of this study was to analyze and improve the understanding of the comparative performance of maize genotypes across several environments of Ethiopia, using different statistical methodologies.

The aims of this study were therefore:

a) to evaluate the adaptation of ten maize genotypes across five different locations and

b) to investigate the G X E interactions and stability performance of ten maize genotypes across 15 environments within Ethiopia.

CHAPTER 2

LITERATURE REVIEW

2.1.Origin and history

Maize (*Zea mays* L.) is a member of the grass family, *Gramineae*. It is believed that maize originated in Mexico and that it was introduced to West Africa in the early 1500's by Portuguese traders (Dowswell *et al.*, 1996). It reached Ethiopia in the 1760's or 1860's (Haffanagel, 1961). Today maize is widely grown in most parts of the world over a wide range of environmental conditions ranging between latitudes 50^0 North and South of the equator. It also grows from sea level to over 3000 m above sea-level (Singh, 1987; Dowswell *et al.*, 1996).

Maize is native to the Americas. It was the principal food plant of the Indians when Columbus arrived, and it is still the most important cereal food crop in Mexico, Central America and many countries in South America. Maize is one of the oldest cultivated crops. Two locations have been suggested as possible centers of origin for maize, namely the highlands of Peru, Ecuador and Bolivia, and the region of southern Mexico and Central America. Many types of maize have been found in both areas. Several theories to account for the origin of maize have been formulated, but the exact relationship between Teosinte, *Tripsacum*, and early pod maize found in archaeological ruins has not yet been fully resolved (Poehlman, 1987).

Maize is the world's second leading cereal crop, after wheat. It is however the leading grain crop in the United States, with a production of more than 2.5 times that of wheat, the next leading cereal grain. The United States produces nearly one half of the total world production. The next largest maize producing countries are China and Brazil. Maize is the primary food grain in Mexico, Central America, and parts of South America and Africa (Poehlman, 1987).

2.2. Maize production in Ethiopia

Ethiopia is a country of great environmental variation (EMA, 1988). In Ethiopia, maize can grow on extensive areas ranging from sea level up to 2800 m above sea-level (IAR, 1980). It is being grown in light to heavy soils and wide ranges of temperature and rainfall, indicating that it has good adaptability to different arrays of environmental variables. Maize is also the staple food and one of the main sources of calories in the major maize producing regions of the country (Kebede *et al.*, 1993). It is cultivated on about 1.2 million ha, accounting for 19.3 % of approximately 6 million ha of land allocated for all cereals. It also stands first in total national crop production and yield ha^{-1} (CSA, 1996/97).

Maize can be used as human food, livestock feed and for industrial purposes such as the production of maize starch, sugar and oil (Dowswell *et al.*, 1996). In sub Saharan Africa millions of people depend on maize for their daily food (Byerlee & Heisey, 1996).

Breeding of maize in Ethiopia started 50 years ago (Benti, 1988). In the late 1960's and early 1970's, numerous promising hybrids and composites of east African origin were introduced and evaluated at different locations. This resulted in the recommendation of maize varieties for the maize producing regions of Ethiopia (Benti, 1988; Benti *et al.*, 1997). Most of these maize varieties have been replaced by locally developed and better performing varieties and hybrids (Mosisa *et al.*, 1994). The superiority of the average performance of these varieties were demonstrated (Benti *et al.*, 1997; Gemechu & Fekede, 1998), but the interaction of these varieties and other promising maize varieties with variable environmental conditions, still needs systematic investigation.

2.3. Genotype x environment interaction

The basic cause for differences between genotypes in their yield stability is a wide occurrence of G X E interactions. Such phenotypic stability is often used to refer to fluctuations of yields across the environments. In other words, G X E interaction is a differential genotypic expression across environments. Genotypes refer to the set of genes possessed by individuals that is important for the expression of the traits under investigation. The environment is usually defined as all non-genetic factors that influence the expression of the traits. It may include all sets of biophysical factors including water, nutrition, temperature, and diseases that influence the growth and development of the individuals and thereby influencing the expression of the traits (Basford & Cooper, 1998).

When the effects of environmental differences are large, it may be expected that the interaction of G X E will also be large. As a result it is not only average performance that is important in genotype evaluation programs, but also the magnitude of interactions, i.e. one cultivar may have the highest yield in some environments, while a second cultivar may excel in other environments (Fehr, 1991; Gauch & Zobel, 1997).

According to Ramagosa and Fox (1993), G X E interaction reduces association between phenotypic and genotypic values, and may cause promising selections from one environment to perform poorly in another, forcing plant breeders to examine genotypic adaptation. Its measurement is also important to determine an optimum breeding strategy for releasing genotypes with adaptation to target environments.

The study of G X E interaction is particularly relevant for countries like Ethiopia that has diversified agro-ecologies. Under such diversified agro-ecological conditions, the breeder should be able to select desirable genotypes without losing valuable germplasm and other vital resources. Hence, agro-ecological diversity could complicate breeding and testing of improved varieties with adequate adaptation, but it could also permit identification of extreme environmental conditions that might offer selection pressure from different stresses.

Changes in relative rankings appear to be the inevitable consequence of growing a set of plant genotypes in even a few locations or seasons. This is especially true in tropical regions, where not only environmental fluctuations are greater, but crops also lack the protection conferred by purchased inputs. Thus, for plant breeders large G X E interaction impedes progress from selection and have important implications for testing and cultivar release (Smithson & Grisley, 1992).

Performance tests over a series of environments give information on G X E interactions at population level, but from a practical point of view, it is important to measure the stability of the performance of an individual genotype (Eberhart & Russell, 1966). Variation in genotypic yield response in different environments (location and/or years) in multi-environment yield trials is known as G X E interaction. The effects of genotypes and environments are statistically non-additive, which means that differences between genotypes depend on the environment. For data sets with more than two genotypes and more than two environments, the G X E interactions are commonly calculated by analyses of variance (ANOVA) techniques, leading to an estimated variance component for G X E interactions.

G X E interaction is a major concern in plant breeding for two main reasons; it reduces progress from selection, and secondly, it makes cultivar recommendation difficult, because it is statistically impossible to interpret the main effect. G X E interaction occurs both in short-term (three to four years testing at a location) and long-term (several years at several locations) crop performance trials. Several methods have been proposed to analyze G X E interaction (Lin *et al.;* 1986; Becker & Leon, 1988; Kang, 1990).

An understanding of environmental and genotypic causes of G X E interaction is important at all stages of plant breeding, including ideotype design, parent selection based on traits, and selection based on yield (Jackson *et al.,* 1998; Yan & Hunt, 1998). Understanding of the cause of G X E interaction can be used to establish breeding objectives, to identify ideal test conditions, and to formulate recommendations for areas of optimal cultivar adaptation.

For two genotypes A and B, and two environments X and Y, the best types of relationships between G X E interactions and change of rank orders are demonstrated schematically in Figure 2.1 (A to C).

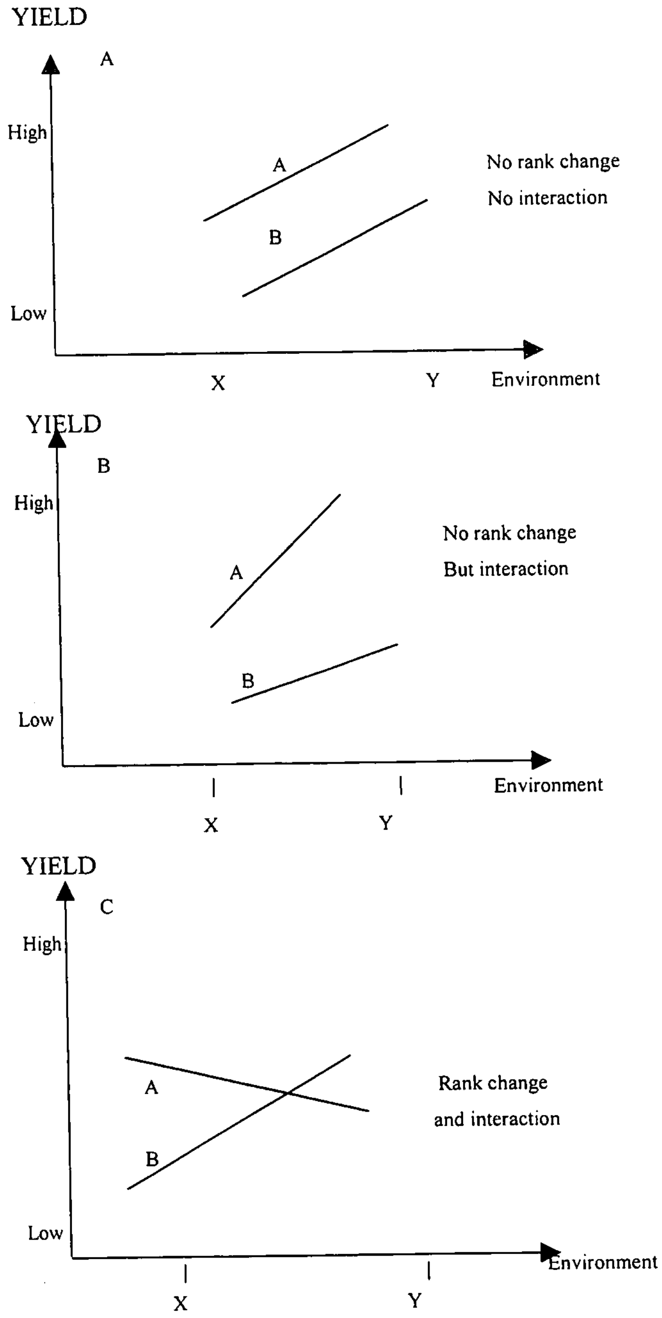

Figure 2.1. Different types of Genotype x Environment interactions and changes of rank orders for two environments X and Y and two genotypes A and B (modified from Wricke, 1965).

2.3.1. Stability

Different parametric statistical approaches have been developed over the years to analyze G X E interaction, especially yield stability over environments. Whether or not a given crop species or cultivar can be planted in an agro-climatic region depends on its adaptability as well as its yield stability. In terms of crop production, adaptability refers to good performance over a wide geographic region under conditions of variable climate and environment (Stoskopf, 1981). On the other hand, stability of yield is defined as the ability of a genotype to avoid substantial fluctuations in yield over a range of environmental conditions (Heinrich *et al.*, 1983). The causes of a species or cultivar's adaptability or stability are often related to physiological, morphological and phenological mechanisms.

Grafius (1957) found that there was a tendency to stabilize yield depending on the temporal development of yield and yield components. He defined yield as a product of several yield components and reductions in which one component may be compensated, to varying degrees, by an increase in other yield components. Tolerance to problem soils and resistance to pathogens and insects are examples of stress tolerance that enhance stability (Mahadevappa *et al.*, 1979).

Knowledge about the magnitude of G X E interactions is important in order to develop cultivars that combine high yield and stable performance over a wide range of environmental conditions. Individual genotypes may react to transient fluctuations in the environment in two different ways. Genotypes that are buffered against environmental variation and develop a similar phenotype over a range of environments possess a "biological" or "static" stability . This type is seldom a desired feature of crop cultivars, since no response to improved growing conditions would be expected. In contrast, "agronomic", or "dynamic" stability permits a predictable response to environments, and stability according to the "agronomic" concept has no deviation from this response to environments (Becker 1981a,b; Becker & Leon, 1988). With quantitative traits, the majority of genotypes often react similarly to favorable or unfavorable environmental conditions.

This average response to environment results in varying mean levels among environments. According to the "agronomic" concept, only the deviation of the genotype from this general reaction is considered as a contribution to instability, because the general response of all genotypes may be interpreted as an environmental effect (Becker & Leon, 1988).

There is a misconception that if a method or selection criterion contributes to yield and stability simultaneously, there would be a reduction in yield. It must be clarified that the main purpose of crop performance trials is to estimate or predict genotype performance in future years, using past performance data. If a crossover type of G X E interaction (one that causes genotype rank changes) (Baker, 1990) is present, the mean yield of genotypes selected *via* a method that combines yield and stability would usually be lower than that of genotypes selected on the basis of yield alone (Kang *et al.*, 1991). However, the lower yield relates to past performance, and it would not necessarily translate into reduced yield on growers' farms.

Another way to clarify the misconception is by examining the consequences to growers of researchers committing Type I (rejecting the null hypothesis when it is true) and Type II errors (accepting the null hypothesis when it is false) relative to selection on the basis of yield alone (conventional method, CM) and on the basis of yield and stability. Generally, Type II errors constitute the most serious risk for growers (Glaz & Dean, 1988; Johanson *et al.*, 1992). For Kang's (1991) modified rank sum (KMR) method, Type I and Type II error rates can be determined for the stability component, but not for the yield component. Therefore, a new statistic, designated as yield-stability statistic (YS), was proposed (Kang, 1993).

The stability component in YS is based on Shukla's (1972) stability variance statistic. He partitioned G X E interaction into components, one corresponding to each genotype, and termed each component as a stability variance. Lin *et al.* (1986) classified Shukla's stability variance as Type II stability, meaning that it was a relative measurement depending on genotypes included in a particular test. Kang *et al.* (1987) reported on the relationship between Shukla's stability variance and Wricke's ecovalence (Wricke, 1962) and concluded that it was identical in ranking cultivars for stability (rank correlation coefficient = 1.00). This measure should be acceptable and useful to breeders and agronomists, as it provides contribution of each genotype in a test to total G X E interaction attributable to all genotypes.

Usually researchers ignore G X E interaction encountered, especially in short-term trials, and base genotype selection solely on mean performance across environments. Only recently it was found that it could be useful to incorporate G X E interaction into genotype selection in short-term trials (Kang & Pham, 1991; Kang, 1993; Magari & Kang, 1993).

In analyzing G X E interactions, plant breeders often strive to grow all genotypes in all environments, thus producing balanced data. This is sometimes not possible, especially when wide ranges of environments or long-term trials are considered. The number of replications may also not be equal for all genotypes due to the discarding of some experimental plots for various reasons. In such cases, plant breeders have to deal with unbalanced data that are more common in practice than considered in literature.

Searle (1987) classified unbalancedness into planned unbalanced data and missing observations. In studying G X E interaction, both categories of unbalancedness may occur, but planned unbalancedness (a situation when, for different reasons, one does not have all genotypes in all environments) is more difficult to handle. Researchers have used different approaches for studying G X E interaction in unbalanced data (Freeman, 1975; Pedersen *et al.*, 1978; Zhang & Geng, 1986; Gauch & Zobel, 1990; Rameau & Denis, 1992). Usually environmental effects are considered as random and cultivar effects as fixed.

Growers would prefer to use a high-yielding cultivar that performs consistently from year to year. They may even be willing to sacrifice some yield if they are guaranteed, to some extent, that a cultivar would produce consistently from year to year (Kang *et al.,* 1991). The guarantee that a cultivar would perform consistently would be in statistical terms, based on Type I and Type II error rates for a selection criterion that encompasses both yield and stability (Kang, 1993).

2.4. Statistical analysis of G X E interaction

The statistical analysis of G X E interaction is important in applied statistics as well as for the analysis of experiments in plant breeding and crop production (Kang, 1996). Different statistical methods have been proposed for the estimation and partitioning of G X E interactions such as variance components, regression methods, multi-variate analysis and cluster techniques (Freeman, 1973; Hill, 1975; Cox, 1984; Skroppa, 1984; Freeman, 1985,1990; Westcott, 1986; Crossa, 1990).

The analysis of G X E interactions is closely linked with the quantitative estimation of phenotypic stability of genotypes over environments (Kang, 1996). When significant G X E interactions are present, the effects of genotypes and environments are statistically non-additive, which means that differences between genotypes depend on the environment. Existing G X E interactions may, but must not necessarily, lead to different rank orders of genotypes in different environments.

In many practical situations, the researcher is not interested in a knowledge of the numerical amount of G X E interactions *per se*, but only the existence (or non-existence) of G X E interactions in so far as they lead to different rankings of genotypes in different environments.

This concept of G X E interaction is closely related to the concept of selection in plant breeding. The breeder is mainly interested in the ranking of genotypes in different environments and in the changes of these rankings (Kang, 1996). Breeders are interested in questions such as whether the best genotype in one environment is also the best in other environments, which means that the relative characterizations and comparisons of the genotypes (orderings) are often more important than absolute characterizations and comparisons. Therefore, it is an obvious idea to use rank information for a quantitative description of these relationships.

Numerous methods have been used in the search for an understanding of the cause of G X E interactions (Van Eeuwijk *et al.*, 1996). These methods can be categorized into two major categories. The first category involves factorial regression analysis of the G X E matrix (i.e. the yield matrix after the environment and genotype main effects are removed) against environmental factors, genotypic traits, or combinations thereof (Baril *et al.*, 1995). The second category involves the correlation or regression analysis, which relates the genotypic and environmental scores, derived from principal component analysis of the G X E interaction matrix to genotypic and environmental covariates.

Frensham *et al.* (1998) and Vargas *et al.* (1998, 1999) used methods that belong to the first category. Frensham *et al.* (1998), when analyzing 10 years of oat (*Avena sativa* L.) evaluation data in Australia, incorporated several genotypic covariates into a mixed model. They indicated that plant type (plant height, kernel type) by environment interaction explained 50% of the observed G X E interaction. Vargas *et al.* (1998) used a partial least squares regression procedure in studying the cause of G X E interaction in wheat multi-environment trial (MET) data sets. Their procedures involved partial regression of the G X E interaction matrix against some latent variables derived from principal component analyses of various explanatory traits or environmental variables. The partial regression procedure was introduced to avoid the problem of explanatory variables.

The second category is associated with the use of the additive main effects and multiplicative interaction model (AMMI) in MET data analysis, which partitions the G X E interaction matrix into individual genotypic and environmental scores.

2.4.1. Analysis of variance

In a conventional cultivar evaluation trial in which the yield of G genotypes is measured in E environments over R replicates, the classic model to analyze the total yield variation contained in GER observations is the analysis of variance (Fisher & Mackenzie, 1923). After replicate effects are removed when combining the data, the G X E observations are partitioned into two sources, namely (a) additive main effects for genotype and (b) the non-additive effect due to G X E interaction. The analysis of variance of the combined data expresses the observed (Yij) mean yield of the i^{th} genotype at the j^{th} environments as

$$Y_{ij} = \mu + G_i + E_j + GE_{ij} + e_{ij}$$

Where μ is the general mean, G_i, E_j and GE_{ij} represent the effect of the genotype, environment and G X E interaction respectively, and e_{ij} is the average of random errors associated with the r^{th} plot that receives the i^{th} genotype in the j^{th} environment. The non-additivity interaction (GE_{ij}) as defined in the above equation implies that an expected value (Y_{ij}) depends not only on the level of G and E separately, but also on the particular combination of levels G and E (Crossa, 1990).

The most important limitation in this analysis is that error variances over environments should be homogenous to test for genotype differences. If error variances are heterogeneous, this analysis is open for criticism as the F-test of the G X E interaction mean squares against the pooled error variances is biased towards significant results.

The principal deficiency of the combined analysis of variance of multi-location yield trials is that it does not explore the underlying structure within the observed non-additivity G X E interaction. Analysis of variance fails to determine the pattern of response of the genotypes and environments, in other words the valuable information contained in (G-1) (E-1) degrees of freedom is practically lost if no further analysis is performed (Crossa, 1990).

The important advantage of the analysis of variance is that the variance component related to the different sources of variation, including genotype and G x E interaction can be estimated. In a breeding program, variance component methodology is used to measure genetic variability, to estimate the heritability and to predict the gain of the trait under selection. However, the nature and causes of the G x E interaction cannot be established with variance components (Crossa, 1990).

2.4.2. Crossover interaction and non-parametric analysis

Some authors introduced the terms qualitative interactions (crossover interactions) and quantitative interactions (non-crossover interactions). For non-crossover interactions, the true treatment differences vary in magnitude, but not in direction, whereas for crossover interactions, the direction of true treatment differences varies (Kang, 1996). Although these terms and the corresponding tests of significance for these effects have been developed in the field of medicine, they can be appropriately applied to questions concerning G X E interactions in crop improvement.

From a breeder's point of view, interaction is tolerable as long as it does not affect the rank orders. So the question arises, under which circumstances does interaction become rank-interaction (Haldane, 1946; Baker, 1988, 1990).

Azzalini and Cox (1984), Berger (1984), Gail and Simon (1985) and Zelterman (1990) have published some interesting statistical test procedures. Denis (1979, 1982) has developed a statistical approach for a test of interaction under order restrictions (identical rankings of genotypes in different environments). Closely connected with these concepts of crossover interactions *versus* non-crossover interactions is the mathematical concept of reparability *versus* non-reparability introduced by Gregorius and Namkoong (1986).

The shifted multiplicative model by Cornelius *et al.* (1992) was originally developed for analyzing non-additivity in a two-way classification. It provides a statistical tool for the investigation of reparability (Cornelius *et al.*, 1992; Crossa & Cornelius, 1993).

For data sets with more than two genotypes and more than two environments, the G X E interactions are commonly calculated by the analysis of variance techniques leading to an estimated variance component. For a two-way table with n genotypes (rows) and m environments (columns), the relationships between the numerical amount of the variance component of G X E interactions and the rank changes of the genotype in different environments are of particular interest in the field of practical applications.

Non-parametric statistics for G X E interactions based on ranks provide a useful alternative to parametric approaches currently used, which are based on absolute data. Some essential advantages of non-parametric statistics compared to parametric ones are reduction or even avoidance of the bias caused by outliers, no assumptions are needed about the distribution of the analyzed values, homogeneity of variances, and additivity (linearity) of effects are not necessary requirements. Statistics based on ranks and rank-orders are often easy to use and interpret.

2.4.3. Stability analysis: concepts and classical analysis techniques

In earlier times, methods of analyzing G X E interaction were associated with the linear regression approach. This was first introduced by Mooers (1921) and was given prominence by Yates and Cochran (1938), who used the mean performance of all genotypes grown in an environment as a suitable index of its productivity. The performance of each genotype was plotted against this index for each environment, and a simple linear regression fitted by least squares to summarize the genotype's response, was drawn, the mean regression slope being 1.0.

The most widely used criteria for selecting for high yield and stable performance are mean yield, regression response on site mean yield, and deviations from regression (Finlay & Wilkinson, 1963; Eberhart & Russel, 1966; Freeman, 1973; Eagles *et al.*, 1977; Langer *et al.*, 1979; Rosielle & Hambling, 1981; Heinrich *et al.*, 1983). Finlay and Wilkinson (1963) proposed that regression coefficients approaching zero indicates stable performance. Figure 2.2. shows the generalized interpretation of genotype yield stability when mean yield is plotted against regression coefficients. Regression coefficients approximating 1.0 indicate average stability. When this is associated with high mean yield, varieties have good general adaptability. When associated with low mean yield, genotypes are poorly adapted to all the environments. Regression values increasing above 1.0, describe genotypes with increasing sensitivity to environmental change (below average stability) and greater specificity of adaptability to high yielding environments. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change (above average stability) and, therefore, increasing specificity of adaptability to low yielding environments.

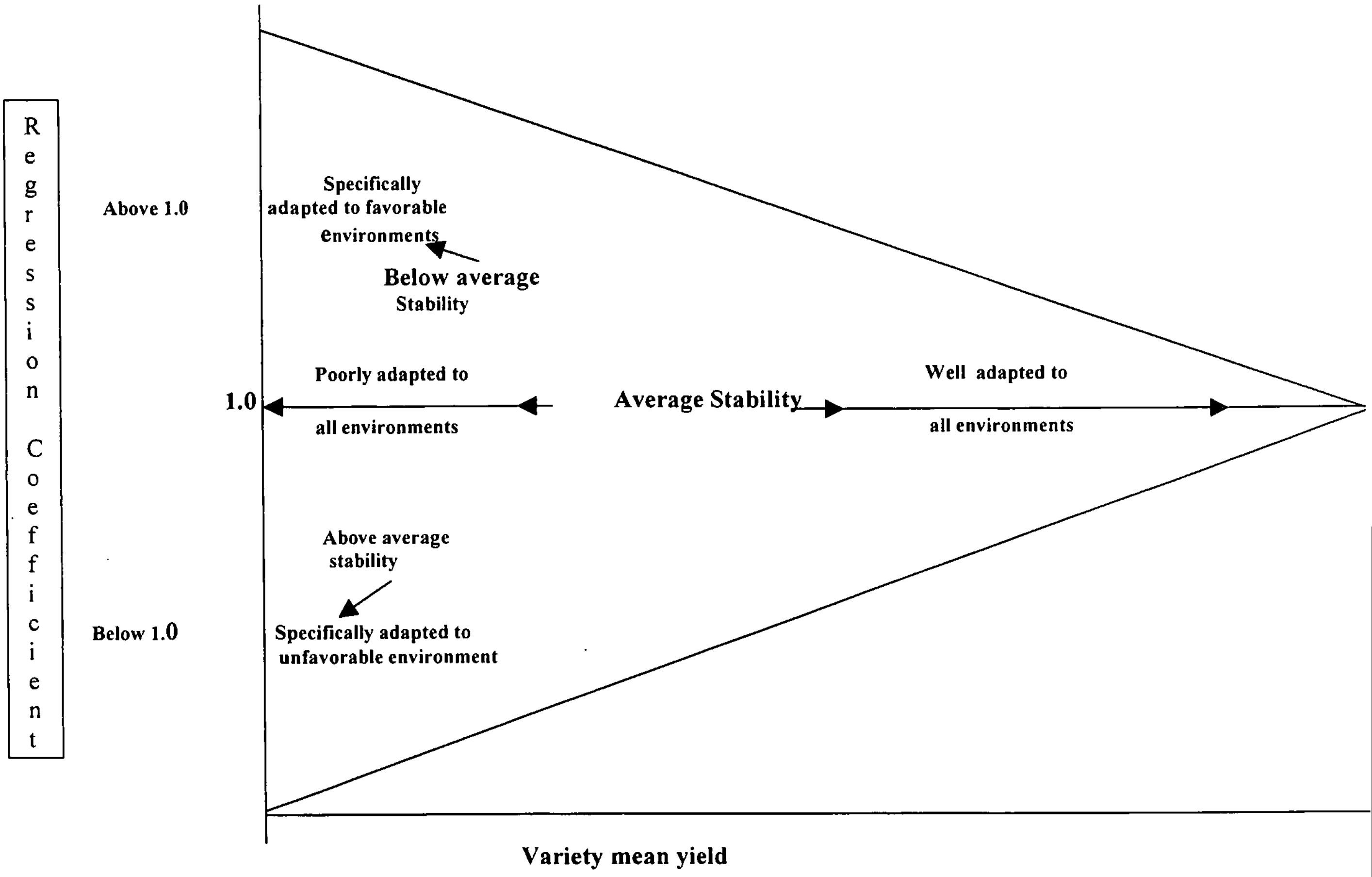

Figure 2.2. A generalized interpretation of the variety population pattern obtained when variety regression coefficients are plotted against variety mean, according to Finlay and Wilkenson (1963).

An appropriate statistical test of significance for G X E interactions is the common F-test of ANOVA. The test statistics is F=mean square (interaction) / mean square (error) with (L-1) (M-1) degrees of freedom for the numerator and LM (N-1) degrees of freedom for the denominator, where L is the number of genotypes, M is number of environments, and N is the number of replications.

Delacy *et al.* (1996) showed that many statistical methods have been developed for the analysis of G X E interactions. Nevertheless, better methods that more effectively describe the data for predicting performance to selection (i.e. optimizing selection among genotypes) are of greater interest to breeders. In fact, analytical alternatives seem to have some merit and thus looking into their inter-relationships appears to be a sound approach.

The context of G X E interactions in crop production systems and how they are encountered in multi-environmental trials are shown in Table 2.1, as summarized by DeLacy et al., (1996). It also shows the objectives of selection in breeding programs and how G X E interaction influences the selection strategies and the response to selection. Accordingly, phenotypic performance of genotypes in combination with different environments can be analyzed to quantify the amount of variation attributable to the effects of the environment, genotype, and G X E interactions. DeLacy *et al.* (1996) recommended the use of the residual maximum likelihood (RELM) analysis of variance and prediction of genotype performance by the use of the best linear unbiased predictor (BLUPs) to investigate patterns of adaptation of genotypes across environments.

The existence of G X E interactions complicates the identification of superior genotypes for a range of environments. G X E interactions can be an outcome of genotype rank changes from one environment to another, a difference in scale among environments, or a combination of these phenomena. Many authors have emphasized that cultivar rank changes are of greater importance than scale change interactions in cultivar trials conducted over a series of environments. For these authors, G X E interactions are critical only if they involve significant crossover interactions (significant reversal in genotypic rank across environments) (Becker & Leon, 1988).

Table 2. 1. Consideration for analysis and understanding the form of GXE in terms of their application to selection in plant breeding (DeLacy *et al.*,1996)

		Applications in plant breeding		
Form of GXE	Model assumptions	Analysis method	Objectives of analysis	Selection strategy
Non-repeatable	Environment: random genotype: random	Analysis of variance RELM Best linear unbiased predictors (BLUBs) of G performance	1.Estimate components of variance to determine the relative sizes of sources of variation and estimate heritability 2.Characterise the form of GXE by Examining them for both G&E for: (a)Heterogenity (HV) + lack of correlation (this enables calculation of the pooled genetic correlation) (b)Rank change+no rank change partition (c) The impact of rank change on the composition of the selected group at a defined selection intensity	Selection for broad adaptation. Decision on sample size (i.e.how test E, replicates and Gs to
Mixture of non-repeatable and repeatable	Es:a mixture of random & fixed genotype: random	Indirect selection pattern analysis	3.Relationship among Es measured in terms indirect response to selection 4.Grouping, ordination&partitioning (size&shape)of GXE for individual Es.	Selection for broad and specific adaptability.
Mixture of non-repeatable and repeatable	Environments:random Genotypes:a mixture of random and fixed	Pattern analysis	5.Grouping,ordination & partitioning of Gs and Es 6.Investigation of causes of differences in patterns of adaptation.	Selection for specific adaptability & stability
Repeatable genotypes:fixed	Environments:fixed biological model	Pattern analysis	7.Interpretation of causes of GXE interacts	Decision on breeding and selection strategies. How many, what types of test Es?

Note:RELM=Residual Maximum Likelyhood; BLUPS=Best Linear Unbiased Predator; Gs=Genotypes; Es=Environments

In order to determine the yield stability of cultivars, they need to be tested under different environments. Various methods of evaluating phenotypic stability have been suggested. Lin *et al.* (1986) investigated the statistical relationship between nine stability statistics and classified stability into three types:

TYPE 1: Where a stable genotype is characterized by a small variance across all environments.

TYPE 2: Where the stable genotypes fit a linear regression model and have a unity slope.

TYPE 3: Based on residual mean squares of deviation from regression, stable genotypes are those with smaller deviation from regression.

Stability analysis provides a method to characterize the response of a hybrid to varying environmental conditions. A number of approaches to stability analysis have been developed. By far the most common technique in the commercial sector is based on the analysis developed by Eberhart and Russell (1966). In this analysis the yields of a specific hybrid from many locations are regressed on the mean yield of all hybrids grown at the same set of locations. Maize breeders who use this analysis tend to define a stable hybrid as one with high mean performance, a regression coefficient close to 1.0 and small deviations from the regression.

Both Jensen and Cavalieri (1983) and Hallauer *et al.* (1988) noted that a large number of locations are necessary to obtain reliable estimates for the stability of a hybrid. Regression coefficients and cultivar mean yields over environments have been used to identify cultivars adapted to high or low environments and for general adaptability.

Average phenotypic stability is shown by a regression coefficient of unity (bi=1.0). A cultivar with (bi>1.0) reflects its adaptability to high yielding environments, and cultivars with (bi<1.0) imply adaptability to low yielding environments. Finlay and Wilkinson (1963) described the ideal cultivar as one possessing genetic potential in the highest yielding environment and with maximum phenotypic stability.

Eberhart and Russel (1966) proposed the use of two stability parameters to describe the performance of a variety over an array of environments. They proposed the regression of each cultivar on an environmental index as a function of the squared deviation.

In arable crop breeding, yield performance consists of yield level and yield stability. Breeders search for genotypes that show a stable high yield over years and locations. In general a genotype is considered stable when its performance across environments does not deviate from the average performance of a group of standard genotypes. Several measures have been devised to quantify yield stability. Extensive reviews have been presented by Lin *et al.* (1986) and Becker and Leon (1988).

In discussing the most appropriate biometrical method, Becker and Leon (1988) noted that the regression approach is of little use if the regression coefficient (b) is included in the definition of “stability”. For this reason b is generally viewed by authors not as a measure of stability, but rather as additional information on the average response of a genotype to advantageous environmental conditions. This approach is schematically presented in Figure 2.3.

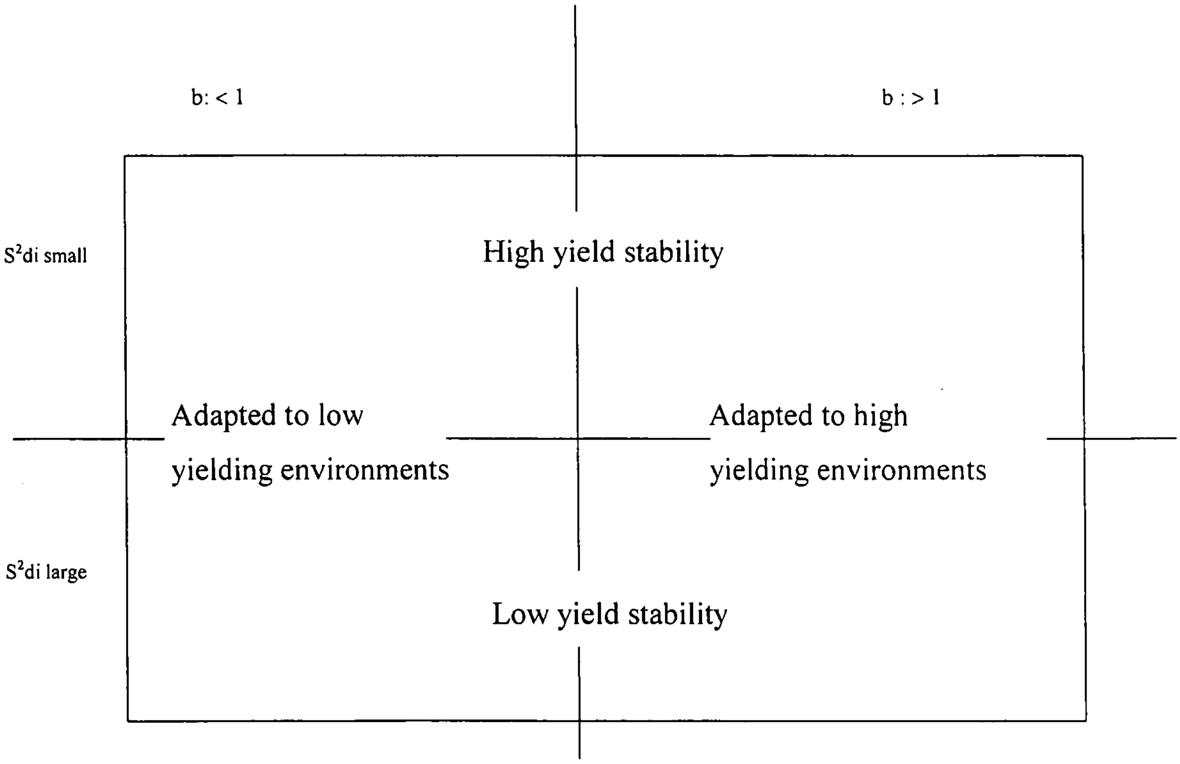

Figure 2.3. Interpretation of the parameter bi and S^2di of the regression approach (Adapted from Becker and Leon, 1988).

Wricke (1962) proposed using the contribution of each genotype to the G X E interaction sum of squares as a stability measure and defined this concept or statistic as ecovalence (Wi). Ecovalence is simple to compute and is expressed as:

$$\mathbf{Wi = \sum_j [\ Y_{ij} - Y\ I - Y_j + Y\ ....]^2}$$

Where Yij is the mean performance of genotype I in the j^{th} ennvironment and Yi and Yj are the genotype and environment mean deviations respectively. Y… is the overall mean. For this reason, genotypes with a low Wi value thus have smaller deviations from the mean across environments and are thus more stable.

Becker and Leon (1988) illustrated ecovalence by using a numerical example of plot yields of genotype I in various environments against the respective mean of environments (Figure 2. 4)

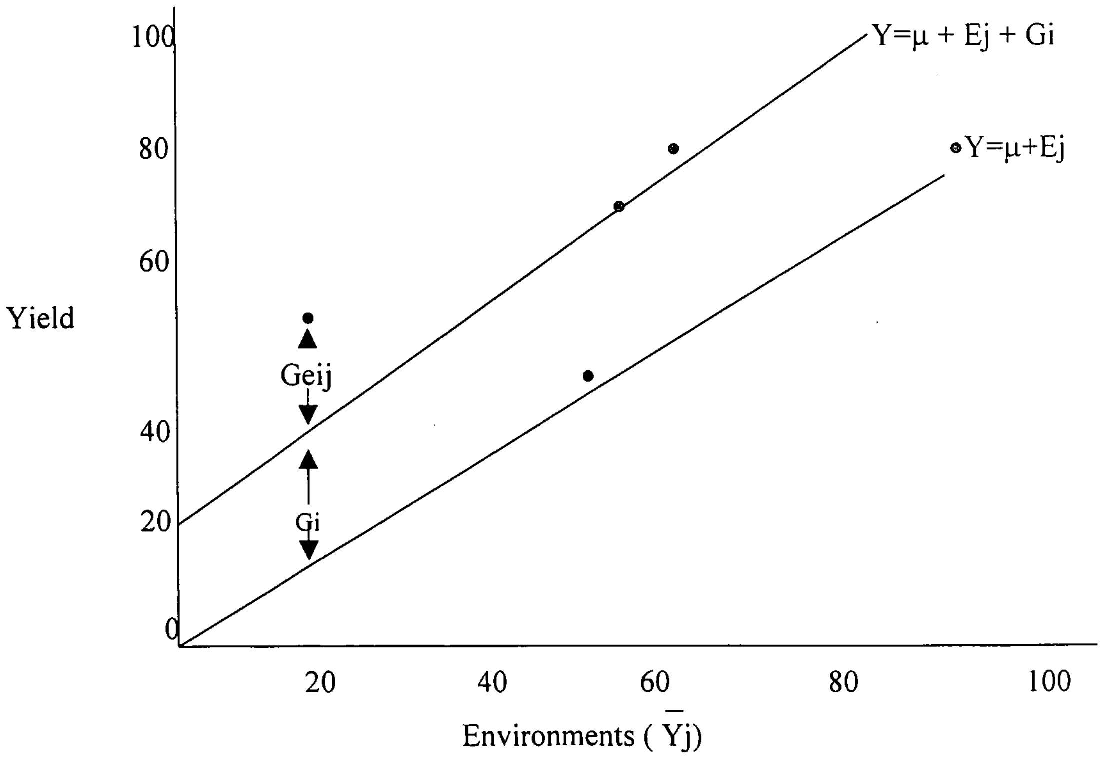

Figure 2. 4. Graphical representation of G X E interactions: the stability statistic ecovalence (Wi) is the sum of squares of the deviations from the upper strait line (Becker & Leon, 1988).

The first measure is the slope bi from the regression of the yields of genotype I on an environmental index (Finlay & Wilkinson, 1963). Where b is equal to 1, it indicates that a cultivar reacts to a change in environment in the same way as the group mean. The second statistic is the stability variance (Shukla, 1972). Based on the residuals from the additive model this variance of cultivar I is defined as the variance of the cultivar across environments. For ranking purposes, the stability variance is equivalent to the ecovalence (Wricke, 1962). The third measure used is the mean-squared deviation, di^2, from the Finlay-Wilkinson regression (Eberhart & Russel, 1966). A cultivar is considered stable when di^2 is small. Wricke and Weber (1986) showed that δ^2 (stability variance) is the sum of a linear term based on bi and a non-linear term based on di^2.

G X E interaction is usually investigated by inspection of the deviations from the linear model with additive genotype and environment effects. Genotypes with similar patterns of residuals from the additive model have the same kind of sensitivity to changes in the environment, but the above-mentioned stability measures describe only part of the response patterns of genotypes. Genotypes showing different values for a specific stability measure show a different response to changes in the environment. Habgood (1977, 1983) proposed using linear correlation between the residual of pairs of cultivars to indicate their difference in response to changes in environment. He used this correlation as an estimate of their genetic similarity, in order to obtain an indication of the variation in yield among the offspring. This is based on the idea that genetic similarity will result in a similar response to environmental changes, and therefore in high correlation between the genotype residual vectors. Conversely, genotypes with dissimilar responses will have few yield genes in common.

Maize studies conducted in the different agro-ecological zones of Swaziland have shown no performance consistency among genotypes, but large location and year to year yield variations, suggesting probable confounding effects of G X E interactions (Funnah & Pali-Shikulu, 1987). Similar studies involving sorghum genotypes show a wide range of responses to different environments, again suggesting the presence of G X E interaction, which, according to Gorman *et al.* (1989), makes it difficult to evolve varietal recommendations.

Kang and Gorman (1989) also reported significant G X E interaction effects in a maize study involving 17 hybrids, in which seven hybrids showed unstable performance across environments. According to Ristanovic and Mungoma (1989) stability varietal linear responses to environments were significant. However, within any one group some varieties showed high yield performance and good yield stability.

While yield is an important criterion often used to determine adaptability among genotypes and ultimately, the release for commercial use, the presence of G X E interaction effects often leads to unreliable recommendations as farmers demand more than just a genotype with satisfactory yields (Nor & Casidy, 1979). Because G X E interactions minimize the usefulness of a genotype, it is imperative that, in making such decisions, yield levels as well as adaptation and stability are taken into account (Pham & Kang, 1988).

Analysis of variance combining environments give useful information on yield levels, and to some extent adaptation, but it does not detect stable genotypes nor does it show causes of significant interactions.

Regression of a cultivar's performance with respect to a calculated environment index has been widely used in analyzing G X E interactions. Eberhart and Russel (1966) proposed a method of measuring stability based on three parameters, namely grain yield, regression coefficients and deviation from regression for each genotype to describe cultivar adaptability.

Shukla (1972) showed that genotypes could not be reliably described if the proportion of G X E interaction sums of squares due to heterogeneity among regression coefficients was small. Besides, there is lack of independence between performance and means of sites and between slopes and intercepts. Instead he proposed that G X E interaction sums of squares are partitioned into variance components (σi^2) corresponding to each of the genotypes. On the basis of these variances, he described as stable a genotype with a variance equal to the environmental variance (σ_0^2) and as unstable those genotypes with large and significant σi^2. Heterogeneity due to covariates such as for environment and rainfall was removed from the G X E interaction sums of squares to derive another set of statistics, $Si^{2,}$ for each genotype. Using his statistic, Shukla (1972) suggested that if a genotype becomes stable after applying the covariate, it can be suspected that the instability of the particular cultivar was introduced by the linear effects of that covariate. This approach is considered of practical importance because it identifies environmental factors that contribute to the heterogeneity in the G X E interaction.

Grain yield and Shukla's stability indices were subsequently advocated as a sound basis for the selection and identification of desirable genotypes (Kang, 1991). In a further application of Shukla's approach rank-sums combining grain yield and the two indices were developed to improve the efficiency of the approach in identifying desirable genotypes (Kang & Pham, 1991).

2.4.4. Stability analysis: AMMI analysis

The additive main effects and multiplicative interaction (AMMI) model combines analysis of variance for the genotype and environment main effects with principal component analysis of the G X E interaction. It has proven useful for understanding complex G X E interactions (Kang, 1996). The results can be graphed in a very informative biplot that shows both main and interaction effects for both genotypes and environments. Also, the AMMI model can partition the data into a pattern rich model and discard noise-rich residual to gain accuracy.

The AMMI model is used to separately estimate interaction components and adjust yield mean for the interaction. The advantage of using AMMI is that it accounts for a large proportion of variability in its first few components with subsequent dimensions accounting for diminishing percentage of pattern and increasing percentage of noise.

Zobel (1990) found that the AMMI has powerful for analyzing numerous shoot and root traits of soybeans (*Glycine max L.*). He reported that interactions tend to be larger for traits, especially, root traits for which breeders have not imposed strong selection and hence reduced genetic variability. Gauch (1990) found AMMI useful for understanding complex interactions, gaining accuracy, improving selections, and increasing experimental efficiency. Also, the expectation-maximization version, EM-AMMI, can impute missing data. AMMI combines analysis of variance (ANOVA) and principal component analysis (PCA) into a single model with additive and multiplicative parameters.

The AMMI model equation is:

$$Y_{ger}=\mu + \alpha_g + \beta_e + \sum_n \lambda_n \gamma_{gn}\delta_{en} + p_{ge} + \sum_{ger}$$

Where Yger is the observed yield of genotype g in environment e for replicate r. The additive parameters are: μ = grand mean, αg = the deviation of genotype g from the grand mean, and βe = the deviation of environment e.

The multiplicative parameters are: λn the singular value for interaction principal component axis (IPCA) n, γ_{gn} the genotype eigenvector for axis n, and δen the environment eigenvector. The eigenvectors are scaled as unit vectors and are unitless, whereas λ has the units of yield.

Regarding agricultural problems from G X E interaction, there exist two basic options, one aimed at the genotypes and the other at the environments (Ceccarelli, 1989; Simmonds, 1991; Zavala-Garcia *et al.*, 1992). One option is to seek a high yielding, widely adapted genotype that wins throughout the growing region of interest. The other option, particularly relevant when the first fails, is to subdivide the growing region into several relatively homogeneous macro-environments (with little interaction within each macro-environment) and then breed and recommend varieties for each. As explained earlier, AMMI can help with both of these options.

AMMI results can illuminate plant physiological processes that cause genotypes to interact with environments. They can also reveal the relative importance of various environmental factors or stresses. Most agricultural papers using AMMI provide a biological interpretation of AMMI genotype parameters. The analysis helped to identify morphological and physiological traits related to stress tolerance.

Wallace *et al.* (1993) concluded that AMMI statistical analysis can separate and quantify the G X E interaction effects on yield and on each physiological component that is caused by each genotype and by the different environment of each yield trial. Charcosset *et al.* (1993) applied several statistical models to a top-cross mating design with 58 maize inbreds. AMMI was found most efficient in predicting hybrid performance. With the AMMI model, a manageable amount of data from Line x Tester crosses can identify promising hybrids, which is helpful when direct field evaluation of all Line x Line hybrids is not feasible, because of the large number of all possible crosses.

Recent development comprises the application of a multiplicative interaction model, which was first introduced by Mandel (1961, 1969, 1971) and Gallob (1968), and has been introduced in the agricultural context as the AMMI model (Gauch, 1988, 1992). These models are appropriate, if one is interested in predicting genotypic yields in specific environments, when yield trial data are available. A further advantage of these models is that they may be used for modeling and understanding interactions (Gauch, 1992).

If, on the contrary, one is interested in genotypes that perform larger, well-defined regions, of which only a small sample of environments has been tested, one cannot predict interactions for each environment of that region. Then, from a practical point of view, all interactions become unpredictable noise, and it is reasonable to minimize G X E interaction, which is in accordance with the dynamic concept.

Eskridge (1990) argued that in situations where there are sufficient funds and economic justification to breed for a particular environment, stability is irrelevant and yield in that environment is paramount. However, if cultivars are selected for a large group of environments, then stability and mean yield across all environments are of major importance and yield in a specific environment is of marginal importance.

Like every other model, AMMI has its weakness. The nature of the residuals after fitting the additive main effects inevitably produces the appearance of multiplicative effects. Consequently the sum of square for fitting the multiplicative term, which may be read directly from the latent root proportions of explained variation, will tend to be much larger than the expected value. Therefore, it is not possible to recommend a single model to be used at all times, because these models, depending on the type of data and research purposes, can be complimentary rather than being competitive.

Although strategies may differ in overall appropriateness, different methods usually lead to the same or similar conclusions for a given data set. For example, Baril *et al.* (1995) compared factorial regression and AMMI score-based analysis for a potato (*Solanum tuberosum* L.) data set and came to the same conclusion, that the interaction between maturity and cold or drought stress explained the G X E interaction for yield. Using the method of Van Eeuwijk (1996), the partial least square regression method and the factorial regression method (Vargas *et al.*, 1998) arrived at similar conclusions. Thus, it appears that it is the quality of data, rather than the method of analysis, that is more limiting to the understanding of G X E interaction.

Chapter 3

Adaptation of maize genotypes under different environments in Ethiopia

3.1. Introduction

Ethiopia is a country of great environmental variation (EMA, 1988). Where environmental differences are great, it may be expected that the interaction of G X E will also be higher. As a result it is not only average performance that is important in genotype evaluation programs, but also the magnitude of the interactions that has an influence on stability (Fehr, 1992; Gauch & Zobel, 1997). Stability performance is of special importance in Ethiopia where environmental conditions vary considerably and means of modifying the environment are far from adequate. For the plant breeder, the environment is a general term that covers conditions under which plants grow and may involve locations, years, management practices or a combination of theses factors (Romagosa & Fox, 1993). Every factor that is a part of the environment of a plant has the potential to cause differential performance that is associated with G X E interaction (Fehr, 1991). Allard and Bradshaw (1964) classified environmental variables as unpredictable and predictable factors. The unpredictable variations include the fluctuating features of the location such as rainfall, relative humidity and temperature, whereas the predictable variations are those factors which are under human control, like planting date, row spacing, plant population and rates of nutrient application. Both conditions provide a greater range of environmental conditions to test genotypes (Eberhart & Russel, 1966). Since Ethiopia has a wide range of locations, environment and soil fertility conditions for maize production, testing of maize genotypes under different environmental conditions will assist in the selection of stable maize genotypes. Thus, this study was intended to evaluate the adaptation of 10 maize genotypes across five locations of Ethiopia.

3.2. Materials and methods

3.2.1. Materials

Ten maize genotypes, which reached the stage of national variety trial, from Africa and CIMMYT Mexico were included in this study. The genotypes selected were three-way crosses, single crosses, top-crosses and open- pollinated varieties. Descriptions of the genotypes are given in Table 3.1.

Table 3.1. Description of the maize genotypes tested over three years across five locations.

No	Genotypes	Status	Source	Year of release
1	(A-7032xF-7189) x142-1-e	TWC	East Africa	-
2	(A-7032xF-7215) x144-7-b	TWC	East Africa	-
3	(A-7016xG-7462) x142-1-e	TWC	East Africa	-
4	(A-7032xG-7462) x142-1-e	TWC	East Africa	-
5	(A-7033xF-7215) x144-7-b	TWC	East Africa	2001
6	BH-660	TWC	East Africa	1990s
7	BH-540	SC	East Africa	1990s
8	BH-140	TC	East Africa, CIMMYT	1980s
9	Kulani	OPV	CIMMYT	1990s
10	Gibe-1	OPV	East Africa, Pioneer & CIMMYT	2000

TWC: Three way cross

TC: Top-cross hybrid

OPV: Open-pollinated variety

SC: Single cross

3.2.2. Methods

3.2.2.1. Description of locations

Two of the four maize producing mega-environments in Ethiopia were used in this study, namely a mid-altitude and a high altitude sub-humid zone. Descriptions of the test locations are given in Table 3.2.

Table 3.2. Description of the test locations used in this study

Location	**Altitude (m)**	**Annual rain fall (mm)***	**Soil type**	**Mega-environment**
Bako	1650	1200	Nitosol	Mid-altitude sub-humid
Jimma	1750	1595	Nitosol	Mid-altitude sub-humid
Awasa	1700	1110	Andosol	Mid-altitude sub-humid
Adet	2240	1284	Nitosol	High-altitude sub-humid
Alemaya	1980	850	Fluvisol	High-altitude sub-humid

* Averages over 10 year's (1990 - 2001)

These locations are the best maize testing sites in Ethiopia. They are believed to represent the major maize growing regions of the country in the intermediate to highland areas, where maize is grown predominantly. These localities are located in the altitude ranges of 1650 to 2240m above sea level and the annual rainfall varies between 850 to 1595 mm (Table 3.2).

Bako (the main testing center), Jimma and Awassa represent the intermediate altitude regions whereas Alemaya and Adet represent the higher altitude maize growing regions of Ethiopia.

3.2.2.2. Experimental design

The genotypes were planted in a completely randomized block design at five locations. Four replications were planted each year from 1999 to 2001 at each location. Plots consisted of four rows, 5.1m in length, of which the middle two rows were harvested. The spacing between rows was 75cm, while spacing between plants was 30cm. All trials were hand-planted. Phosphorus (100kg) was applied at planting. Nitrogen (100kg) was split applied; the first half at planting and the remaining half when the genotypes were at knee height, Potassium (K) is not used, as the soil in Ethiopia is rich in Potassium. Urea and diamonium phosphate (DAP) were used as sources of N and P respectively. No irrigation was used, since the trials were conducted during the main rainfall season, between May and September. All trial management practices were in accordance with the recommendations for the particular location.

3.2.2.3. Statistical analyses

Grain yield (t ha^{-1}) was calculated using the average shelling percentage of 80%, adjusted to 12.5% grain moisture content. Yield data were analyzed with the AGROBASE 2000 (Agronomix software, Inc., 2000) software computer program. Analysis of variance was done for the individual trials. Thereafter a combined analysis of variance was performed on the pooled data over test environments.

The following statistical analyses were performed to test the significance level of grain yield of the genotypes, locations and their interactions:

1. Separate trial analysis for each location and year.

   The separate analysis of each trial was made individually to give local variety means and estimates of the experimental error. This was done for the 15 separate trials planted across the five locations for the years 1999-2001.

2. Combined analysis across:

   a) Locations for each year

   b) Years for each location

   c) Locations and years

   The combined analyses of trials across locations, years and locations and years were made in order to determine differences between genotypes across locations and years, and also to determine whether there was a significant difference among locations and the different years.

3.3.Results and discussion

Cropping season of 1999

Highly significant differences ($P< 0.01$) were found between genotypes for the locations Bako and Awassa (Table 3.3.). Significant differences ($P<0.05$) between the genotypes were found at Jimma and Adet. There were however, no significant differences between the genotypes at Alemaya. Alemaya represents the eastern highland of Ethiopia.

The three-way hybrids had the highest yields across locations as indicated in Table 3.4. Of these hybrids, (A-7033 X F-7215) X 144-7-b, (A-7016 X G-7462) X 142-1-e and (A-7032 X G-7462) X 142-1-e had the highest yields, with an average yield of 9.59, 9.51 and 9.14 t ha^{-1} respectively. (A-7033 X F-7215) X 144-7-b is a three-way hybrid, which was released in the year 2001 for the intermediate to highland maize producing regions. It out-yielded the best check variety (BH-660) by 12.93% in this particular cropping season.

The open-pollinated check varieties (Kulani and Gibe-1) and the top-cross hybrid (BH-140) had the lowest average yields, with yields of 6.96, 7.16 and 7.08 t ha^{-1} respectively. The genotypes performed the best in Adet and Jimma in this year. All the genotypes had however, low yields and higher CV at Alemaya, this is because Alemaya is not among the major maize producing area as compared with other locations in this study.

Table 3.3. Mean squares from analysis of variance and percentage of variance components for grain yield of 10 maize genotypes tested across five locations in Ethiopia, during 1999.

SOURCE	**DF**	Location									
		BAKO		**JIMMA**		**AWASSA**		**ALEMAYA**		**ADET**	
		MS	% SS	MS	% SS	MS	% SS	MS	% SS	MS	% SS
BLOCK	3	3.98	12.05	7.16	17.46	3.63	9.503	1.24	4.386	0.50	1.221
ENTRY	9	7.15**	64.93	5.84*	42.737	7.76**	60.868	1.38	14.606	7.65*	55.536
ERROR	27	0.85	23.03	1.81	39.803	1.26	29.629	2.55	81.009	1.98	43.243
TOTAL	39	----	100	----	100	----	100	----	100	----	100
CV%	-----	10.76	-----	13.98	----	15.21	----	27.09	-----	14.14	----

*, ** = Significantly different at P = 0.05 and 0.01 levels, respectively.

Table 3.4. Grain yield performance (t ha^{-1}) of 10 genotypes of maize tested across five locations in Ethiopia, during 1999.

No	Genotype	Location						
		Bako	Jimma	Awassa	Alemaya	Adet	Mean	R
1	(A-7032xF-7189) x142-1-e	9.02s	10.34rs	6.75r	5.71	11.50rs	8.66	5
2	(A-7032xF-7215) x144-7-b	9.49rs	10.62rs	8.13qrs	6.95	9.08	8.85	4
3	(A-7016xG-7462) x142-1-e	9.75rs	10.41rs	9.95qrs	5.69	11.74qrs	9.51	2
4	(A-7032xG-7462) x142-1-e	9.67rs	10.78rs	8.35qrs	5.88	11.03rs	9.14	3
5	(A-7033xF-7215) x144-7-b	9.98qrs	11.05rs	8.69qrs	6.95	11.29rs	9.59	1
6	BH-660*	8.66s	9.85rs	6.97r	5.88	10.41rs	8.35	6
7	BH-540	7.80	8.70	6.56r	5.29	9.31	7.53	7
8	BH-140*	8.36s	7.16	5.14	5.57	8.70	7.08	9
9	Kulani*	6.01	8.53	6.93r	5.39	7.93	6.96	10
10	Gibe-1	6.76	8.40	6.31r	5.63	8.68	7.16	8
	Mean	8.55	9.63	7.38	5.90	9.97	8.28	
	LSD	1.10	1.25	1.04	1.48	1.31		
	CV %	10.76	13.98	15.21	27.09	14.14		

Note: * Check entries

Means followed by different letters differ significantly from check entries at P = 0.05, according to one-tailed LSD.

Cropping season of 2000

Highly significant differences ($P<0.01$) were found between the genotypes at Bako, while at Awassa, significant differences were observed (Table 3.5). There also was a highly significant difference between the blocks at Alemaya. There was however no significant differences found between the genotypes or blocks for the other locations.

The three-way hybrid (A-7032 X F-7215) X 144-7-b had the highest yield (9.33 t ha^{-1}) followed by the local top-cross check, BH-140 (8.70 t ha^{-1}) and the three-way hybrid (A-7033 X F-7215) X 144-7-b (8.67 t ha^{-1}). Although the three-way hybrids again had high yield during this year, BH-140 and BH-660 were found to be under the top five highest yielders.

The single cross hybrid (BH-540) and an open-pollinated variety (Gibe-1) had the lowest average yields, with yields of 6.93 and 7.19 t ha^{-1} respectively.

The genotypes performed the best at Awassa and Jimma during this year. Although the highest yield recorded for 1999 was at Adet, all the genotypes performed poorly at this location during 2000.

Table 3.5. Mean squares from analysis of variance and percentage of variance components for grain yield of 10 maize genotypes tested across five locations in Ethiopia, during 2000.

Source	DF	Location									
		BAKO		JIMMA		AWASSA		ALEMAYA		ADET	
		MS	% SS	MS	%SS	MS	% SS	MS	%SS	MS	%SS
Block	3	0.54	0.994	2.26	8.254	3.46	11.932	26.753^{**}	47.025	1.86	8.758
Entry	9	12.66^{**}	69.304	1.79	19.576	4.70^{*}	48.657	2.615	13.792	2.60	36.696
Error	27	1.81	29.702	2.20	72.171	1.27	39.411	2.477	39.184	1.3	54.545
Total	39	-----	100	----	100	----	100	----	100	----	100
CV%	----	17.50	----	17.64	----	12.22	----	19.06	----	15.96	----

*, **= significantly different at P = 0.05 and 0.01 levels, respectively

Table 3.6. Grain yield (t ha^{-1}) of 10 genotypes of maize tested across five locations in Ethiopia, during 2000.

No	Genotype	Location						
		Bako	Jimma	Awassa	Alemaya	Adet	Mean	Rank
1	(A-7032xF-7189)x142-1-e	7.57s	8.96	9.84s	7.86	7.01	8.25	6
2	(A-7032xF-7215)x144-7-b	10.25qrs	9.26s	9.87s	9.39q	7.89s	9.33	1
3	(A-7016xG-7462)x142-1-e	7.32s	7.86	10.36s	8.08	8.50rs	8.42	4
4	(A-7032xG-7462)x142-1-e	8.49s	7.84	8.70	8.68	7.00	8.14	7
5	(A-7033xF-7215)x144-7-b	10.50qrs	8.78	9.20s	8.23	6.65	8.67	3
6	BH-660*	8.2s	7.91	10.22s	7.84	7.62	8.36	5
7	BH-540	5.66	7.64	8.36	7.18	5.80	6.93	10
8	BH-140*	7.68s	9.07s	10.38s	9.40q	6.99	8.70	2
9	Kulani*	5.77	9.05s	7.35	7.12	7.49	7.35	8
10	Gibe-1	5.41	7.67	7.95	8.80	6.14	7.19	9
	Mean	7.68	8.40	9.22	8.26	7.11	8.13	
	LSD	1.25	1.37	1.04	1.46	1.05		
	CV%	17.50	17.64	12.22	19.06	15.96		

Note: * Check entries

Means followed by different letters differ significantly from check entries at P = 0.05, according to one-tailed LSD.

Cropping season of 2001

Highly significant differences ($P<0.01$) were found between the genotypes at Bako (Table 3.7). Significant differences ($P<0.05$) between the genotypes was found at Awassa and Alemaya. There was however, no significant difference between the genotypes at Jimma and Adet. There were also highly significant differences ($P<0.01$) found between blocks for the location Adet, whereas the other four locations showed non-significant differences between blocks.

Two three-way hybrids and one top-cross hybrid had the highest yields across locations as indicated in Table 3.8. Of these hybrids, (A-7033 X G-7462) X 142-1-e, (A-7032 X F-7215) X 144-7-b and BH-140 (top-cross) had the highest yields, with an average yield of 9.07, 8.69 and 8.46 t ha^{-1} respectively. As observed during previous years, the three-way hybrids were again the best yielders in this cropping season.

The open-pollinated check varieties (Kulani and Gibe-1) had the lowest average yields, 6.94 and 6.37 t ha^{-1} respectively. The genotypes performed the best at Awassa and Bako. All the genotypes had however, low yields at Jimma.

When the performance of genotypes across all the test environments was considered, the genotypes showed different responses to the environments, resulting in genotype rank changes indicating that there were G X E interactions. This indicated the need for further analysis in order to determine which genotypes had relatively stable performances across environments.

Table 3.9 shows the average grain yield performance (t ha^{-1}) of the 10 maize genotypes tested across five locations during the years 1999-2001. The best yielders across locations and years based on their average yield were all three-way crosses, namely (A-7032 X F-7215) X 144-7-b, (A-7032 X G-7462) X 142-1-e and (A-7033 X F-7215) X 144-7-b. Kulani and Gibe-1 (the open-pollinated varieties) had the lowest yields.

Among the locations, all genotypes performed well at Awassa and Bako (Table 3.9). These two areas are the major maize producing regions in Ethiopia. The performances of the genotypes varied from place to place and from year to year and the genotype, which performed best in one location did not show the same performance at other locations. This was also found across years.

Table 3.10 indicates the percentage of variance components for grain yield across five locations during the three years 1999-2001. As shown the genotypes had a higher share of the variance component at Bako and Awassa, indicating the stability of these locations for maize production. When an average of all three years was taken into account, 42% of the total variance was accounted for entries and 13% were attributed to blocks. The remaining 45% was attributed to error variance (Table 3.10). In this case the environment was the important source of variation. This indicates the divergent response of the genotypes to their environments, which can be a barrier to select for superior genotypes unless stability analyses are performed.

Table 3.7. Mean squares from analysis of variance and percentage of variance components for grain yield of 10 maize genotypes tested across five locations in Ethiopia, during 2001.

SOURCE	DF	Location									
		BAKO		JIMMA		AWASSA		ALEMAYA		ADET	
		MS	% SS	MS	% SS	MS	% SS	MS	% SS	MS	% SS
BLOCK	3	0.38	0.942	3.95	9.437	3.19	8.796	1.82	7.751	13.20^{**}	45.41
ENTRY	9	9.26^{**}	68.949	1.67	11.938	6.37^{*}	52.642	3.72^{*}	47.427	1.82	18.776
ERROR	27	1.35	30.110	3.66	78.624	1.55	38.562	1.17	44.822	1.16	35.815
TOTAL	39	----	100	----	100	----	100	---	100	----	100
CV %	---	12.40	----	27.72	---	12.76	----	16.42	----	14.96	----

*, ** = Significantly different at P= 0.05 and 0.01, respectively.

Table 3.8. Grain yield (t ha^{-1}) of 10 genotypes of maize varieties tested across five locations in Ethiopia, during 2001.

No.	Genotypes	Location						
		Bako	Jimma	Awassa	Alemaya	Adet	Mean	Rank
1	(A-7033xF-7189)x142-1-e	8.96s	6.44	8.43	6.80s	7.25s	7.58	8
2	(A-7032xF-7215)x144-7-b	10.94qs	7.48	10.48s	7.19s	7.35s	8.69	2
3	(A-7016xG-7462)x142-1-e	9.60s	6.64	10.90s	6.54s	7.39s	8.21	5
4	(A-7032xG-7462)x142-1-e	11.17qrs	8.01s	10.81s	8.04s	7.32s	9.07	1
5	(A-7033xF-7215)x144-7-b	9.83qs	6.24	9.40s	6.50s	7.71s	7.94	6
6	BH-660*	8.62s	6.77	11.39s	7.06s	7.85s	8.34	4
7	BH-540	10.60qs	6.84	10.03s	6.41s	5.79	7.93	7
8	BH-140*	10.08qs	7.19	10.42s	7.35s	7.27s	8.46	3
9	Kulani*	6.56	7.52	8.05	4.81	7.77s	6.94	9
10	Gibe-1	7.31	5.19	7.91	5.23	6.19	6.37	10
	Mean	9.37	6.83	9.78	6.59	7.19	7.95	
	LSD	1.07	1.77	1.15	1.00	0.99		
	CV%	12.40	27.72	12.76	16.42	14.96		

Note: * Check entries

Means followed by different letters differ significantly from check entries at P = 0.05, according to one-tailed LSD.

Table 3.9. Average grain yield (t ha^{-1}) of 10 genotypes of maize varieties tested across five locations in Ethiopia, during 1999-2001.

No	Genotypes	Location						
		Bako	Jimma	Awassa	Alemaya	Adet	Mean	Rank
1	(A-7032XF-7189)X142-1-E	8.52	8.58	8.34	6.76	8.59	8.16	6
2	(A-7032XF-7215)X144-7-B	10.23	9.12	9.49	7.84	8.11	8.93	1
3	(A-7016XG-7462)X142-1-E	8.89	8.30	10.40	6.77	9.21	8.71	4
4	(A-7032XG-7462)X142-1-E	9.78	8.88	9.29	7.53	8.45	8.79	2
5	(A-7033XF-7215)X144-7-B	10.11	8.69	9.10	7.23	8.55	8.74	3
6	BH-660	8.50	8.18	9.53	6.93	8.63	8.36	5
7	BH-540	8.02	7.73	8.32	6.30	6.97	7.47	8
8	BH-140	8.71	7.96	8.65	7.44	7.65	8.08	7
9	Kulani	6.11	8.37	7.44	5.77	7.73	7.08	9
10	Gibe-1	6.50	7.33	7.39	6.55	7.00	6.95	10
	Mean	8.52	8.31	8.80	6.91	8.09	8.13	

Table 3.10. Percentage of variance components (out of total) for grain yield of 10 maize genotypes tested across five locations in Ethiopia from 1999-2001.

Locations	Source	1999	2000	2001	Mean
Bako	Block	12.0	1.0	0.9	4.7
	Entry	64.9	69.3	68.9	67.7
	Error	23.0	29.7	30.1	27.6
	Total	100.00	100.00	100.00	100.00
	LSD	1.1	1.2	1.0	
	CV%	10.8	17.5	12.4	
Jimma	Block	17.5	8.2	9.4	11.7
	Entry	42.7	19.6	11.9	24.7
	Error	39.8	72.2	78.6	63.5
	Total	100.00	100.00	100.00	100.00
	LSD	1.2	1.4	1.8	
	CV%	13.9	17.6	27.7	
Awassa	Block	9.5	11.9	8.7	10.8
	Entry	60.9	48.7	52.6	54.0
	Error	29.6	39.4	38.5	35.8
	Total	100.00	100.00	100.00	100.00
	LSD	1.0	1.0	1.1	
	CV%	15.2	12.2	12.7	
Alemaya	Block	4.4	47.0	7.7	19.7
	Entry	14.6	13.8	47.4	25.3
	Error	81.0	39.1	44.8	55.0
	Total	100.00	100.00	100.00	100.00
	LSD	1.5	1.4	1.0	
	CV%	27.0	19.0	16.4	
Adet	Block	1.2	8.7	45.4	18.4
	Entry	55.5	36.7	18.7	37.0
	Error	43.2	54.5	35.8	44.5
	Total	100.00	100.00	100.00	100.00
	LSD	1.3	1.0	0.9	
	CV%	14.1	15.9	14.9	
Over all mean	Block	8.9	15.3	14.4	12.9
	Entry	47.7	37.6	39.9	41.7
	Error	43.3	47.0	45.5	45.3
	Total	100.00	100.00	100.00	100.00

Combined analyses of variance across locations

The combined analyses of variance across locations and years showed highly significant differences ($P<0.01$) between locations (L) and genotypes (G) for the individual years tested. For the year 2000, there were also highly significant differences for G X L interactions as shown in Table 3.11. The grain yield of the different genotypes was therefore highly affected by differences in the environment.

Table 3.11. Mean squares of the combined analyses of variance for grain yield of 10 maize genotypes tested across five locations in Ethiopia, 1999-2001.

YEAR	**SOURCE**	**DF**	**GRAIN YIELD**
1999	Location	4	112.44**
	Block in location	15	3.30
	Genotype	9	21.10**
	Loc by genotype (LXG)	36	2.18
	Residual	135	1.69
	CV (%)		15.70
2000	Location	4	25.24**
	Block in location	15	6.97**
	Genotype	9	11.43**
	Loc by genotype (LXG)	36	3.23**
	Residual	135	1.81
	CV (%)		16.53
2001	Location	4	88.73**
	Block in location	15	4.51**
	Genotype	9	12.24**
	Loc by genotype (LXG)	36	2.65
	Residual	135	1.78
	CV (%)		16.74

*, ** Significantly different at P = 0.05 and 0.01, respectively.

Table 3.12 shows that much of the variability could be attributed to the different locations, as it ranged from 15.10 to 45.18% over the three years. The highest variability was found during the years 1999 and 2001. The variability accounted for by the genotypes ranged between 12.66 and 19.04%. The yield variance component for G X L interaction ranged from 7.88% in 1999 to 17.41% in 2000. The average yield variance was 12.09% (Table 3.12). The repeatability for the three years was 79%, indicating variability in environmental conditions. This can create complications with selection, indicating the necessity to determine GXE interaction and stability.

Table 3.12. Percentage (out of total) of variance components from combined analyses of variance (LXG) for grain yield of 10 maize genotypes tested across five locations in Ethiopia, 1999-2001.

Source	DF	1999	2000	2001	mean
Location	4	45.18	15.10	40.87	33.72
Block in loc	15	4.98	15.64	7.79	9.47
Genotypes	9	19.04	15.38	12.66	15.69
L X G	36	7.88	17.41	10.99	12.09
Residual	135	22.92	36.48	27.66	29.02
Total	199	100.00	100.00	100.00	100.00
CV %		15.70	16.53	16.74	16.32
LSD 0.05 for entry		0.681	0.704	0.698	0.694
Repeatability		0.897	0.717	0.783	0.799

The mean yield for all the genotypes was the highest during 1999. The three-way hybrids performed better during this year than in the other two years, except for (A-7032 x F-7215) x 144-7-b, which had a higher yield during 2000.

The average yield across years, showed that (A-7032 x F-7215) x 144-7-b, (A-7032x G-7462) x 142-1-e and (A-7033x F-7215) x144-7-b were the highest yielders. They all were three-way hybrids. The open-pollinated varieties (Kulani and Gibe-1) had the lowest yields.

Table 3.13. Mean grain yield (t ha^{-1}) and the rank (Rk) of 10 maize genotypes tested at five locations in Ethiopia, 1999-2001.

No	Genotypes	**1999**	**Rk**	**2000**	**Rk**	**2001**	**Rk**	**Mean**	**Rk**
1	(A-7033xF-7189) x142-1-e	8.66rs	5	8.25s	6	7.58s	8	8.16	6
2	(A-7032xF-7215) x144-7-b	8.85rs	4	9.33qs	1	8.69s	2	8.96	1
3	(A-7016xG-7462) x142-1-e	9.51qrs	2	8.42s	4	8.21s	5	8.71	4
4	(A-7032xG-7462) x142-1-e	9.14qrs	3	8.14s	7	9.07qs	1	8.78	2
5	(A-7033xF-7215) x144-7-b	9.59qrs	1	8.67s	3	7.94s	6	8.73	3
6	BH-660*	8.35rs	6	8.36s	5	8.34s	4	8.35	5
7	BH-540	7.53	7	6.93	10	7.93s	7	7.46	8
8	BH-140*	7.16	8	8.70s	2	8.46s	3	8.11	7
9	Kulani*	7.07	9	7.36	8	6.94	9	7.12	9
10	Gibe-1	6.96	10	7.19	9	6.51	10	6.89	10
	Mean	8.28		8.13		7.97		8.13	
	LSD	0.68		0.70		0.69			

Note: *Check entries

Means followed by different letters differ significantly from check entries at $P = 0.05$, according to one-tailed LSD.

The average yield performance of the genotypes at the five locations for the three years is given in Table 3.14. The highest average yield of 8.80 t ha^{-1} was found for Awassa, while the lowest average yield was for Alemaya (6.91 t ha^{-1}). The other of the three sites had yields ranging from 8.09 to 8.54 t ha^{-1}. At Bako the three-way hybrid (A-7032xF-7215) x144-7-b with yield of 10.23 t ha^{-1} exceeded the other varieties. It was also stable at this particular site as it had a relatively small coefficient of variability (Francis & Kannenberg, 1978; Lin *et al.*, 1986). This particular genotype also ranked first at Jimma and Alemaya. Another three-way cross hybrid (A-7016xG-7462) x 142-1-e was the top ranking one at both Awassa and Adet. The two open-pollinated varieties (Kulani and Gibe-1) performed lower than the hybrids at all locations, however Kulani ranked fifth at Jimma. Details of yield performance along with its coefficients of variation for each locality over the three years are summarised in Table 3.14.

Table 3.14. Mean grain yield (t ha^{-1}), rank and CV (%) of 10 maize genotypes tested across five locations in Ethiopia, 1999-2001.

No	Genotypes	Bako			Jimma			Awassa			Alemaya			Adet		
		yield	Rk	CV	yield	Rk	CV	yield	Rk	CV	yield	Rk	CV	Yield	Rk	CV
1	(A-7033xF-7189)x142-e	8.52	6	15.5	8.58	4	15.5	8.34	7	18.0	6.76	7	26.4	8.59	3	18.9
2	(A-7032xF-7215)x144-7-b	10.23	1	10.9	9.12	1	13.3	9.49	3	8.5	7.84	1	25.7	8.11	6	22.2
3	(A-7016xG-7462)x142-1-e	8.89	4	12.8	8.30	6	18.7	10.4	1	8.4	6.77	6	12.9	9.21	1	8.1
4	(A-7032xG-7462)x142-1-e	9.78	3	13.8	8.88	2	18.9	9.29	4	14.5	7.53	2	19.5	8.45	5	12.8
5	(A-7033xF-7215)x144-7-b	10.11	2	16.7	8.69	3	23.0	9.10	5	18.1	7.23	4	22.8	8.55	4	12.2
6	BH-660	8.50	7	11.8	8.18	7	24.4	9.53	2	14.3	6.93	5	25.6	8.63	2	12.1
7	BH-540	8.02	8	16.6	7.73	9	18.2	8.32	8	12.3	6.30	9	21.1	6.97	10	18.4
8	BH-140	8.71	5	9.2	7.96	8	22.2	8.65	6	9.2	7.44	3	22.0	7.65	8	12.0
9	Kulani	6.11	10	15.4	8.37	5	18.7	7.44	9	13.0	5.77	10	27.4	7.73	7	20.7
10	Gibe-1	6.50	9	13.2	7.33	10	16.2	7.39	10	16.6	6.55	8	16.9	7.00	9	13.3
	Mean	8.54			8.31			8.80			6.91			8.09		

Combined analyses across locations and years

A better understanding of the relative contribution of cultivars, environments and their interaction as a source of variation could potentially help breeders to develop cultivars with more stable performances (Basford & Cooper, 1998; De Lange, 1999). The results of the combined analyses of the measured trait across locations and years (Y X L X G) are given in Table 3.15. Grain yield differed significantly ($P<0.01$) across locations, genotypes and their interaction with the year and with each other (Y X L, Y X G and L X G). These significant differences and their interactions indicate the fluctuations of entries in their response to different environments. The significant interactions show that there are genotypes that are not stable.

Because of the interactions between genotypes and environments, yield of genotypes tested across locations over years vary and this creates difficulties for plant breeders to identify varieties that consistently gave high yields in locations with diverse environmental conditions. Kang and Gorman (1989) reported that G X E interactions significantly reduced correlations between phenotypic and genotypic values. In other words, G X E interactions of multi-location trials tend to confound varietal selection and make varietal recommendation difficult, which indicates a need for analyzing stability of genotypes across environments. Pham and Kang (1988) indicated that since G X E interactions minimize the usefulness of genotypes, it is thus imperative that yield levels, adaptation and stability are taken into account in multi-location trials. Furthermore, Crossa (1990) elaborated that only qualitative or crossover interactions are relevant in agriculture, and appropriate statistical analyses are required for quantifying them.

The partitioning of variance components indicated that 25.64% was due to Y X L interaction, 10% was due to location, while 11.30% could be attributed to the genotypes (Table 3.15). These results show that the environment was the most important source of variation. The major component of environmental variability was rainfall, which differed greatly across the locations with the annual rainfall ranging between 850 (Alemaya) and 1595mm (Jimma).

Generally, when G X E interaction is due to variation in predictable environmental factors (e.g. soil types and management practices), the plant breeder may choose to develop different varieties for different environments (regions, soil types, management systems), or develop broadly adapted varieties that will perform reasonably well under a range of conditions. However, when G X E interaction is due to the variation in unpredictable environmental factors (e.g. year to year rainfall variation), the breeder has to develop stable varieties that can perform reasonably well under a range of conditions. That is why testing over locations and years becomes important, as was seen in this trial. If G X E is significant and environmental variation is unpredictable, it is however necessary to carry out stability analysis to identify stable varieties, using the appropriate analytical methods.

Table 3.15. Mean squares and its percentage (out of total) contribution of combined analyses of variance (Y X L X G) for grain yield of 10 maize genotypes tested across 15 environments of Ethiopia, 1999-2001

Source	DF	Mean square	%
Year (Y)	2	5.04	0.4
Location (L)	4	63.42**	10.00
Y X L	8	81.41**	25.64
Genotype (G)	9	31.94**	11.30
Y X G	18	6.39**	4.53
L X G	36	4.19**	5.94
Y X L X G	72	1.93	5.48
B (Y X L)	45	4.93**	8.72
Error	405	1.76	28.00
Total	599		
CV % = 16.32			

*, ** Significantly different at P = 0.05 and 0.01 , respectively. B= block

Chapter 4

Stability analyses

4.1. Introduction

The major maize production areas of Ethiopia have a combination of climates and soils that provide for high potential yields. The national average maize yield, however, remained at around 2.0 t ha^{-1} during the last 20 years and self-sufficiency in maize has been declining over the years (Benti, 1988). Taking note of the low yield potential, a systematic maize research program started in the late 1960s. From 1967, Ethiopia participated in the " East African Cooperative Maize Variety Trial" which included the most promising composites and hybrids of the East African countries. From this cooperative yield trials, high yielding composites and hybrids were identified. Although these composites and hybrids have high yield potential, their performance under varied environmental conditions is not well documented. Therefore, identifying genotypes that show minimum interaction with the environment or possess the greatest yield stability is an important consideration particularly in regions where environmental fluctuations are considerable and means of modifying the environment are remote (Allard & Bradshaw, 1964).

Stability in performance across environments is one of the most desirable properties of a genotype to be recommended for wide cultivation. Assessing any genotype without including its interaction with the environments is incomplete and thus limits the accuracy of yield estimates. A number of statistical methods are known for estimating phenotypic stability. A genotype is stable and desirable if it performs well with respect to others under adverse environmental conditions and has the ability to respond to favorable conditions. The objectives of this study were to test different techniques to find the best one to describe stability.

4.2. Materials and methods

4.2.1. Materials

Ten maize genotypes from Africa and CIMMYT Mexico were included in this study The genotypes selected included three-way crosses, single crosses, top crosses and open pollinated varieties. Descriptions of the genotypes were provided in Table 3.1, Chapter 3.

4.2.2. Methods

4.2.2.1. Description of locations

Two of the four maize producing mega-environments in Ethiopia were used in this study, namely a mid-altitude and a high-altitude sub-humid zone. Descriptions of the test locations are given in Table 3.2, Chapter 3.

4.2.2.2. Experimental design

Please refer to 3.2.2.2, Chapter 3 for a detailed discussion of the experimental design.

4.2.2.3. Statistical analyses

Grain yield (t ha^{-1}) was calculated using the average shelling percentage of 80%, adjusted to 12.5% grain moisture content. Yield data were analyzed with the AGROBASE 2000 (Agronomix software, Inc., 2000) software computer program.

Four stability models (Finlay & Wilkenson, 1963; Eberhart & Russel, 1966), ecovalence (Wricke, 1962) and the stability variance (Shukla, 1972) along with the AMMI were performed using AGROBASE 2000. For all the analyses, data of 10 tested genotypes were used. AMMI's stability value (ASV) was calculated using the formula suggested by Purchase (1997) as shown below. Analysis of variance was generally used to test the significance level of genotypes, locations and G X E interactions for the measured characteristics.

$$\mathrm{ASV} = \sqrt{\frac{\mathrm{SS\ IPCA1}}{\mathrm{SS\ IPCA\ 2}}(\mathrm{IPCA1\ score})^2 + (\mathrm{IPCA2\ score})^2}$$

Where,
ASV = AMMI's stability value
SS = Sum of squares
IPCA = Interaction of principal component analysis

The following statistical analyses were performed to test the stability of the measured trait (grain yield) of the genotypes.

1. Stability analysis:

    - Joint regression model (Finlay & Wilkinson, 1963; Eberhart & Russel, 1966)

    - Ecovalence (Wricke, 1962)

    - Stability variance (Shukla, 1972)

2. Additive Main Effect and Multiplicative Interaction (Zobel *et al.*, 1988)

4.3. Results and discussion

4.3.1. Joint regression model

Finlay and Wilkinson (1963) indicated that yield of entries across all environments and regression coefficients are important indicators of cultivar adaptation. According to them, a regression coefficient close to unity indicates average stability and when it is associated with high mean yield, an entry is categorized as possessing general adaptability. However, when it is associated with low mean yield, the genotype is said to be poorly adapted to its environment. Similarly, genotypes with regression coefficients larger than one are regarded as increasingly sensitive to environmental change (above average stability) and specifically adapted to high-yielding environments (Finlay & Wilkinson, 1963; Adugna, 2000). When regression coefficient values are below one, the entries are said to posses average stability, resisting fluctuations of environments and thus are specifically adapted to low-yielding environmental conditions. Eberhart and Russel (1966) added one more parameter, namely deviation from the regression as a measure of stability across environments. Hence, genotypes with high mean yields, regression coefficients equal to unity (b=1) and a small deviation from the regression ($S^2di=0$) is considered stable.

According to the above concepts and principles, the genotypes BH-140, (A-7033 x F-7215) x 144-7-b, (A-7032 x F-7215) x 144-7-b and BH-660 were closer to the coefficient of regression (b=1) and thus had average stability that helped them to adapt in diverse environments (i.e. wide adaptability). Such high and stable performances are desirable characters of varieties even though it is not always easy to obtain them, especially where environmental variations are high and unpredictable (Becker & Leon, 1988). These authors indicated that coefficients of regression could be used to describe the general response of genotypes to environmental conditions, while the deviations from the regression measure the yield stability. Kulani and (A-7016 x G-7462) x 142-1-e were found to be poorly adapted as they showed more deviations from linearity (Table 4.2). (A-7016 x G-7462) x 142-1-e, BH-540 and (A-7033 x F-7189) x 142-1-e were adapted to high yielding environments. The deviations from the regression (S^2di) showed that genotypes (A-7032 x G-7462) x 142-1-e and (A- 7032 x F-7215) x 144-7-b were the most stable with the minimum deviations from the regression (Table 4.2).

The analysis of variance, which was computed according to the regression model (Eberhart & Russel, 1966) for grain yield of 10 maize genotypes, is presented in Table 4.31. The result shows highly significant differences ($P<0.01$) among genotypes, which indicates the presence of G X E interaction. The stability parameters are given in Table 4.32, in addition with the overall mean yield. The three-way hybrid (A-7032 x F-7215) x 144-7-b with an average yield of 8.96 t ha^{-1} significantly out-yielded the other genotypes followed by the other four three-way hybrids that yielded from 8.35 to 8.78 t ha^{-1}. Similarly, the three-way hybrid (A- 7032 x F-7215) x 144-7-b which was the top-yielder was the most stable genotype since its regression coefficient (b) was close to unity and it had also the second lowest deviation from the regression line (Table 4.2).

Table 4.1. Analysis of variance for stability analysis according to the joint regression model (Eberhart & Russel, 1966).

Source	DF	SS	MS	F-value	
Total	599	402.21			
Varieties	9	71.87	7.98	11.36**	0.0000
Env.+ in var. x Env.	140	330.34	2.36		
Env. X in linear	1	228.99			
Var.x Env. (linear)	9	9.96	1.10	1.57	0.1296
Pooled deviation	130	91.38	0.703		
Residual	450	232.87	0.518		
R-squared = 0.7234		CV= 17.70%			

*, ** Significantly different at P = 0.05 and 0.01.

Table 4.2. Mean yield (t ha^{-1}) and stability parameters of 10 maize genotypes tested at 15 environments in Ethiopia, 1999-2001.

No	Genotypes	Mean	bi	S^{2}di	CV%
1	(A-7033x F-7189) x 142-1-e	8.16s	1.1462	-0.0464	18.8
2	(A-7032 x F-7215) x 144-7-b	8.96rs	0.9044	0.0293	16.1
3	(A-7016 x G-7462) x 142-1-e	8.72rs	1.2458	0.2834	12.2
4	(A-7032 x G-7462) x 142-1-e	8.78rs	1.1208	0.0163	15.9
5	(A-7033x F-7215) x 144-7-b	8.73rs	1.0665	0.4384	18.5
6	BH-660*	8.35s	1.0978	-0.1155	17.6
7	BH-540	7.46	1.1571	0.0664	17.3
8	BH-140*	8.08s	0.9579	0.6697	14.9
9	Kulani*	7.09	0.4996	0.5598	19.0
10	Gibe-1	6.95	0.8039	-0.0466	15.2
	Mean	8.13			

Note: * Check entries

Means followed by different letters differ significantly from check entries at P = 0.05, according to one-tailed LSD.

4.3.2. Wricke's ecovalence analysis

Wricke (1962) proposed, in a similar analysis, that the contribution of a genotype to the interaction sum of squares in a two-way analysis of variance could be used as a measure of its stability. Wricke's ecovalence (1962) is among the methods used most frequently to determine stability of genotypes based on G X E interactions. This method indicates the contribution of each genotype to the G X E interaction. Genotypes with small ecovalence will have small deviations from the mean across environments, could thus be considered more stable (Purchase, 1997). In other words, according to Wricke (1962), cultivars with the lowest ecovalence contributed the least to the G X E interaction and are thus more stable than others.

The ecovalence was computed for the 10 genotypes of maize. Results are summarized in Table 4.3. According to these results, BH-660 followed by the three-way hybrid (A-7033 x F-7189) x 142-1-e and the open-pollinated variety (Gibe-1) were the most stable genotypes. (A-7032 x G-7462) x 142-1-e and (A-7032 x F-7215) x 144-7-b were moderate in their stability, while Kulani and the top-cross variety, BH-140 were the most unstable ones.

Table 4.3. Wricke's (1962) ecovalence value, overall mean (t ha^{-1}) and their ranks for 10 maize genotypes tested in 15 environments of Ethiopia, 1999-2001

No	Genotypes	Ecovalence	Rank	Mean yield	Rank
1	(A-7033XF-7189) X142-1-e	6.6142	2	8.16	6
2	(A-7032XF-7215) X144-7-b	7.3171	5	8.96	1
3	(A-7016XG-7462) X142-1-e	11.7956	7	8.72	4
4	(A-7032XG-7462) X142-1-e	7.2731	4	8.78	2
5	(A-7033XF-7215) X144-7-b	12.5279	8	8.73	3
6	BH-660	5.4457	1	8.35	5
7	BH-540	8.1563	6	7.46	8
8	BH-140	15.4740	9	8.08	7
9	Kulani	19.7392	10	7.09	9
10	Gibe-1	7.0027	3	6.95	10

4.3.3. Shukla's method of stability variance

Shukla's stability variance (1972), mean yield and the ranking order of genotypes to these values are given in Table 4.4. According to Shukla's stability parameter, entries with minimum stability variance are considered to be more stable. Therefore, genotypes that are the most stable are BH-660, (A-7033xF-7189) x142-1-e and Gibe-1 respectively, whereas Kulani, BH-140 and (A-7033xF-7215) x144-7-b could be considered as unstable genotypes. Both ecovalence and the Shukla's stability variance found BH-660, (A-7033xF-7189) x142-1-e and Gibe-1 as the most stable genotypes, and Kulani and BH-140 as unstable genotypes.

Table 4.4. Shukla's (1972) stability variance, overall mean yield (t/ha) and their ranks for 10 maize genotypes tested across 15 environments of Ethiopia, 1999-2001

No	Genotypes	Stability variance	Rank	Mean yield	Rank
1	(A-7033XF-7189) X142-1-e	1.9601	2	8.16	6
2	(A-7032XF-7215) X144-7-b	2.2111	5	8.96	1
3	(A-7016XG-7462) X142-1-e	3.8105	7	8.72	4
4	(A-7032XG-7462) X142-1-e	2.1954	4	8.78	2
5	(A-7033XF-7215) X144-7-b	4.0721	8	8.73	3
6	BH-660	1.5427	1	8.35	5
7	BH-540	2.5108	6	7.46	8
8	BH-140	5.1243	9	8.08	7
9	Kulani	6.6476	10	7.09	9
10	Gibe-1	2.0987	3	6.95	10

4.3.4. Additive main effects and multiplicative interaction (AMMI)

The additive main effect and multiplicative interaction (AMMI) model combines analysis of variance for the genotype and environment main effects with principal components analysis of the G X E interaction.

The AMMI analysis of variance for grain yield of the 10 maize genotypes tested in 15 environments of Ethiopia is given in Table 4.6. The best-fit model was AMMI2 for this experiment as IPCA1 and IPCA2 were highly significant (P <0.01). IPCA1 declared 30.90% of the G X E interaction sum of squares, whereas IPCA2 declared 24.92%. This indicates that both IPCA's accounted for 55.82% of the total interaction, while the remaining 44.18% was the residue or noise, that could not be interpreted and thus was discarded as described by Purchase (1997).

Gauch and Zobel (1988) and Purchase (1997) reported that the IPCA scores of genotypes in the AMMI analysis are an indication of the stability of a genotype across environments. The closer the IPCA scores to zero, the more stable the genotypes are across their testing environments. However, the higher the IPCA scores (either positive or negative), the more specifically adapted the genotypes are to certain environments. According to this concept, BH-660 was the most stable hybrid genotype, followed by (A-7032 x F-7215) x 144-7-b and (A-7033 x F-7189) x 142-1-e (i.e when IPCA1 score was taken into account). In contrast, (A-7033 x F-7215) x 144-7-b and Kulani were adapted to specific environments, like Bako and Awassa for the former and Jimma for Kulani, where they had top yields (Table 3.14). Similarly, when the IPCA2 score was considered, the same was found. BH-660 was again the most stable hybrid followed by Gibe-1 and (A-7033 x F-7189) x 142-1-e. In both IPCA1 and IPCA2 scores the most stable varieties were BH-660 and (A-7033 x F-7189) x 142-1-e. Both of them are three-way hybrids and BH-660 is one of the most popular hybrids growing in mid-high altitudes in Ethiopia. The other option is to calculate the AMMI stability value (ASV), by use of the formula as indicated in the material and methods. This stability value was reported to a balanced measurement between the two IPCA scores (Purchase, 1997). According to this stability parameter, BH-660 was the most stable variety, followed by (A-7032 x F-7215) x 144-7-b, (A-7033 x F-7189) x 142-1-e and BH-540 respectively (Table 4.6). Kulani and BH-140 were considered to be unstable varieties.

The AMMI model has been extensively and successfully used during the past few years to analyze and understand the G X E interactions in various crops (Zobel *et al.*, 1988; Crossa, 1990; Annicchiarico, 1997; Purchase, 1997). Crossa (1990) found that the combination of analysis of variance and principal components analysis in the AMMI model is a valuable approach for understanding G X E interaction and obtaining better yield estimates. Purchase (1997) also found that the AMMI model can accurately describe both the G X E interaction and stability analysis through its response patterns that can be illustrated on biplot or on scatter diagram of IPCA 1 *versus* IPCA 2 scores.

Figure 4.1 indicates the AMMI model 2 biplot for 15 environments in Ethiopia. According to this biplot patterns are seen with the higher potential environments predominating in the second and third quadrants, like Bako (1999), Bako (2001), Adet (1999), Awassa (2000), Awassa (2001), Jimma (1999), Jimma (2000) and Alemaya (2000). The lower potential environments are prevailing in the first and fourth quadrants, like Awassa (1999), Alemaya (1999), Adet (2000), Adet (2001) and Jimma (2001). Some of these environments were affected by the erratic nature of the rain. However, most of the entries except Kulani, Gibe-1 and BH-540 were plotted on more than the average yields of 8.13 t ha^{-1}.

ASV, IPCA scores and locations of genotypes on the biplot showed that BH-670 and (A-7016 x G-7462) x 142-1-e were specifically adapted to favourable environments. BH-660, (A-7033 x F-7189) x 142-1-e and (A-7032 x F-7215) x 144-7-b were the most stable genotypes over the different environments.

Purchase (1997) found that IPCA2 also plays a significant role in the G X E interaction. Therefore IPCA 1 scores were plotted against IPCA 2 scores to further test the stability of the 10 maize genotypes tested in 15 environments of Ethiopia (Fig. 4.2). The closer the genotype to the centre or zero of this figure, the more stable they are. BH-660, (A-7032 x F-7215) x 144-7-b and (A-7033 x F-7189) x 142-1-e were less interactive with environments and thus more stable than the other genotypes. The IPCA 2 scores also showed that BH-660, Gibe-1 and (A-7033 x F-7189) x 142-1-e were the most stable genotypes over the tested environments (Table 4.6).

Table 4.5. Analysis of variance and tests of interaction principal components in AMMI for grain yield of 10 maize genotypes tested in 15 environments of Ethiopia, 1999-2001.

Source	DF	SS	MS	F-value	Pr > F
Total	599	2540.353			
Environments	14	915.997	65.428	13.28	<0.0001
Reps.with in Env.	45	221.670	4.926		
Genotypes	9	287.474	31.942	9.93	<0.0001
Genotype x Env.	126	405.382	3.217	1.84	<0.0001
IPCA 1	22	125.277	5.694	3.25	<0.0001
IPCA 2	20	101.016	5.051	2.88	<0.0001
Residual	405	709.830	1.753		

Table 4.6. Mean yield (t ha^{-1}), rank, IPCA 1 and IPCA 2 scores and AMMI stability values (ASV) of 10 maize genotypes tested across 15 environments of Ethiopia,1999-2001.

No	Genotypes	Yield	Rank	IPCA1 Score	IPCA 2 Score	ASV	R
1	(A-7033XF-7189) X142-1-e	8.16	6	0.2658	0.3821	0.484	3
2	(A-7032XF-7215) X144-7-b	8.96	1	0.1070	-0.4372	0.453	2
3	(A-7016XG-7462) X142-1-e	8.72	4	0.7473	0.6571	1.053	7
4	(A-7032XG-7462) X142-1-e	8.78	2	0.7127	-0.3902	0.884	6
5	(A-7033XF-7215) X144-7-b	8.73	3	1.0307	0.4895	1.423	8
6	BH-660	8.35	5	0.0765	-0.0783	0.013	1
7	BH-540	7.46	8	0.1006	-0.7593	0.588	4
8	BH-140	8.08	7	-0.8825	-1.3661	2.144	9
9	Kulani	7.09	9	-1.4409	1.1300	3.589	10
10	Gibe-1	6.95	10	-0.7173	0.3724	0.712	5

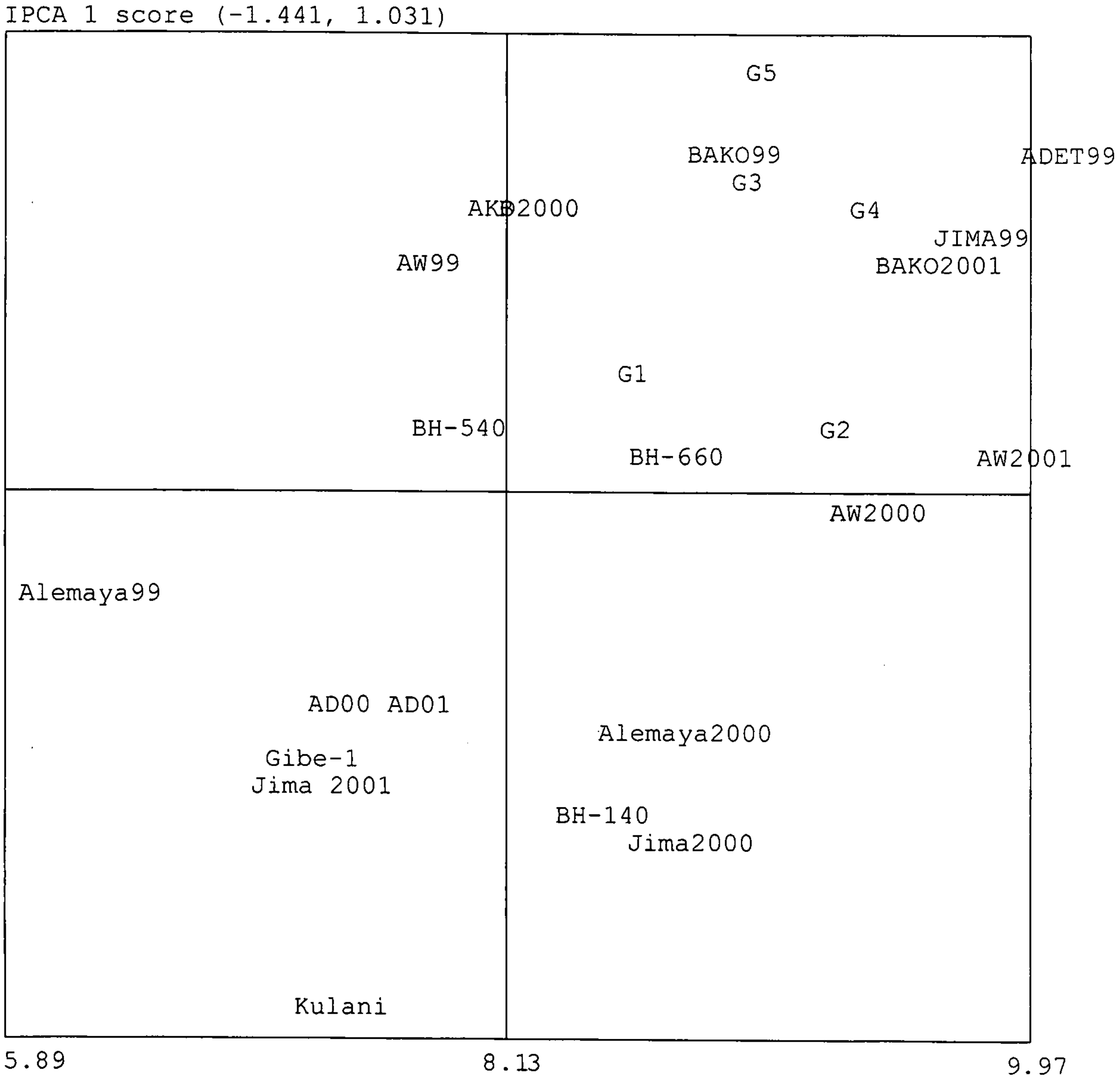

Figure 4.1. AMMI model 1 biplot for grain yield of 10 maize genotypes tested environments of Ethiopia, 1999-2001. The first letter of all genotypes and environments the right spot on the biplots; AW = Awassa, AD = Adet., G=genotype

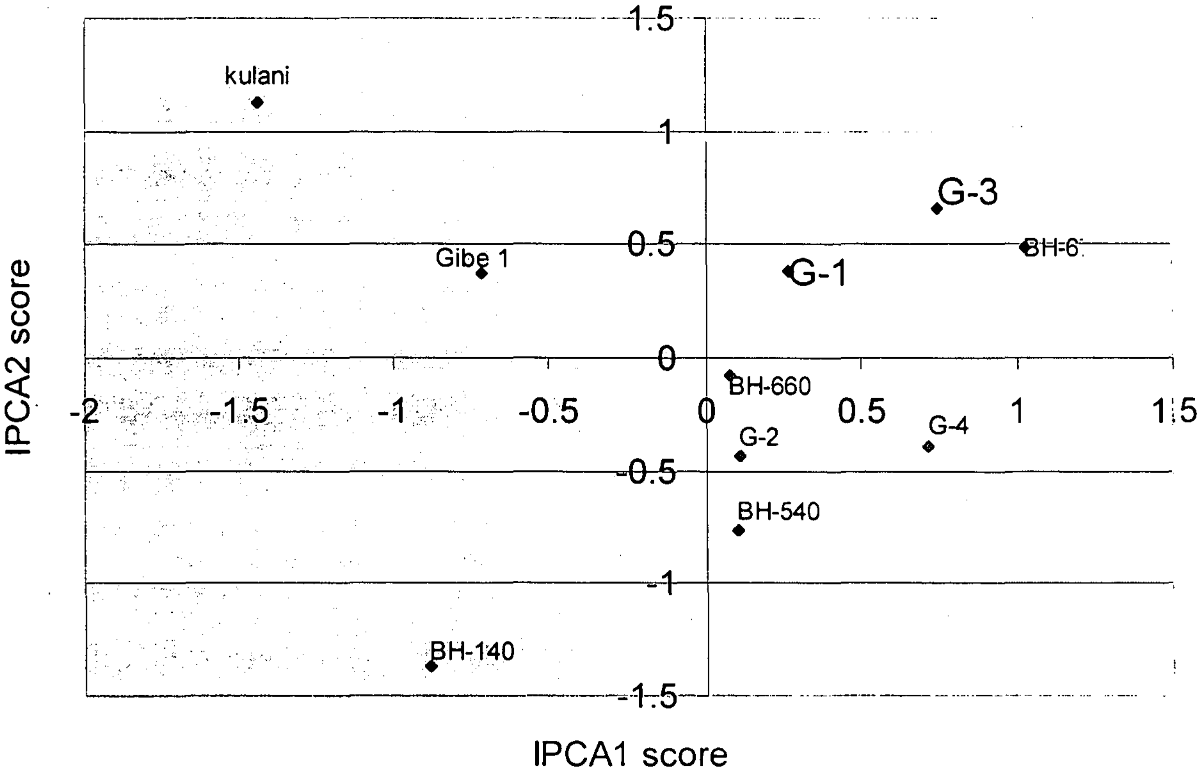

Fig 4.2. Plotted IPCA1 and IPCA2 scores of 10 maize genotypes tested in 15 environments of Ethiopia

4.4. Comparison of the stability parameters

Table 4.7 provides the summary of five the stability parameters used to analyze maize grain yield performance. These stability parameters were: Coefficient of variation CV% (Francis & Kannenberg, 1978), deviation from regression line S^2di (Eberhart & Russel, 1966), ecovalence Wi (Wricke, 1962), stability variance (Shukla, 1972), and AMMI stability value ASV (Gauch & Zobel, 1996; Zobel *et al.*, 1988; Purchase, 1997). The coefficient of regression b and the overall mean yield were included to support the stability parameters and also to compare them. Leon and Becker (1988) indicated that b can be used to describe the general response to the goodness of environmental conditions, while S^2di actually measures yield stability.

As indicated in Table 4.7, the value of ecovalence Wi (Wricke, 1962), stability variance (Shukla, 1972) and AMMI's stability value (ASV) found the most popular three-way hybrid, BH-660 as the most stable genotype. Only deviation from the regression ranked this variety as 6th, which categorised it as having average stability. (A-7033 x F-7189) x 142-1-e was considered as the second most stable genotype being ranked secondly by both ecovalence Wi and stability variance. It ranked third by deviation from regression and AMMI's ASV, whereas the coefficient of variation ranked this genotype 9th.

Most of the parameters were similar in identifying the third (A-7032 x F-7215) x 144-7-b and the fourth (Gibe-1) stable genotypes. The unstable genotypes were Kulani and BH-140, as they were released to serve the highland and low-intermediate maize growing areas of the country respectively. Kulani is an open-pollinated variety and BH-140 is a top-cross. When the mean yields were considered, Gibe-1, was ranked 10th. It had an average yield of 6.95 t ha^{-1}, and is an open-pollinated variety from CIMMYT and east Africa.

All of these stability parameters were closely related in differentiating between yield stability of the evaluated maize genotypes. This study found AMMI, ecovalence and stability variance as the most important in assessing the stability of maize genotypes tested in Ethiopia. However, the repeatability of different stability parameters has to be compared and the ones with high repeatability should be superior in identifying the stable genotypes. Additionally, methods to simultaneously select for high yield and stability are more useful to determine the best genotypes for practical purposes.

The stability parameters considered as superior in identifying stable genotypes in this study, found those genotypes as stable that are officially released and popular, such as BH-660.

In summary, the above stability parameters found BH-660, (A-7033 x F-7189) x 142-1-e, (A-7032 x F-7215) x 144-7-b and Gibe-1 as the most stable genotypes, while Kulani and BH-140 were unstable. The remaining genotypes were intermediate between these two groups. The result of this analysis recommend (A-7033 x F-7189) x 142-1-e to be released for the maize growing regions of the country. The most stable genotype (BH-660) is already recommended, and this variety is the most popular currently under production. This variety was tested and adequately demonstrated to have superiority in yield performance, adaptation and other agronomic traits. Stoskopf (1993) found that clear indication of varietal superiority in a specific area or areas, genetic purity to ensure distinctiveness, uniformity and stability across sites and years are essential, with a reasonable degree of reliability needed for licensing new cultivars.

Table 4.7. Mean grain yield (t ha^{-1}), different stability measurements and rankings (Rk) for the maize genotypes tested.

No	Genotypes	Overall mean	Rk	CV %	Rk	bi	S^2di	Rk	Ecovalence Wi	Rk	Stability variance	Rk	AMMI ASV	Rk
1	(A-7033xF-7189)x142-e	8.16	6	18.9	9	1.1462	-0.4640	3	6.6142	2	1.9601	2	0.484	3
2	(A-7032xF-7215)x144-7-b	8.96	1	16.1	5	0.9044	0.0293	2	7.3171	5	2.2111	5	0.453	2
3	(A-7016xG-7462)x142-1-e	8.72	4	12.2	1	1.2458	0.2834	7	11.7956	7	3.8105	7	1.053	7
4	(A-7032xG-7462)x142-1-e	8.78	2	15.9	4	1.1208	0.0163	1	7.2731	4	2.1954	4	0.884	6
5	(A-7033xF-7215)x144-7-b	8.73	3	18.5	8	1.0665	0.4384	8	12.5279	8	4.0721	8	1.423	8
6	BH-660	8.35	5	17.6	7	1.0978	-0.1155	6	5.4457	1	1.5427	1	0.013	1
7	BH-540	7.46	8	17.3	6	1.1571	0.0664	5	8.1563	6	2.5108	6	0.588	4
8	BH-140	8.08	7	14.9	2	0.9579	0.6697	10	15.4740	9	5.1243	9	2.144	9
9	Kulani	7.09	9	19.0	10	0.4996	0.5598	9	19.7392	10	6.6476	10	3.589	10
10	Gibe-1	6.95	10	15.2	3	0.8039	-0.0466	4	7.0025	3	2.0987	3	0.712	5

Note: R= Rank; CV% = Coefficient of variability; bi= regression coefficient; S^2di= Deviation from regression line; Wi= Wricke's ecovalence; ASV= AMMI satiability value.

Chapter 5

Conclusions and recommendations

The interaction of genotypes with the environment is significant in maize. G X E interaction results in different genotype rankings in different environments, therefore testing of the genotypes needs to be conducted at different locations. Performances of genotypes at different locations were not consistent from year to year thus testing must also take place across years. Variety selection is being complicated by G X E interactions, which requires the testing of genotypes over locations and years for reliable estimates of yield to be obtained. This increased testing procedure in turn places a greater demand on the resources available. Thus analytical methods that effectively take account of the G X E interactions and the efficient use of the resources available are essential for a successful variety evaluation program.

The three-way cross, (A-7032 x F-7215) x 144-7-b out-yielded all other genotypes, with an average yield of 8.93 t ha^{-1} across locations and years. The next high yielding varieties were two three-way hybrids namely, (A-7032 x G-7462) x 142-1-e and (A-7033 x F-7215) x 144-7-b with yields of 8.79 and 8.74 t ha^{-1} respectively. (A-7033 x F-7215) x 144-7-b has been previously released and recommended for commercial production to serve the intermediate to high-land maize producing regions of Ethiopia.

Five methods of stability analysis were applied to determine the relative stability of 10 maize genotypes tested across 15 environments of Ethiopia. Shukla's (1972) stability variance, Wricke's (1962) ecovalence and AMMI's stability values unanimously found the most stable genotype, to be BH-660. Eberhart and Russel's (1966) deviation from the regression also indicated this genotype as one of the most stable. The same applied to (A-7033 x F-7189) x 142-1-e, which was identified as the second most stable across environments. These stability parameters identified BH-660, (A-7033 x F-7189) x 142-1-e, Gibe-1 and (A-7032 x F-7215) x 144-7-b as the most stable genotypes in the order given. The AMMI model, Shukla's (1972) stability variance and Wricke's (1962) ecovalence were found to be important in determining the comparative stability of the tested genotypes in this study.

AMMI combines the analysis of variance and the principal component analysis in one model, thus it was found useful in describing both G X E interactions and stability analysis through its responsive patterns. Since information on G X E interactions and stability of varieties are essential for farmers, breeders and other agricultural experts, the data on stability analysis need to be made available to users whenever new varieties are proposed for commercial release, whether they are recommended for specific or broad adaptations.

CHAPTER 6

SUMMARY

The study was undertaken to assess the performance of 10 maize genotypes across 15 maize growing environments of Ethiopia. The study was conducted from 1999 to 2001. The grain yields of these genotypes were analyzed using different statistical procedures to determine their G X E interactions and grain yield stability. The main objective of this study was to investigate the G X E interactions and stability performance of genotypes in various environments by applying different statistical methods of analysis in order to make useful recommendations for future utilization.

Separate and combined analyses of variance across locations and years and five types of stability parameters were performed, using the AGROBASE 2000 program. In order to perform the stability analyses, data of 10 maize genotypes tested across five locations and three years were analyzed using the procedures of Finlay and Wilkenson (1963), Eberhart and Russel, (1966) for the joint regression, Wricke (1962) for ecovalence, Shukla (1972) for stability variance and (Gauch and Zobel, 1988) for the AMMI stability model.

Separate trial analyses for the three years showed highly significant ($P<0.01$) differences among genotypes and locations for grain yield. In the year 1999, BH-670 was the best performer, followed by (A-7016 x G-7462) x 142-1-e and (A-7032 x G-7462) x 142-1-e with average yields of 9.59, 9.51 and 9.14 t ha^{-1} respectively. This ranking changed during 2000 and 2001, due to the presence of interactions. Across locations and years, (A-7032 x F-7215) x 144-7-b ranked first, followed by (A-7032 x G-7462) x 142-1-e and BH-670. All are three-way hybrids with mean yields of 8.93, 8.79 and 8.74 t ha^{-1} respectively. Among the locations the highest yield of 8.80 t ha^{-1} was obtained from Awassa, followed by Bako and Jimma over the three years, indicating the high potential of these sites for maize production. The results also showed yield variations over locations and years, confirming the presence of G X E interactions. The average of

ANOVA components over the three years indicated that about 42% of the total variance was accounted for by genotypes and 13% by blocks. This confirmed variability between genotypes in their response to environmental factors.

Combined analyses of variance across locations found highly significant (P<0.01) differences among locations (L) and genotypes (G) for grain yield. There was a differential response of genotypes over locations, mainly due to edaphic and climatic factors. About 34% of the variance components were attributed to locations, while 16% of the variance components were attributed to genotypes and 12% to their interactions over the three years. This confirms the effect of environmental factors and thus the necessity of stability analyses for the appropriate genotypes.

The combined analyses across locations, years and their interaction indicated highly significant differences (P<0.01) among the genotypes for grain yield, which suggests differential responses of genotypes to their environments. Significant G X E interaction makes the genotype selection processes difficult, which create problems in cultivar characterization. Stability analyses with appropriate statistical methods are therefore required to overcome this problem. Most of these interactions were highly significant due to abiotic and biotic factors, which need in-depth studies for better understanding. Generally, when G X E interaction is mainly caused by unpredictable environmental factors, breeing efforts should be aimed at the development of stable varieties with a relatively good performance under a range of environments. When the interaction is however due to predictable environmental factors the aim should be to develop either different varieties for different environments or broadly adapted varieties for a range of environments.

The joint regression model for grain yield indicated highly significant differences between the genotypes. The joint regression model identified (A-7032 X G-7462) X 142-1-e as the most stable genotype, followed by (A-7032 X F-7215) X 144-7-b and (A-7033 X F-7189) X 142-1-e. These last two genotypes were the best yielders across all environments and both are three-way hybrids.

Wricke's (1962) ecovalence considered BH-660 (one of the popular hybrids) as the most stable genotype, followed by (A-7033 X F-7189) X 142-1-e and Gibe-1 (an open-pollinated variety). BH-660 is the most popular hybrid currently under production in the country and Gibe-1 is a newly released open-pollinated variety (OPV). (A-7032 X G-7462) X 142-1-e and (A-7032 X F-7215) X 144-7-b were categorized as intermediate in stability, unlike Kulani and BH-140, which were found to be unstable according to this stability measurement.

According to Shukla's stability variance (1972), BH-660 followed by (A-7033 X F-7189) X 142-1-e and Gibe-1 were the most stable genotypes, whereas Kulani and BH-140 were considered as the least stable genotypes. BH-660, the popular three-way hybrid was the most stable genotype as measured by both ecovalence and the stability variance. Joint regression was also in agreement with these results with only slight differences.

Additive main effects and multiplicative interactions (AMMI) stability values, and scores of the interaction principal component analysis (IPCA) showed that BH-660 was the most stable genotype followed by (A-7032 X F-7215) X 144-7-b and (A-7033 X F-7189) X 142-1-e, whereas Kulani and BH-140 were considered to be unstable. AMMI gave the same results as the ecovalence and Shukla in identifying the stable genotypes.

OPSOMMING

Die studie is onderneem om te toets hoe 10 mielie genotipes in 15 verskillende omgewings in Etiopië sou presteer. Die studie is uitgevoer vanaf 1999 tot 2001. Die graanopbrengs van die verskillende genotipes is ge-analiseer deur verskillende statistiese metodes te gebruik om hul G x E interaksie en opbrengs stabiliteit te bepaal. Die hoofdoel van die studie was om die G x E interaksies en stabitliteitsprestasies van genotipes in verskillende omgewings te bepaal deur van verskillende statistiese metodes gebruik te maak, sodat nuttige voorstelle vir gebruik in die toekoms gemaak kon word.

Afsonderlike en gekombineerde analises van variansie oor omgewings en jare en vyf verskillende stabiliteits parameters is gedoen met behulp van die AGROBASE 2000 sagteware. Die data van 10 mielie genotipes oor vyf omgewings en drie jare is gebruik in die analises van die modelle van Finlay en Wilkenson (1963), Eberhart en Russel (1966) vir die gesamentlike regressie, Wricke (1962) vir ekovalensie, Shukla (1972) vir stabiliteitsvariansie en Gauch en Zobel (1988) vir die AMMI stabiliteitsmodel.

Afsonderlike proef analises vir drie jaar het hoogs betekenisvolle verskille ($P<0.01$) tussen genotipes en gebiede vir graan opbrengs gevind. In 1999, het BH-670 die beste presteer, gevolg deur (A-7016 x G-7462) x 142-1-e en (A7032 x G7462) x 142-1-e met gemiddelde opbrengste van 9.59, 9.51 en 9.14 t ha^{-1} respektiewelik. Die rangordes het egter verander gedurende 2000 en 2001, as gevolg van die teenwoordigheid van interaksies. Oor gebiede en jare het (A-7032 x F-7215) x 144-7-b die hoogste rang gehad, gevolg deur (A7032 x G7462) x 142-1-e en BH-670. Al drie is drie-rigting basters met gemiddelde opbrengste van 8.93, 8.79 en 8.74 t ha-1 respektiewelik. Tussen die gebiede is die hoogste opbrengs gekry in Awassa, gevolg deur Bako en Jimma oor die drie jare. Dit dui op die hoë potensiaal van hierdie gebiede vir mielie produksie. Die resultate toon ook opbrengsverskille oor gebiede en jare, wat weer op G x E interaksies dui. Die gemiddelde van die ANOVA komponente oor die drie jare toon dat ongeveer 42% van die totale variansie was as gevolg van die genotipes, terwyl 13% die gevolg van blokke was. Dit bevestig die variasie tussen genotipes in hul reaksies tot omgewingsfaktore.

Gekombineerde analises van variasie oor gebiede toon hoogs betekenisvolle verskille ($P<0.01$) tussen gebiede (L) en genotipes (G) vir graanopbrengs. Daar was 'n differensiële respons van genotipes oor gebiede, hoofsaaklik as gevolg van klimaatsfaktore. Ongeveer 34% van die variansie komponente was as gevolg van gebiede, terwyl 16% toegeskryf kon word aan die genotipes en 12% aan die interaksies oor die drie jare. Dit bevestig die effekte van omgewingsfaktore en dus die noodsaaklikheid van stabiliteitsanalises om die belangrikste genotipes te bepaal.

Die gekombineerde analises oor gebiede, jare en hul interaksie toon hoogs betekenisvolle verskille tussen die genotipes vir hul opbrengste, wat dui op die verskillende reaksies van genotipes teenoor die omgewing. Betekenisvolle G x E interaksies bemoeilik die seleksie van genotipes en veroorsaak probleme in die karakterisering van kultivars. Om hierdie probleem te oorkom, is stabiliteitsanalises met behulp van gepasde statistiese metodes dus nodig. Meeste van die interaksies is hoogs betekenisvol as gevolg van biotiese en abiotiese faktore. In diepte studies is egter nodig om dit beter te verstaan. Oor die algemeen as G x E interaksies die gevolg is van onvoorspelbare omgewingsfaktore, moet telers poog om stabiele variëteite te ontwikkel wat goed presteer in verskillende omgewings. As die G x E interaksies egter die gevolg is van voorspelbare omgewingsfaktore, moet spesifiek aangepasde variëteite vir spesifieke gebiede of wyd aangepasde variëteite vir 'n wye reeks gebiede ontwikkel word.

Die gemeenskaplike regressie model vir graanopbrengs het hoogs betekenisvolle verskille tussen genotipes gewys. Hierdie model het gevind dat (A7032 x G7462) x 142-1-e die mees stabiele genotipe was, gevolg deur (A-7032 x F-7215) x 144-7-b en (A-7033 x F-7189) x 142-1-e. Laasgenoemde twee genotipes het die hoogste opbrengste oor al die omgewings gehad en altwee was drie-rigting basters.

Die ekovalensie van Wricke (1962) het gevind dat BH-660 ('n baie populêre baster) die mees stabiele was, gevolg deur (A-7033 x F-7189) x 142-1-e en Gibe-1 ('n oopbestuiwende variëteit). BH-660 is die mees gewildste baster tans onder produksie in die land, terwyl Gibe-1 is nuut vrygestelde oop-bestuiwende varieteit is. (A7032 x G7462) x 142-1-e en (A-7032 x F-7215) x 144-7-b het intermidiêre stabiliteit, terwyl Kulani en BH-140 as onstabiel geklassifiseer word.

Shukla's se stabiliteits variansie (1972) het gevind dat BH-660, gevolg deur (A-7033 x F-7189) x 142-1-e en Gibe-1 stabiel was, terwyl Kulani en BH-140 as onstabiel geklassifiseer is. Ekovalensie sowel as die stabiliteits variansie het gevind dat BH-660 was die mees stabiele genotipe. Die gesamentlike regressie het ongeveer dieselfde resultate gehad as laasgenoemde twee.

Die stabiliteits waardes van additiewe hoofeffekte en vermenigvuldige interaksies (AMMI) en rangordes van die interaksie hoofkomponent analises (IPCA) het ook gevind dat BH-660 die mees stabiele genotipe was, gevolg deur (A-7032 x F-7215) x 144-7-b en (A-7033 x F-7189) x 142-1-e, terwyl Kulani en BH-140 as onstabiel geklassifiseer is. AMMI het dieselfde resultate as die ekovalensie en Shukla gehad ten opsigte van die mees stabiele kultivars.

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