UTILIZATION OF MULTI-LOCATIONAL PIGEONPEA PERFORMANCE DATA FOR DETERMINATION OF STABILITY PARAMETERS

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AND TECHNOLOGY

Utilization of Multi-Locational Pigeonpea Performance Data for Determination of Stability Parameters

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Declaration

This dissertation is my original work and has not been presented for award of a degree in any other university.

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AG332-1960/2010

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Dedication

I dedicate this dissertation to God for His grace, my late parents David Lawrence Kamau and Mary Muringi Kamau, my uncle Joseph Nduruhu Kimani and my sister Esther Kamau Muchai for their parental support and the rest of my siblings for their moral support.

Table of contents

List of Tables

List of Figures

List of Acronyms and Abbreviations

AEA	Average Environment Axis
AMMI	Additive Main Effects and Multiplicative Interaction effects
ANOVA	Analysis of Variance
DAF	Days to 50% flowering
DAM	Days to 75% maturity
FAO	Food and Agricultural Organization
GxE	Genotype by Environment Interaction
GGE	Genotype main effect plus genotype by environment interaction
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
PCA	Principal Component Analysis
UNESCO	United Nations Educational, Scientific and Cultural Organization

Abstract

Multi-locational data on medium duration pigeonpea varieties in Eastern and Southern Africa was analyzed for genotype performance. The objective was to utilize multi-locational data to identify superior genotypes. The study also aimed at ranking the pigeonpea varieties using different yield based stability parameters. The relationship between temperature and performance of these varieties was also evaluated. Data were obtained from trials conducted at research stations in Kenya, Uganda, Tanzania, Malawi and Mozambique by the International Crops Research Institute for the Semi-Arid Tropics. Seven common genotypes were selected from data collected between 1997/98 to 2009/2010 crop seasons to constitute 22 environments. Analysis of variance, Eberhart and Russell, AMMI and GGE biplot models were used to evaluate genotype by environmental interactions. In addition, analysis was done to test the relationship between crop performance vis-à-vis mean maximum and minimum temperature during crop growth period. Analysis of variance showed that genotype by environmental interaction was significant ($p<0.001$). Different stability parameters gave different genotype rankings. Eberhart and Russell model ranked genotypes ICEAP 00550 as the most stable genotypes, AMMI model ranked ICP 6927 as the most stable genotype while ICEAP 00068 was ranked as the most stable genotype by GGE biplot. Considering ranking by the three models the three most stable genotypes were found to be ICEAP 00550, ICP 12734 and ICP 6927. Temperature, showed a significant relationship with crop performance($p<0.001$). Recommendations were

that stable genotypes should be subjected to on farm national performance trials for adoption. Temperature could be considered by scientists when predicting duration from planting to flowering and maturity.

CHAPTER 1

1. INTRODUCTION

1.1. Background

1.1.1. Food Security Situation in Africa

Hunger and malnutrition are still serious concerns throughout Africa particularly in Sub-Saharan Africa, (UNESCO, 2009). World population continues to increase geometrically but food production only does so arithmetically (Malthus, 1766-1834). This has resulted in perennial food shortages. This occurs despite implementation of the Millennium Development Goal number one of eradicating extreme poverty and hunger by the United Nations. The most vulnerable people are those living in developing countries (FAO, 2010).

Millennium Development Goal number four and five aim to reduce child mortality and improve maternal health respectively. In order for these to be achieved, the core cause of hunger and malnutrition must be addressed and a practical solution found. The shocking observation is that a child born in Sub-Saharan Africa is still more likely to be malnourished than to go to primary school (Leisinger, 1996). This is despite the implementation of Millennium Development Goal number one (MDG 1) of eradicating extreme poverty and hunger and MDG 2 of achieving universal primary education. UK Hunger Alliance predicts that food prices are to stay high and volatile for the foreseeable future and it is the poorest that will be hit hardest (IFPRI, 2011). If these challenges are not addressed adequately it may not be feasible to attain the Millennium Development Goals.

1.1.2. Climate Change and its Effects on Agriculture in Africa

Climate change is the most severe problem the world is facing today, more serious than even the threat of terrorism (King, 2004). Unfortunately this is emerging as a major challenge to agriculture development in Africa (FAO, 2009). Therefore there may be worse food insecurity situation experienced in future in SSA if more effort is not made to cope with this challenge.

Estimated marginal impacts of climate variables suggest that global warming is harmful for agricultural productivity and that changes in temperature are much more important than changes in precipitation (Mariara and Karanja, 2007). It is estimated that the global average surface temperature has increased over the 20^{th} century by about 0.6°C (Houghton *et al*, 2001). Further reports state that 1995 to 2006, rank among the twelve warmest years in the instrumental record of global surface temperature since 1850 (Allali *et al*, 2007). These are clear indications that the threat of climate change is real and Sub-Saharan Africa should be ready for it. There are fears that progress in human development achieved over the last decade may be slowed down or even reversed by climate change, as new threats emerge to water and food security, agricultural production, nutrition and public health (Ludi, 2009).

It has been projected that 2.5°C warming would result in net revenues from farming in all of Africa falling by $23 billion and that 5°C warming would cause net revenues in Africa to fall by $38 billion (Kurukulasuriya and Mendelsohn, 2006). A number of countries in sub-Saharan Africa (SSA) are already experiencing considerable water stress a result of insufficient and unreliable rainfall, changing rainfall patterns or flooding (Ludi, 2009). Ludi predicts that the impact of climate change is likely to exacerbate the stresses of agricultural productivity and food insecurity even further. Projections show that climate change will affect all four dimensions of foods security; food availability, food accessibility, food utilization and food systems stability (FAO, 2008). It is therefore necessary that effort is put in growing drought tolerant crops that are also high in nutrient content.

1.1.3. Alleviating food insecurity and climate change challenges

Despite the enormous work done by plant breeders in developing high yielding crop varieties the changes in climate may limit the gains as this is tantamount to a shifting target. One of the remedies may be to breed new and adapted as well as the preservation of traditional locally adapted varieties that can tolerate climate variability and are suitable for changed climatic conditions (Borron, 2006). Legumes in particular have many advantages. In addition to being a rich source of soil proteins, they enrich soil through biological nitrogen fixation. Studies have shown that the rotation of chickpea and pigeonpea reduces the use of chemical fertilizers and also enhances the output of paddy and wheat significantly (Kumar and Bourai, 2012).

Pigeonpea being a drought tolerant crop with numerous benefits including being a leguminous crop would contribute significantly to farmers adapting to climate change (Odeny, 2007). The crop can withstand drought compared to other legumes. As a legume it assists in nitrogen fixation since inorganic nitrogen fertilization is too expensive for many farmers. In addition, pigeonpea is a rich source of protein for many households as animal protein is unaffordable to many poor households leading to malnutrition. Pulses, pigeonpea being one, have a wide adaptability to latitudes, longitudes and climate variables but adaptability of individual species is confined to their areas of origin (Kumar and Bourai, 2012). There is a need to encourage more growing of adaptable varieties as pigeonpea market is enormous with its demand outstripping supply (Odeny, 2007). Pigeonpea may therefore contribute significantly to reducing the challenge Africa continues to face of food insecurity as well as improving farmers' livelihoods in Eastern and Southern Africa, especially those living in arid and semi-arid lands (ASALs).

1.1.4. Importance of pigeonpea

Pigeonpea is both a food crop (dried peas, flour, or green vegetable peas) and a forage/cover crop (ICRISAT, 2011). It contains high levels of protein and the important amino acids; methionine, lysine, and tryptophan. Pigeonpea also contain a high amount of vitamin B, carotene, and ascorbic acid. These nutrients are deficient in cereals. Therefore, pigeonpea has a good supplemental value of cereal-based diet. In helping attain MDG goal number one, pigeonpea can contribute to reducing the proportion of people who suffer from hunger.

Farmers in Eastern and Southern Africa prefer pigeonpea for many reasons: tolerance to drought, important source of protein for the family, vital source of scarce cash, and provider of fodder for livestock (Hilario, 2010). Farmers have evolved elaborate intercropping systems allowing them interplant pigeonpea with maize, sorghum and other cereals making it highly suited to semi-arid, low soil fertility areas. The pods, seeds and leaves are excellent fodder for cattle, sheep and goats (Akande, 2007). Pigeonpea has the ability to utilize residual moisture during the dry season (Sharma and Green, 1975) and can be grown in areas with less than 650 mm annual rainfall. It is grown under rainfed conditions in drought prone areas where day length varies from 11 to 14 hours and a large range in temperature, largely due to variations in altitude and latitude (Silim *et al*, 2004). Due to this, pigeonpea can be grown with relative ease and growing it can uplift farmers' livelihoods especially those living in arid and semi-arid areas. Its wide adaptability also makes it a good crop for helping farmers adapt to climatic variability and change.

1.1.5. Genotype by Environmental Interaction

Genotype is the specific genetic makeup of an organism (Keim *et al*, 2008). The physical or visible characteristics resulting from the interaction between the genetic makeup and the environment are referred to as phenotype (Bondari, n.d.). Phenotypes are observable, measurable, can be categorized or even enumerated. Environmental factors such as rainfall amount, soil structure, temperature and altitude may impact genotypes positively or negatively.

When genotypes performance rank differently in different environments this is what is known as genotype by environmental interaction (Hammami *et al*, 2009).It is the association between the environment and the phenotypic expression of a genotype that is known as G×E interaction. This interaction that determines whether a genotype is adapted to a whole range of environmental conditions or separate genotypes is manifested through growing the genotypes in different sub-environments.

Sub Saharan Africa has diverse agro ecologies for farming pigeonpea. Therefore it is expected that pigeonpea varieties will rank differently in different environments. Thus evaluation of GxE among pigeonpea varieties of interest will identify high yielding and stable varieties, in order to make farming of pigeonpea more profitable to farmers and improve food security in respective environments.

1.2. Problem statement

Despite pigeonpea being an important source of cash for small holder farmers, they have not been able to tap into market demands because of several challenges, among them being low quality grains produced from endemic local varieties

(ICRISAT, 2011). Pigeonpea is grown in various agro-ecologies in Eastern and Southern Africa. Most of these agro-ecologies have a bimodal rainfall pattern in a year. This makes long duration varieties vulnerable to drought before maturity. Climate change is manifested by unpredictable rainfall patterns, further complicating the plight of farmers. There is a need to identify varieties that are adaptable to these challenges. Early research emphasis by ICRISAT in India was on short and medium duration types whereas the main crop in ESA region was long duration (except in Uganda where medium duration is dominant) (ICRISAT, 2011). Medium duration varieties hold part of the solution to escaping drought that may occur during the plant's growth cycle without compromising on grain yield. Medium duration varieties are suitable for most pigeonpea agro-ecological zones in ESA.

Grain yield of chickpea and pigeonpea is low to moderate in the semi-arid tropics with large variation due to high GxE interaction (Upadhyaya et *al*, 2012). There is need therefore to use multi-locational data to identify superior genotypes so as to help farmers attain high yield so that famers not only increase their incomes but also attain food security.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of the study was to use multi-locational data for identification of superior pigeonpea varieties.

1.3.2. Specific objectives

1. To evaluate different genotypes using different stability parameters.

2. To investigate relationship between direct temperature during growth and yield and yield related components.

1.4. Justification

Food insecurity is a big challenge in Africa (UNESCO, 2009). Sub-Saharan Africa is the only region in the world currently facing both widespread chronic food insecurity and threats of famine (Devereux and Maxwell, 2001).This challenge can be addressed through focusing on a crop that requires low input and at the same time can meet major nutritional needs of the people in this region.

Pigeonpea offers an alternative crop which performs well in East and Southern Africa because of its drought tolerance and its high protein content (Odeny, 2007).Despite pigeonpea being a potential crop of high commercial value, farmers in the region have not benefitted much from it. This is because many farmers continue to cultivate indigenous landraces that are low yielding with little knowledge on resistance to biotic stresses and are not aware of improved varieties that are adapted to their regions (Mergeai *et al*., 2001). Adaptable varieties in varying environmental conditions would be desirable (Wachira *et al*., 2002). There is need to identify pigeonpea varieties for ESA to address the challenges of food insecurity and ensure improvement of livelihoods in this region. If farmers select varieties are adaptable to their region they will plant the right varieties and good yield would translate to better income leading to improved livelihoods. Temperature relationships need to be understood as ESA has diverse agro-ecological environments (UNDP, 2012).

CHAPTER 2

2. LITERATUREREVIEW

2.1. Pigeonpea and its distribution

The origin of the pigeonpea is controversial but according to FAO, it originated in both Africa and Asia (Wasike *et al*, 2005). The crop is widely cultivated in all tropical and subtropical regions of both the Old and the New Worlds. Pigeonpea is currently being grown on 5.2 million hectares in the rain fed areas of Asia, eastern and southern Africa, Latin American and Caribbean countries (ICRISAT, 2012). In Eastern and Southern Africa, pigeonpea is grown on 850,031 ha (Table 1). It is an important crop in Mozambique, Malawi, Tanzania, Kenya and Uganda.

Table 1: Area, production and productivity of pigeonpea in ESA

Country	**Area**	**Production**	**Grain Yield**
	Ha	**Metric tonnes**	**Kg/ha**
Malawi	193,207	172,310	905.27
Kenya	157,624	77,989	491.23
Tanzania	215,967	179,967	833.3
Mozambique	193,233	66,566	344.3
Uganda	90,000	91,333	1014.9
ESA total	**850,031**	**588,164**	**691.9**

(ICRISAT, 2012)

Note: values were derived from 2008-2010 crop season averages

In ESA it is mostly grown as an intercrop with cereals (maize, sorghum, finger millet) and root crops. It is the third most important food grain legume in Kenya after bean and cowpea (Mergeai *et al*, 2001).It is clear that pigeonpea has been in Africa for a long time and could partly have evolved in Africa.

Varieties of pigeonpea can be perennial, in which the crop can last three to five years, or an annual variety more suitable for seed production (ICRISAT, 2011). This makes it a versatile crop both for farmers who want to grow it for just one season and those wishing to grow it for several seasons.

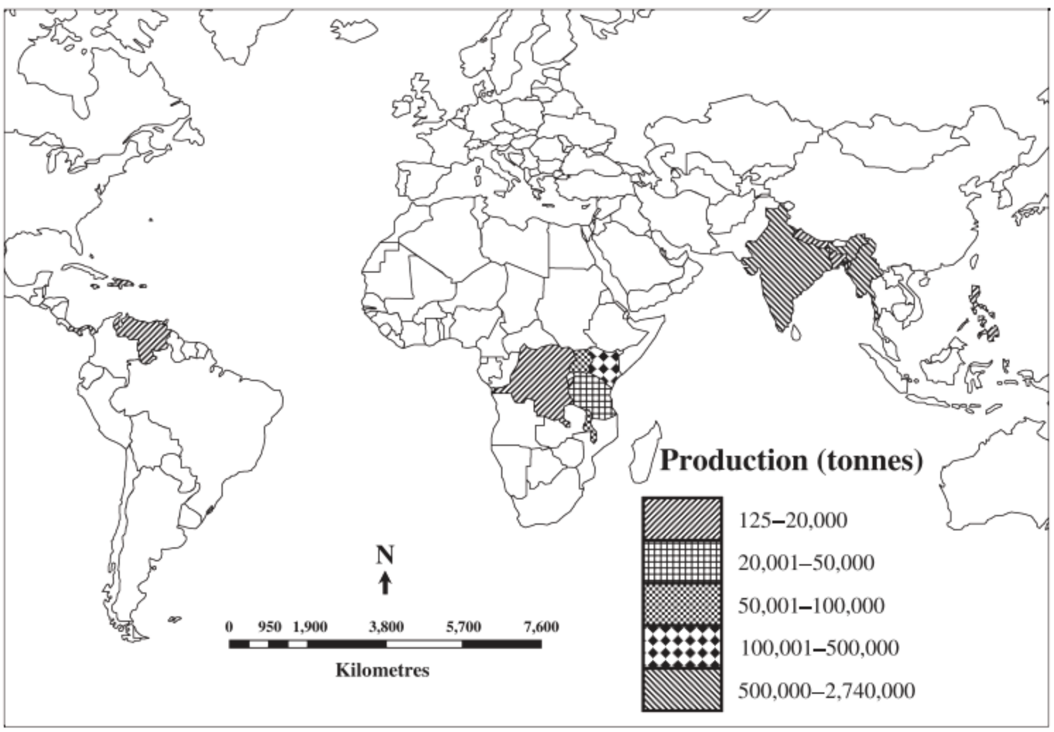

Figure 1: Distribution of pigeonpea in the World (Odeny, 2007)

Pigeonpea is cultivated on marginal lands by resource-poor farmers, who commonly grow traditional medium- and long-duration landraces (ICRISAT, 2011). This makes pigeonpea a suitable crop in helping achieve MDG 1 of eradicating extreme hunger and poverty. Short-duration pigeonpea (3-4 months) suitable for multiple cropping have recently been developed. Traditionally, the use of such input as fertilizers, weeding, irrigation, and pesticides is minimal, so present yield levels are low. This means that the crop can be exploited further to maximize on its benefits by identifying most adaptable varieties. Greater attention is now being given to managing the crop because it is in high demand at remunerative prices.

Pigeonpea are categorized in to mainly 3 maturity groups: short, medium and long duration maturity groups (ICRISAT, 2011).Short-duration varieties are relatively insensitive to photoperiod (day length insensitive) and their optimum temperatures to flower early are high (24^{o}C) and flowering and maturity is delayed mostly by low temperature (ICRISAT, 2011).Medium-duration varieties from low elevation areas near the equator, are sensitive to photoperiod and would only flower under short days. If planted away from the equator, medium-duration varieties will flower only when day length is short.

2.2. Genotype by environmental interaction and its implication

In plant breeding and selection, a large number of genotypes are normally tested over a wide range of environments. Underlying statistical and genetic bases used to explain the behavior of the varieties may be rather complicated (Bondari, n.d.). Several ranking methods may therefore be necessary to identify the most stable genotypes.

Genotype by environmental interaction is considered a hindrance to crop improvement in a target region (Kang, 1998). Moreover, such effects may contribute, together with purely environmental effects, to the temporal and spatial instability of crop yields. Temporal instability, in particular, has a negative effect on farmers' income and, in the case of staple crops, contributes to food insecurity at national and household level.

Eberhart and Rusell (1966) stated that genotype by environment interaction are of major importance to a plant breeder and when varieties are compared over a series of environments, the relative ranking usually differ. However, stable performance of crop cultivars over a wide range of environments is generally regarded desirable (Wachira *et al*, 2002). Selection for stability in genotypes is not possible until a model with suitable parameters is available to provide the criteria necessary to rank the varieties (Eberhart and Rusell, 1966).Adaptation of pigeonpea to temperature and photoperiod is extremely important. Understanding the adaptation is critical to breeding and targeting varieties to areas where they would be most adapted and fit into the cropping systems (ICRSAT, 2011).

2.3. Adaptation

In breeding for wide adaptation, the aim is to obtain a variety which performs well in nearly all environments; in breeding for specific adaptation, the aim is to obtain a variety which performs well in a definite subset of environments within a target region (Hill *et al*, 1998).Breeding for wide adaptation and for high yield stability and reliability have sometimes been considered one and the same.

2.4. Temperature and pigeonpea performance

Research has shown that temperature affects pigeonpea performance (McPherson *et al.,* 1985, Silim *et al*., 2006). A study conducted on different maturity group pigeonpea varieties indicated that temperature has an effect on time taken from sowing to flowering (McPherson *et al.,* 1985). Studies also showed that for photoperiods below 13 hours, rates of progress towards flowering were influenced by temperature in five genotypes (Silim *et al*., 2006). Temperature is therefore an important variable in pigeonpea performance as has been stated in pigeonpea distribution. It could be an important aspect in stability of pigeonpea.

2.5. Assessment of Genetic Stability

Various techniques are available for evaluation of adaptation and genetic stability of genotypes in different environments. These include regression (Finlay and Wilkinson, 1963), model for stability (Eberhart and Russell, 1966), AMMI (Gauch, 1988) and GGE-biplot (Yan, 2006).

2.5.1. Regression Technique

In this model, for each variety, a linear regression of individual yield of all varieties for each site in each season is computed. Mean yield of all varieties and for each season provides a numerical grading of sites and regions. This way the average yield of a large group of varieties is used to describe a complex natural environment without the complexities of having to define and analyze the interacting environmental factors (Finlay and Wilkinson, 1963).

In a study on analysis of adaptation in a plant breeding program by Finlay and Wilkinson (1963), the basic yields were measured on a logarithmic scale since it was found that this introduced a high degree of linearity in the regression of individual yield of site means. Varieties characterized by regression coefficients of order 1.0 have average stability over all environments. Two important indices are regression coefficient and variety mean yield over all environments (Finlay and Wilkinson, 1963). Regression coefficient of approximating 1.0 indicates average stability. When this is associated with high mean yield, varieties have general adaptability. When associated with low mean yields varieties are poorly adapted to all environments (Figure 2).

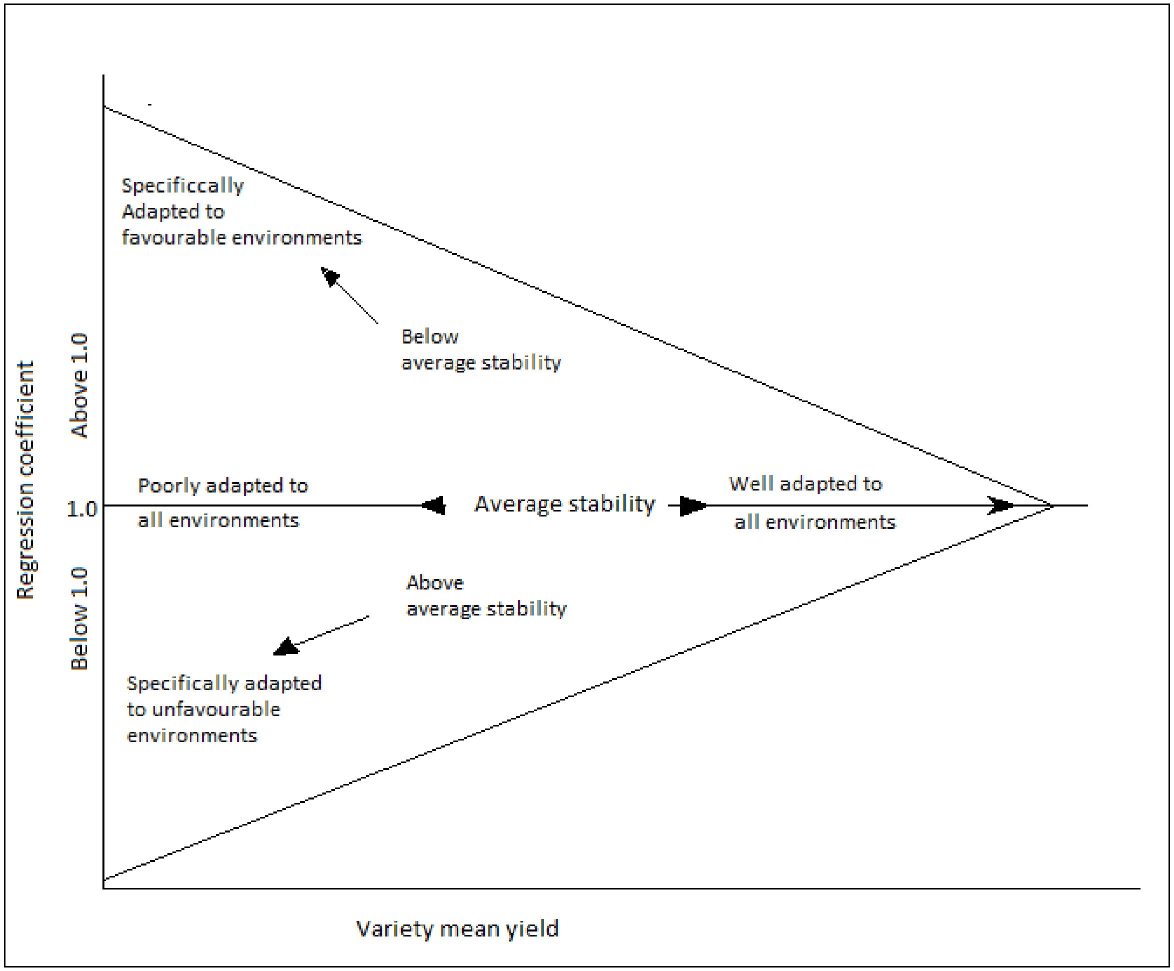

Figure 2: Interpretation of variety population pattern (Adopted from Finlay and Wilkinson, 1963)

A generalized interpretation of the variety population pattern obtained when variety regression coefficients are plotted against variety mean yields (Finlay and Wilkinson, 1963).Regression values increasing above 1.0 describe varieties with increasing sensitivity to environmental change (below average stability) and greater specificity to adaptability to high yielding environments. Regression coefficient 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. The index on variety mean yield over all environments provides a comparative measure of the performance of the individual varieties. Ideal varieties with general adaptability are those with maximum yield potential in the most favourable environments and a maximum phenotypic stability (Finlay and Wilkinson, 1963).

2.5.2. Model for Stability

The regression of each variety in an experiment on an environmental index and a function of the squared deviations from this regression would provide estimates of the desired stability parameters. Parameters are defined with the following model (Eberhart and Russell, 1966):

$$Y_{ij} = \mu_i + \beta I_j + \delta_{ij} ,$$

Where Y_{ij}= mean variety of the i^{th} variety at the j^{th} environment (i =1,2,…, v; j = 1,2,..,n), $\mu_i$is the mean of the i^{th} variety overall environments, β_j is the regression coefficient that measures the response of the i^{th} variety to varying environments, δ_{ij} is the deviation from regression of the i^{th} variety at the j^{th} environment, and I_j is the environmental index obtained as the mean of all varieties at the j^{th} environment minus the grand mean

$$\left[I_j = \left(\frac{\sum_i Y_{ij}}{v}\right) - \left(\frac{\sum_i \sum_j Y_{ij}}{vn}\right)\right], \sum_j I_j = 0.$$

However Eberhart and Russell (1966) state that the varieties must be grown in an adequate number of environments covering full range of possible environmental conditions if the stability parameters are to provide useful information. With this model the sum of squares due to environments, and variety× environment are partitioned into environments (linear), varieties ×environment (linear) and deviations from the regression model.

The first stability parameter is a regression coefficient estimated as follows:

$$b_i = \sum_j Y_{ij} I_j / \sum_j I_j^2$$

Where, $\sum_j Y_{ij} I_j$ is the sum of products and $\sum_j I_j^2$ is the sum of squares

With this model the sum of squares due to Environment and Variety × Environment are partitioned into Environment (linear), Varieties × Environment (linear) and Deviations from the regression model.

The performance of each variety can be predicted by using the estimates of the parameters where, $\hat{Y}_{ij} = \bar{x_i} + b_i I_j$, where x_i is an estimate of the $\boldsymbol{\mu}_i$. The deviation $[\hat{\delta^2_{ij}} = (Y_{ij} - \hat{Y}_{ij})]$ can be squared and summed to provide an estimate of another stability parameter ($\delta^2{}_{d_i}$);

$$\delta^2{}_{d_i} = [\textstyle\sum_j \hat{\delta^2_{ij}} / (n-2)] - S^2{}_e / r$$

Where $S^2{}_e / r$ is the estimate of the pooled error (or the variance of a variety mean at the j^h location) and:

$$\sum_j \hat{\delta^2_{ij}} = \left[\sum_j Y_{ij}^2 - \frac{Y_i^2}{n}\right] - (\sum_j Y_{ij} I_j)^2 / \sum_j I_j^2$$

This model provides a means of partitioning the genotype-environment interaction of each variety into 2 parts: (1) the variation due to the response of the variety to varying environmental indexes (sums of squares due to regression); and (2) the unexplainable deviations from the regression on the environmental index.

Where a breeder wants a variety that does above average in all environments with a high mean yield ($\bar{X}^2{}_i$), unit regression coefficient (b_i =1.0) and the deviation from regression as small as possible ($\delta^2{}_{d_i} = 0$). These define a stable variety.

2.5.3. AMMI Model

The additive main effects and multiplicative interaction effects (AMMI) model first applies the additive analysis of variance (ANOVA) model to two-way data, and then applies the multiplicative principal components analysis (PCA) model to the residual from the additive model, that is, to the interaction(Gauch, 1988). AMMI is frequently applied in yield trials in agricultural research when both main effects and interaction are important.

In many cases this procedure has been shown to increase estimation accuracy since it fits additive main effects for genotypes and environment by an ordinary ANOVA procedure and then applies PCA to the matrix of residuals that remain after the fitting of main effects (Rao, n.d.).

The AMMI model for G genotypes and environment E may be written as follows:

$$Y_{ge} = \mu + \alpha_g + \beta_{ej} + \sum_{n=1}^{N} \lambda_n \gamma_{gn} \boldsymbol{\delta}_{en} + \theta_{ge}$$

Where

Y_{ge} is the yield of genotype *g* in environment *e*;

μ is the grand mean;

α_g is the genotype mean deviations (the genotype means minus the grand mean;

β_{ej} is the environment mean deviations;

λ_n is the eigen value of the principal component analysis (PCA) axis *n*;

γ_{gn} and $\boldsymbol{\delta}_{en}$ are the genotype and environment PCA scores for PCA axis *n*;

N is the number of PCA axes retained in the model;

θ_{ge} is the residual

AMMI model is called a bilinear model because both environmental variables and genotypic sensitivities are estimated from the data table itself: given the column parameters the model is linear in the row parameters and given the row parameters the model is linear in the column parameters (Raju, 2002).The basic model is essentially a two way ANOVA model, which requires that the matrix of interaction parameters be decomposed by using factor analysis techniques. The stability parameters used in AMMI are genotype mean, environmental mean and variance. PI statistic is a measure of genotype performance across all the environments. The higher a genotype mean the better its performance across environments.

2.5.4. GGE-biplot

Mathematically, a biplot may be regarded as a graphical display of matrix multiplication (Yan, 2006). Given a matrix G with m rows and r columns, and a matrix E with r rows and n columns, they can be multiplied to give a third matrix P with m rows and n columns. In GGE-biplot ranking is based on mean and stability. Various plots are generated to give specific information as shown below.

In the environmental vector plot when angle formed between the genotype and the environment about the origin is less than 90^othis shows above average performance of that genotype in that environment (Figure 3). Angle that is bigger than 90^o shows below average performance. An angle close to 90^o shows near average performance. Distance between two environments in the plot shows their dissimilarity in discriminating the genotypes which helps in the identification of mega environments.

Cosine of the angle between the vectors of two environments about the origin is a measure of correlation between them: Acute angle implies positive correlation; Obtuse angle implies negative correlation while a right angle implies zero correlation.

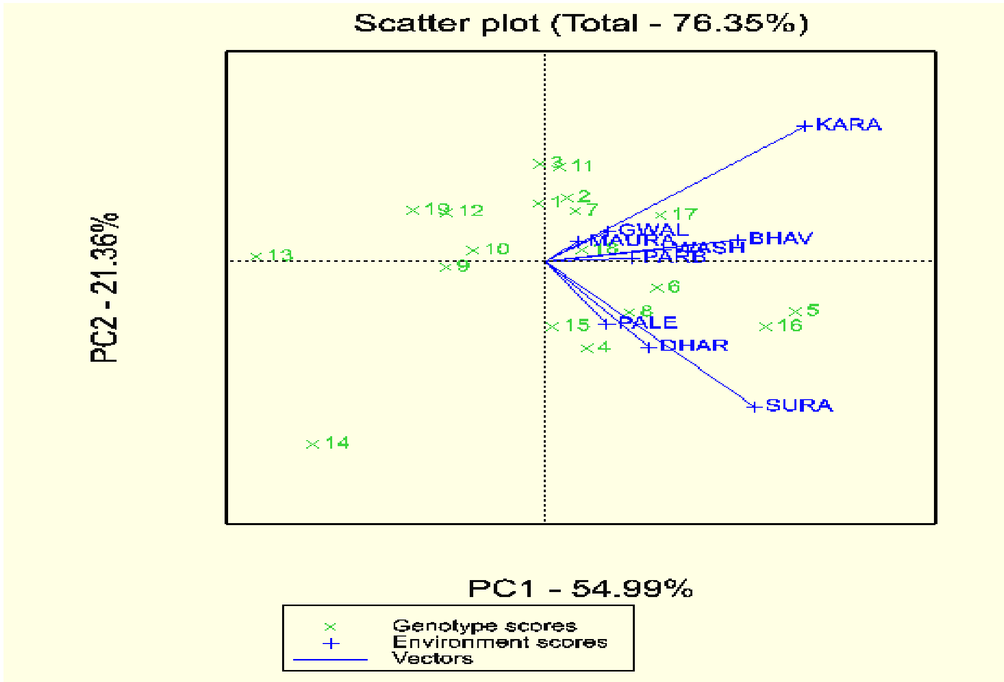

Figure 3: Environmental vector plot (Adopted from Rathore *et al*, 2012).

A representative environment is an environment having smaller angle with Average Environment Axis (AEA) (Figure 4). Good environment is both representative and discriminating. Discriminating but not representative environments are useful for selecting specifically adapted genotypes.

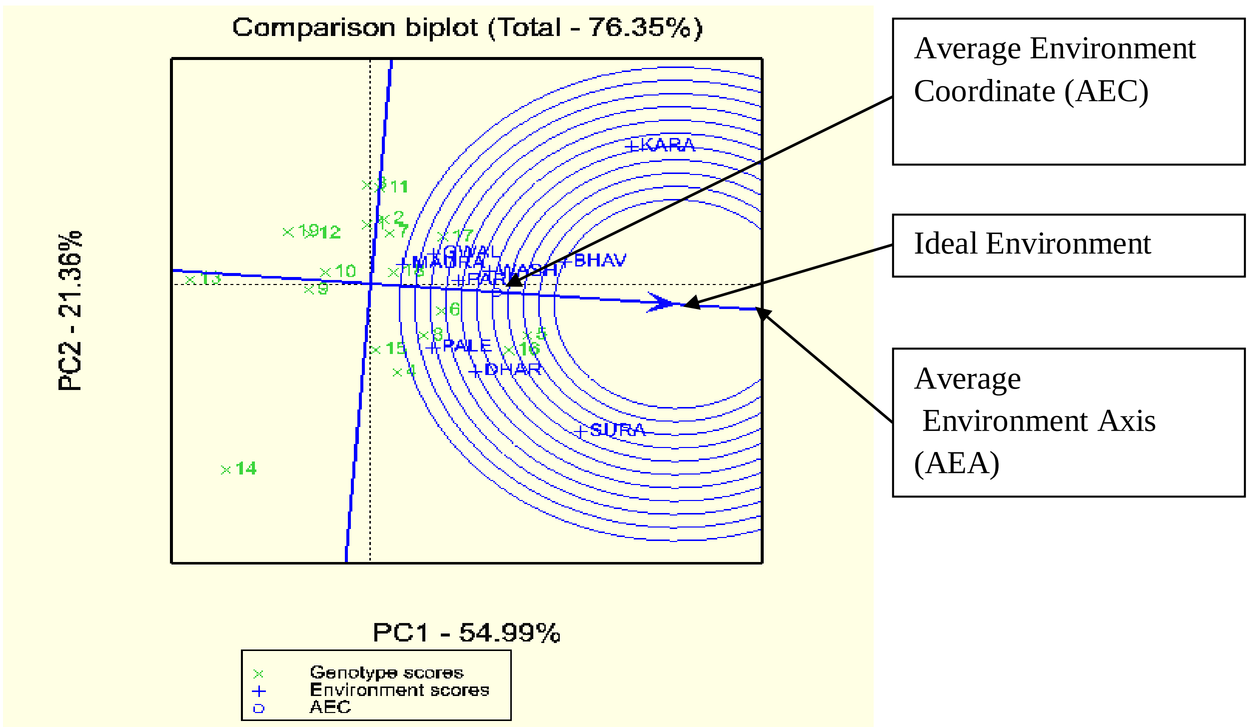

Figure 4: Environmental comparison plot (Adopted from Rathore *et al*, 2012).

Lines perpendicular to Average Environmental Axis measure the stability of genotypes in either direction (Figure 7). Genotype with the shortest perpendicular line projected from the average environment axis and close to Average Environmental Coordinate is considered the most stable genotype.

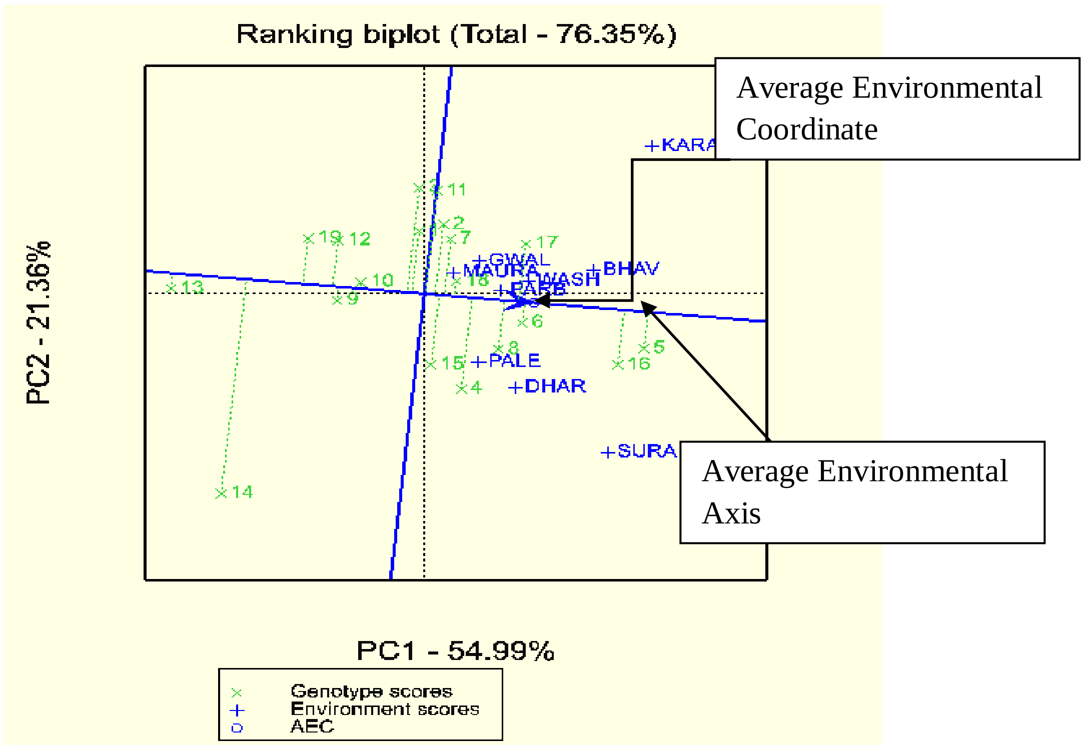

Figure 5: Ranking based on mean performance and stability (Adopted from Rathore *et al*, 2012).

Genotypes located closest to the center of the concentric circles are considered as the most ideal (Figure 8). Good genotypes are close to ideal genotype and can be identified based on concentric circles.

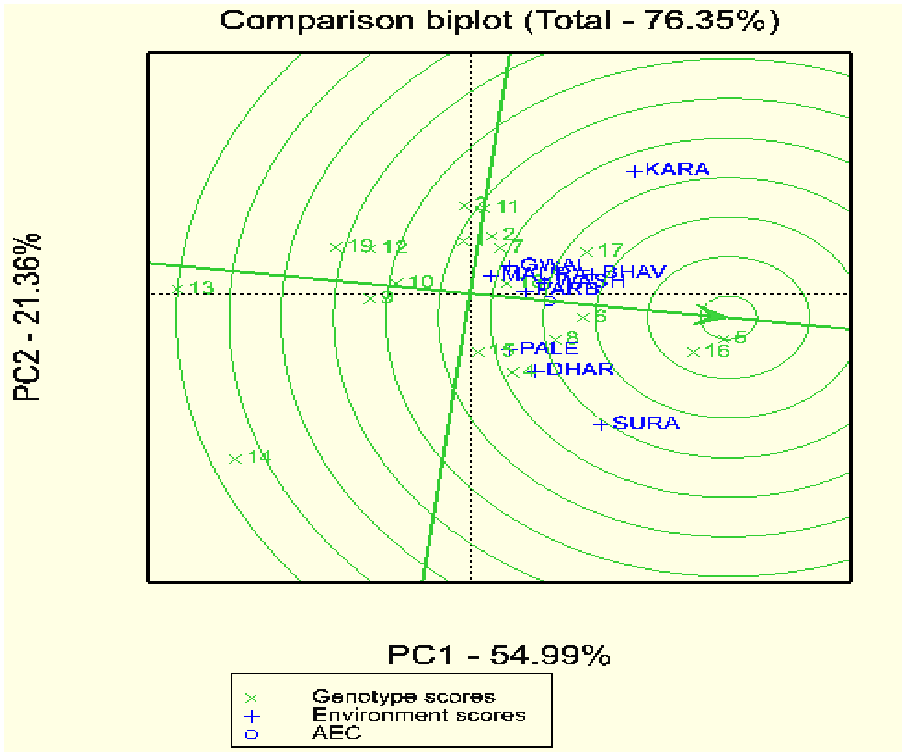

Figure 6: Comparison for genotypes (Adopted from Rathore *et al*, 2012).

CHAPTER 3

3. MATERIALS AND METHODOLOGY

3.1. Materials

Multi-locational and multi-year data on 13 common medium duration pigeonpea varieties were obtained from experiments conducted in research stations across five countries in ESA (Appendix 1).

3.2. Methodology

3.2.1. Location of Study and Variables of Study

Multi-location data from Kenya (Kiboko, Kampi ya Mawe, Kabete), Malawi (Bembeke, Chitala, Chitedze), Tanzania (Ilonga, Naliendale, Katrin and Selian) Uganda (Serere) and Mozambique (Maputo) were organised. Predictor variables comprised of environment (Table 2) and variety (Table 3). Response variables comprised of days to flowering, days to maturity, grain yield and weight of 100 seeds. Data on mean maximum and mean minimum temperature of the different growing areas during crop growing season were also used in assessing relationships between crop performance and temperature at growth. The characteristics of the trial sites are presented (Appendix 1).

Table 2: Pigeonpea growth environments description

Environmental Code	Year	Location	Environmental Code	Year	Location
E1	1997	Bembeke	E17	2001	Katrin
E2	1997	Chitala	E18	2001	Kiboko
E3	1997	Chitedze	E19	2001	Kampi ya Mawe
E4	1997	Ilonga	E20	2001	Selian
E5	1997	KampiyaMawe	E21	2002	Kiboko
E6	1997	Naliendele	E22	2002	KampiyaMawe
E7	1997	Serere			
E8	1998	Kabete			
E9	1998	Kiboko			
E10	1998	KampiyaMawe			
E11	1999	Kiboko			
E12	2000	Kabete			
E13	2000	Kiboko			
E14	2000	KampiyaMawe			
E15	2000	Maputo			
E16	2001	Ilonga			

3.2.2. Organization of Data

Pigeonpea medium duration data were consolidated based on its availability from trials done in 12 locations by ICRISAT during the short rain seasons of 1997/98 to 2009/10. Common varieties in these seasons were selected using pivot tables in MS Excel. Data were obtained from trials conducted in research stations in five countries: Kenya, Malawi, Mozambique, Tanzania and Uganda. A total of 22 environments were obtained (Table 2). From the 22 environments seven medium duration varieties were selected for analysis. Varieties (Table 3) were selected based on their presence across the environments.

Table 3: Pigeonpea Genotypes

Variety code	Variety
G1	ICEAP 00068
G2	ICEAP 00540
G3	ICEAP 00550
G4	ICEAP 00554
G5	ICEAP 00557
G6	ICP 12737
G7	ICP 6927

3.2.3. Data Analysis

3.2.3.1. Unbalanced ANOVA

Data were analyzed using ANOVA to test for differences among genotypes for days to flowering, days to maturity, plant height, seed mass and yield. ANOVA was done for the individual environments as well as for combined environments. This was used to determine whether there was significant genotype by environmental interaction.

3.2.3.2. Stability of genotypes

The stability of genotypes was evaluated based on Eberhart and Russell, AMMI and GGE biplot models. Genotypes and environments were ranked using different stability parameters and plots.

i. Eberhart and Russell Model

Step 1: Computation of Environmental Index (I_j) was done as follows:

$$I_j = \frac{\text{Total yield of variety at jth location}}{\textit{Number of varieties}} - \frac{\text{Grand total for yield}}{\textit{Total number of observations}}$$

Step 2: Computation of Regression Coefficient (b_i)

$$b_i = \frac{\sum_j Y_{ij} I_j}{\sum_j I_j^2}$$

Where,

$\sum_j Y_{ij} I_j$ is the sum of products of the environmental index with the corresponding mean of that variety at each location and $\sum_j I_j^2$ is the sum of squares.

Step 3: Computation of Mean Square deviation ($S_{d_i}^2$)

$$S_{d_i}^2 = \frac{\sum_j \delta_{ij}^2}{s-2} - S_e^2/r$$

Where $\sum_j \delta_{ij}^2$ is pooled deviation, *s* is the number of environments and S_e^2/r is the mean sum of squares from ANOVA.

ii. Analysis using AMMI model

Stability analysis was then done placing the seven varieties as genotypes in the Additive Main Effects and Multiplicative Interaction effects of principal components analysis (PCA) model. Genotype means and scores were generated and used for ranking genotype stability.

iii. Stability evaluation using GGE biplots

Comparison biplots, scatter biplot, and ranking biplots were generated for genotype ranking.

3.2.3.3. Correlation Analysis

Relationship between mean maximum and mean minimum temperature with days to 50% flowering, days to 75% maturity, plant height, 100 seeds mass and crop yield were evaluated by correlation analyses. The model was:

$$Y = \mu + T_{1_i} + T_{2_i} + \varepsilon$$

Where,

Y is the response variable (DAF, DAM, seed mass, plant height and yield), μ is the overall mean performance of the response variable, T_{1_i} is the mean maximum temperature at the i^{th} location during crop growth, T_{2_i} is the mean minimum temperature at the i^{th} location and ε is the error term.

CHAPTER 4

4. RESULTS AND DISCUSSION

4.1. Comparison of stability of different genotypes using different stability parameters

4.1.1. Variation among genotypes and environments

There was significant variation in days to flowering among genotypes, environments and the interaction between the genotypes and environments were significant ($p<0.001$) (Table 4).

Table 4: ANOVA for days to flowering

Source of variation	d.f.	m.s.	v.r.	F pr.
Rep stratum	2	23.83	1.17	
Genotype	6	1000.59	49.32	<0.001
Environment	19	12691.75	625.57	<0.001
Genotype*Environment	114	292.53	14.42	<0.001
Residual	277	20.29		
Total	418			

The variation in days to 75% maturity genotypes, environments and the interaction between genotype and environment had a significant difference ($p<0.001$) (Table 5).

Table 5: ANOVA for days to Maturity

Source of variation	d.f.	m.s.	v.r.	F pr.
Rep stratum	2	65.91	1.66	
Genotype	6	1922.97	48.39	<0.001
Environment	19	20402.24	513.38	<0.001
Genotype*Environment	114	437.41	11.01	<0.001
Residual	277	39.74		
Total	418			

There was significant variation in plant height among genotypes, environments and their interaction (p<0.001) (Table6).

Table 6: ANOVA for Plant height

Source of variation	d.f.	m.s.	v.r.	F pr.
Rep stratum	2	314.7	1	
Genotype	6	1408.4	4.49	<0.001
Environment	21	74343.1	237.23	<0.001
Genotype*Environment	126	736.6	2.35	<0.001
Residual	304	313.4		
Total	459			

There was significant difference in seed mass (p<0.001) among genotypes and environments (Table 7). However, there was no significant difference for genotypes and environments interaction (p=0.534).

Table 7: ANOVA for seed Mass

Source of variation	d.f.	m.s.	v.r.	F pr.
Rep stratum	2	21.571	9.57	
Genotype	6	16.114	7.15	<.001
Environment	19	85.456	37.91	<.001
Genotype*Environment	114	2.216	0.98	0.534
Residual	276	2.254		
Total	417			

Yield was significantly different among genotypes (p=0.043), environments (p<0.001) and interaction between genotype and environment (p<0.001) (Table 8).

Table 8: ANOVA for yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep	2	0.2576	0.1288	0.45	
Genotype	6	3.7696	0.6283	2.2	0.043
Environment	21	238.3121	11.3482	39.75	<.001
Genotype*Environment	126	75.1911	0.5968	2.09	<.001
Residual	303	86.5123	0.2855		
Total	458	400.3397			

This analysis reveals that there was a significant genotype by environmental interaction for days to flowering, days to maturity, plant height and yield. Therefore for these traits the genotypes will rank differently in each of the 22 environments in this study. There was no significant genotype by environmental interaction for seed mass. Genotype ICEAP 00557 had the highest grain yield while 1CP 6927 had the least (Table 9). However genotypes ICEAP 00554, ICEAP 00068, and ICEAP 00550 were not significantly different from others for yield. These results are similar to those generated in others studies done on genotype by environmental interaction in pigeonpea (Sreelakshmi *et al*, 2010).

Table 9: Fisher's protected LSD mean separation for yield

	Mean yield in tonnes/ha	
ICEAP 00557	1.809	a
ICEAP 00540	1.788	a
ICEAP 00554	1.695	ab
ICEAP 00068	1.691	ab
ICEAP 00550	1.662	ab
ICP 12737	1.573	b
1CP 6927	1.551	b

4.1.2. Analysis by Eberhart and Russell Model

From the regression coefficient variables generated genotypes ICP 12737, ICEAP 00550 and ICEAP 00557are the leading three using the regression coefficient as the criterion (Table 10).Genotypes ICP 6927, ICEAP 00550and ICEAP 00557 are the best three with a mean square deviation(S^2_{di}) closest to zero. Using both criteria the three most stable varieties were ICEAP 00550, ICP 6927 and ICEAP 00557. Genotypes ICEAP 00540, ICP 6927, and ICP 12737 had a regression coefficient higher than 1 and therefore would perform well in favourable environments (Ferreira *et al*., 2006).

Table 10: Regression coefficients and Deviations from regression of genotypes

Varieties	$\sigma^2 V_i$	b_i	$\sum_j Y_{ij} Ij$	$b_i \sum_j Y_{ij} I_j$	$\sum_j \delta^2_{ij}$	S^2d	S^2dRank	b_i deviation from 1	b_i rank	Overall Rank
ICEAP 00068	11.296	0.876	9.764	8.554	2.742	1.094	4	0.124	6	5
ICP 12737	17.099	1.012	11.281	11.419	5.680	2.266	6	0.012	1	4
ICP 6927	13.220	1.033	11.517	11.901	1.319	0.526	1	0.033	4	2
ICEAP 00540	24.156	1.245	13.873	17.269	6.887	2.748	7	0.245	7	7
ICEAP 00550	12.380	0.969	10.797	10.460	1.921	0.766	2	0.031	2	1
ICEAP 00554	12.857	0.896	9.982	8.941	3.916	1.563	5	0.104	5	5
ICEAP 00557	12.485	0.968	10.788	10.442	2.043	0.815	3	0.032	3	3

4.1.3. AMMI Analysis

ICP 6927 had the highest genotype mean and therefore it is the most stable genotype according to AMMI model. Genotype G6 (PI= 470,377.9) is the least stable genotype (Table 11). ICEAP 00550 had the lowest genotype mean and therefore the least stable according to this criterion.

Table 11: AMMI Rankings

Variety	NG	Gm	Rank	IPCAg[1]	IPCAg[2]
ICEAP 00068	1	1.69	4	0.52481	0.11347
ICEAP 00540	2	1.568	6	1.02652	0.0042
ICEAP 00550	3	1.551	7	0.11041	0.58019
ICEAP 00554	4	1.788	2	-1.39793	0.135
ICEAP 00557	5	1.662	5	-0.45746	0.12939
ICP 12737	6	1.695	3	-0.03093	-1.31537
ICP 6927	7	1.809	1	0.22458	0.35313

4.1.4. GGE Biplots

The following were the results obtained in the Genotype main effect plus genotype by environment interaction (GGE) biplots:

Genotype ICEAP 00550, and ICEAP 00557 performs above average in environments E2, E16, E3, E11, E22 and E6 (Figure 10). The same applies to genotype ICEAP 00554 in environment E19. This is shown by the acute angle the genotypes form with the environment. Genotype ICEAP 00554 have below average performance in environment E14. This is depicted by the obtuse angle this genotype form with the environment. The far distance between environment E2 and E14 shows the high dissimilarity of these two environments in discriminating genotypes. As such environments E1, E4, E7, E8, E11 and E18 have a high similarity in discriminating against genotypes and hence can be used as mega environment.

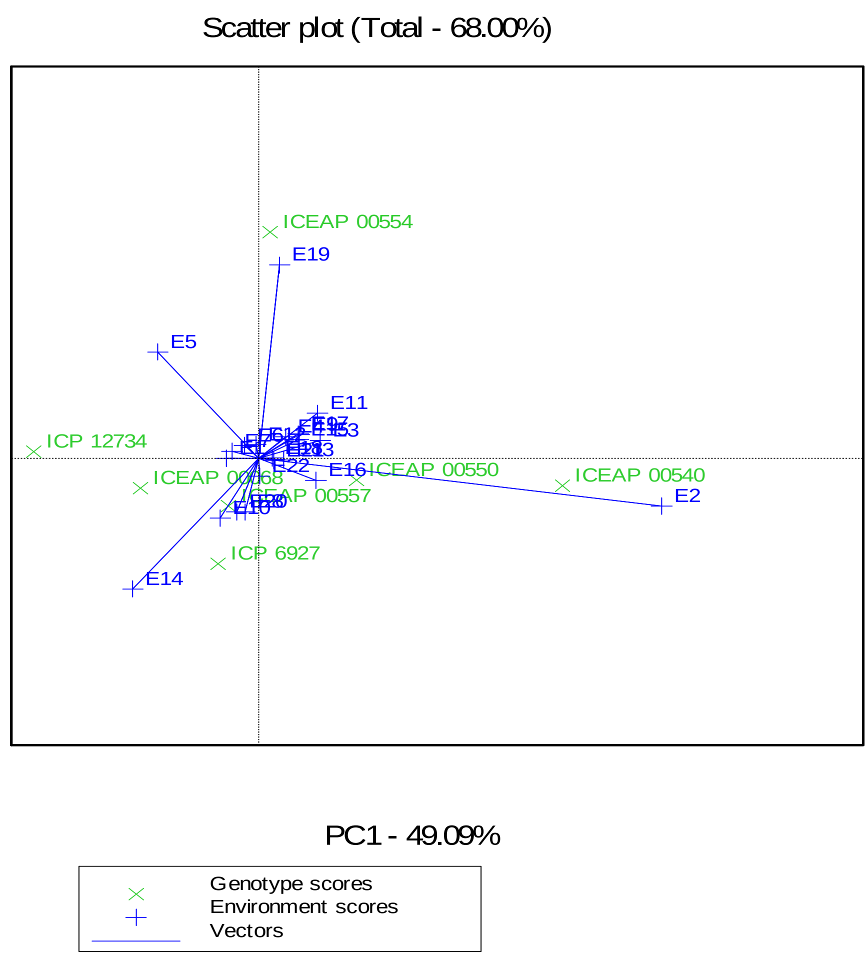

Figure 7: Environment vector plot

Genotypes ICEAP 00068, ICP 12734, and ICEAP 00550 can be considered as the most stable genotypes owing to their closeness to the average environmental coordinate and average environmental axis (Figure11). Genotype ICEAP 00554 can be considered as the least stable genotype.

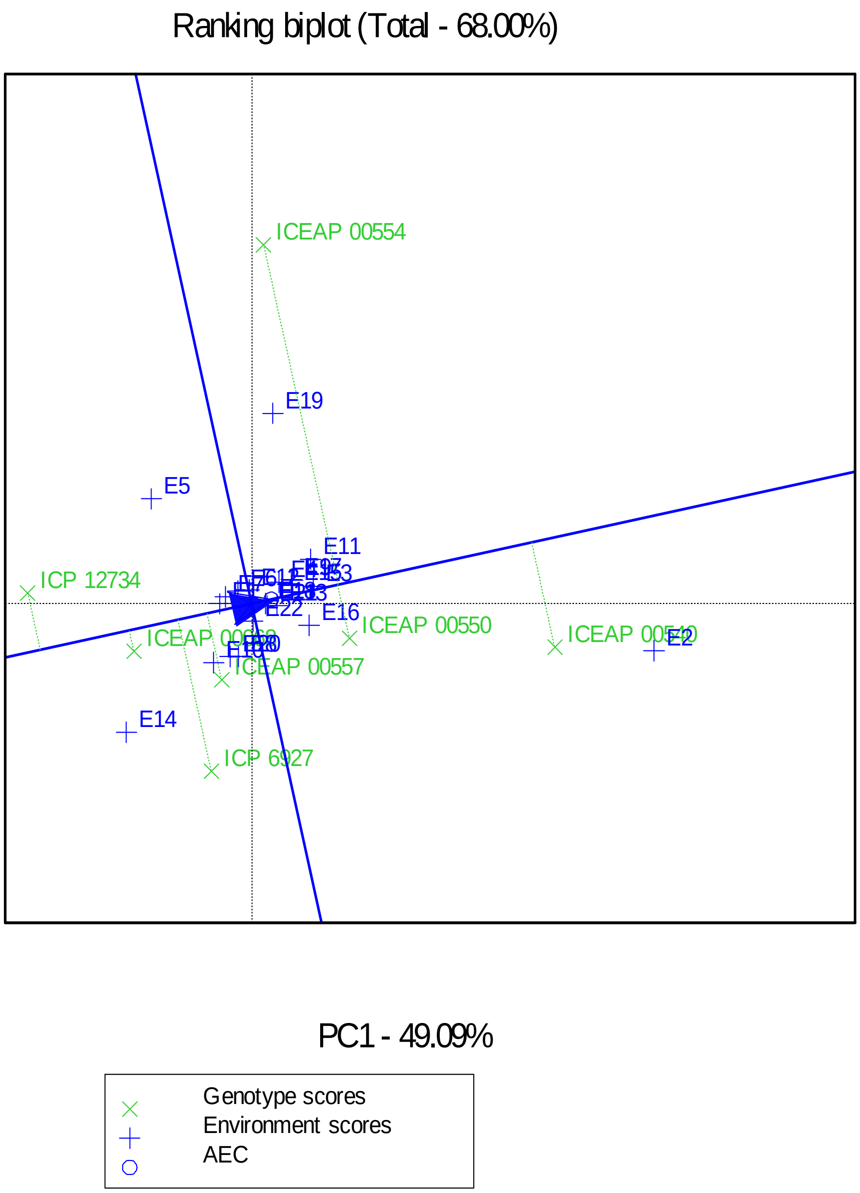

Figure 8: Ranking based on mean performance and stability

The location of ICEAP 00540, ICEAP 00550 and ICEAP 00557 close to the center of concentric circles of the biplot illustrates that they are well performing genotypes (Figure 12). Genotypes ICP 12734, ICEAP 00068, and ICEAP 00554 can be considered poorly performing genotypes as they are located far away from the center of the concentric circles.

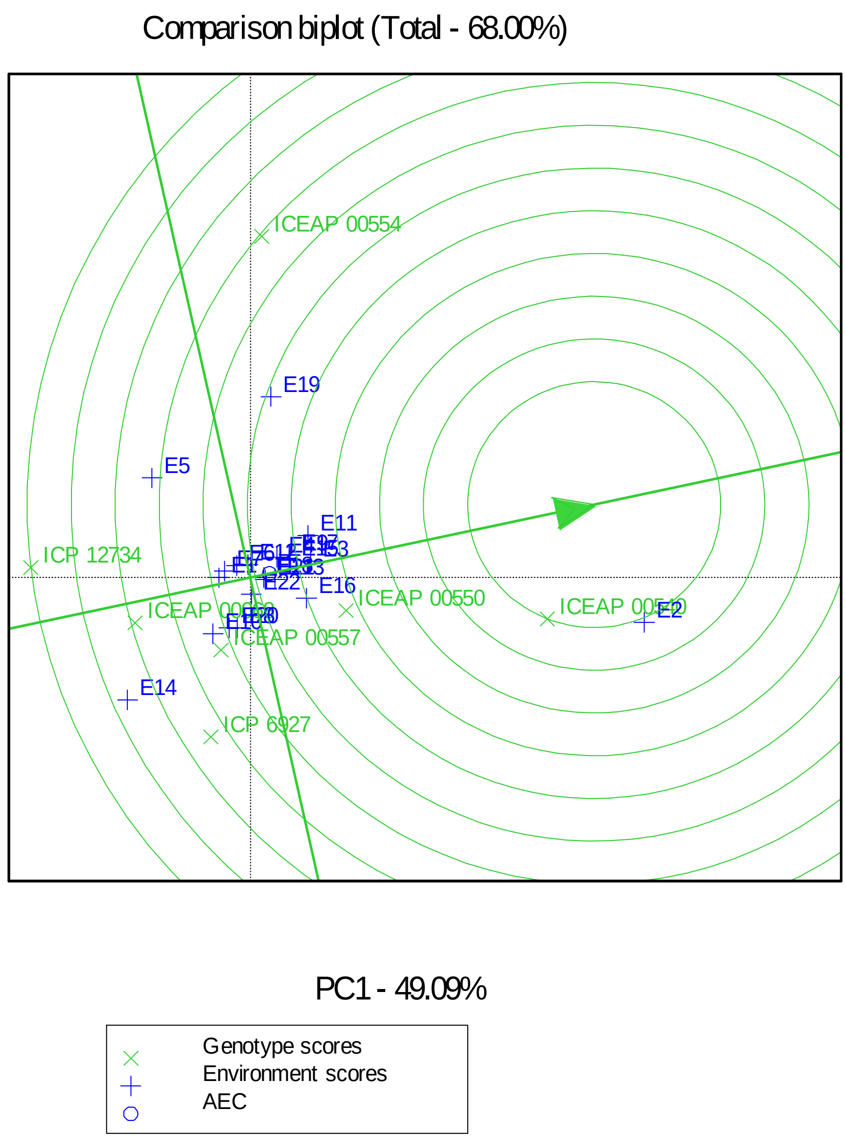

Figure 9: Comparison for genotypes

4.2. Relationship between temperature and performance

The relationship between days to flowering and temperature was significant ($p<0.001$) (Table 13). Mean maximum temperature showed a significant effect on flowering ($p<0.001$) while mean minimum temperature did not show a significant effect on days to flowering ($p=0.098$).Both mean maximum temperature ($p=0.002$) and mean minimum temperature ($p=0.03$) had a significant effect on days to maturity. Plant height was significantly affected by temperature ($p<0.001$) with both mean maximum and mean minimum temperature having a significant effect on plant height ($p<0.001$). There was a significance relationship between temperature and seed mass ($p<0.001$). Both mean maximum temperature and mean minimum temperature had a significant effect on seed mass (both $p<0.001$).Yield was also influenced significantly by temperature ($p<0.001$). Mean maximum temperature had a significant effect on yield ($p=0.003$) while mean minimum temperature did not have a significant effect ($p=0.372$).

Table 12: Relationship between temperature and performance of pigeonpea

Variable	Parameter	Estimated mean	s.e.	p value	Variable	Parameter	estimate	s.e.	p value
DAF	constant	146.43	5.92	<0.001	Seed mass	constant	21.404	0.506	<0.001
	Max temp	-2.396	0.358	<0.001		Max temp	0.1003	0.030	<0.001
	Min temp	1.398	0.844	0.098		Min temp	0.5698	0.067	<0.001
DAM	constant	230.87	7.43	<0.001	Yield	constant	2115	211	<0.001
	Max temp	-1.402	0.449	0.002		Max temp	-36.8	12.5	0.003
	Min temp	-2.25	1.06	0.034		Min temp	25.1	28.1	0.372
Height	constant	115.2	13.1	<0.001					
	Max temp	-9.311	0.778	<0.001					
	Min temp	18.13	1.74	<0.001					

s.e refers to the standard error of the estimate at 5% significance level.

These results agree with other studies which showed that temperature during growth has an effect on growth in pigeonpea (Silim*et al*, 2004; Silim *et al*, 2006; McPherson *et al*, 1985).

The following are the models predicting relationship between temperature and performance:

$$F = 146.43 - 2.396T_1$$

$$G = 230.87 - 1.402T_1 - 2.25T_2$$

$$H = 115.2 - 9.311T_1 + 18.13T_2$$

$$M = 21.404 + 0.1003T_1 - 0.5698T_2$$

$$Y = 2115 - 36.8T_1$$

Where,

T_1 is the mean maximum temperature during growth; T_2 is mean minimum temperature during growth in degrees celsius (°C); F is days to flowering; G is days to maturity; H is plant height in cm; M is seed mass in grams; and Y is yield in kgha^{-1}.

The mean minimum temperature did not affect time to flowering and yield significantly and therefore was not included in their model. Studies on varieties developed by ICRISAT in India show similar results (ICRISAT, 2011) as those done on the influence of temperature and latitude on behavior of different duration groups.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The results show that there was genotype by environmental interaction for the medium duration pigeonpea varieties in the trial sites selected for this research. This was revealed by the significant variation in days to flowering, days to maturity, plant height and yield among genotypes, environment and interaction between genotypes and environment. Different ranking criteria gave different ranking of genotype performance (Table 13).

Table 13: Stability ranking by different models

	Varieties		
Rank	Eberhart and Russell model	GGE biplot	AMMI
1	ICEAP 00550	ICEAP 00068	ICP 6927
2	ICP 6927	ICP 12734	ICEAP 00554
3	ICEAP 00557	ICEAP 00550	ICP 12734
4	ICP 12734	ICEAP 00557	ICEAP 00068
5	ICEAP 00068, ICEAP 00554	ICEAP 00540	ICEAP 00557
6		ICP 6927	ICEAP 00540
7	ICEAP 00540	ICEAP 00554	ICEAP 00550

ICEAP 00550, ICP 12734 and ICP 6927 could be could be considered as the most stable genotypes as each was ranked top three by two models out of the three.

Mean maximum temperature during growth had a significant effect of on duration to flowering, duration to maturity, grain mass, plant height and crop yield. Mean minimum temperature had a significant effect on duration to maturity, plant height and seed mass.

I recommend that the most stable genotypes identified above to be considered for on-farm evaluation and subsequent National Performance Trial evaluations. Understanding on temperature variations in a specific location during crop growth period could be used to fairly predict flowering and maturity periods.

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APPENDICES

Appendix 1: Characteristic of Evaluation Sites

Location	Country	Altitude MASL	Latitude	Crop stage Mean temperature (◦C)		Rainfall during crop period(mm)
				max	min	
Bembeke	Malawi	1,539	14º20’S	13.1	10.3	251
Chitala	Malawi	606	13 º 40’S	18.5	13.9	979
Chitedze	Malawi	1,149	13 º 59’	13.1	10.1	698
Ilonga	Tanzania	503	6 º 42’S	24.1	16.1	773
Kabete	Kenya	1,825	1 º 14’S	26.0	14.1	884
KampiyaMawe	Kenya	1,250	1 º 57’S	29.1	17.9	767
Katrin	Tanzania	506	6 º 42’S	16.0	11.9	585
Kiboko	Kenya	975	2 º 15’S	31.6	17.7	680
Maputo	Mozambique	47	25 º 57’S	29.1	20.4	669
Naliendele	Tanzania	120	10 º 3’S	22.0	15.8	923
Serere	Uganda	1,085	4 º 12'N	18.9	14.1	829
Selian	Tanzania	1,268	3 º 2'S	16.5	11.8	788

Appendix 2: ANOVA for AMMI model

Source	df	SS	MS	F	F probability
Total	857	6.81E+08	794651	*	*
Treatments	285	5.54E+08	1945519	8.69	0
Genotypes	12	5857104	488092	2.18	0.01188
Environments	21	4.54E+08	21604595	32.39	0
Block	44	29351416	667078	2.98	0
Interactions	206	94919288	460773	2.06	0
IPCA	32	39525255	1235164	5.52	0
IPCA	30	18417953	613932	2.74	0
Residuals	144	36976080	256778	1.15	0.14939
Error	434	97191940	223945	*	*