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An evaluation of stress tolerant open pollinated maize varieties in selected environments of the Eastern Cape Province, South Africa

By

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DECLARATION

I, Vimbayi Chimonyo, declare that the dissertation hereby submitted for the degree of Master of Science in Agriculture (Crop Science) at the University of Fort Hare is entirely my work and that all reference materials contained in this thesis have been duly acknowledged. This thesis has not been previously submitted to another university for any other degree.

Signature:…………………………………………………………

Date:……………………………………………………………

Place: University of Fort Hare, Alice Campus

DEDICATION

This work is dedicated to my family.

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PREFACE

This thesis consists of six chapters. Chapter 1 gives background information and justification for conducting the study, and states objectives of the study. A review of relevant literature and background information on methods used for various interventions are presented in Chapter 2. Information on experiments that were conducted is present in Chapters 3 to 5. These three chapters are presented in paper format, complete with the introduction, specific objectives, hypothesis, methods and materials, results and a brief discussion of the results. Chapter 6 discusses the main findings from all the experiments, as well as presenting the general conclusions and recommendations for future studies. All the references cited in the study can be found in the reference list, presented after Chapter 6. Appendices containing the outputs of statistical analyses of data presented in the thesis are listed at the end of the dissertation.

ABSTRACT

The use of farmer acceptable, stress tolerant open pollinated maize varieties (OPVs) could be a strategy to help increase maize productivity for resource-poor farmers in the Eastern Cape (EC) Province. The current study investigated the following: a) participatory selection of newly introduced stress tolerant maize OPVs; b) characteristics of maize producing farmers, their production constraints and criteria for variety selections; c) multi-environment yield trials in which genotype and environment interactions (GEI) were investigated, and d) morphological diversity of newly introduced maize varieties. Nine newly introduced maize OPVs were evaluated in this study. These varieties were: ZM 305, ZM 423 ZM 501, ZM 525, Obatanpa, ZM 621, ZM 627, which were from the International Maize and Wheat Improvement Centre (CIMMYT), BR 993, and Comp 4 which from where the International Institute of Tropical Agriculture (IITA). Check varieties, Pan 6479 (a hybrid) and three locally grown OPVs (Okavango, Afric 1 and Nelson's Choice) were also included.

Participatory variety selection (PVS) was conducted during the 2009/10 summer season to evaluate farmer acceptance of these newly introduced OPVs. The most preferred varieties farmers were Okavango, ZM 305 and ZM 501, and these varieties were not significantly different from the highest yielding variety within each site. Therefore, varieties like ZM 305 and ZM 501 could easily be adopted by farmers, and their use could result in yield improvements. To gather information on farmer characteristics, and perceptions on maize production constraints and maize selection criteria, focus group discussions and household surveys were conducted during the 2009/2010 and 2010/2011 seasons, respectively. Results indicated that, elderly farmers dominated the farming communities. Maize production was generally low, with 98% of the farmers obtaining less than 1.6 t/ha. The most important constraints affecting maize production were extreme weather events (floods and drought), pests and diseases, and poor access to credit. The most preferred traits that made up farmer selection criteria were ear traits such as taste, long cobs, and big kernels. Other traits, such as, prolificacy, early maturity, retainability of seed and dark leaves, were village specific.

Yield trials, assessing genotype and environment interactions, were conducted in eight sites during the 2009/10 and 2010/11 seasons. The genotypes exhibited non-significant crossover and non-crossover GEI over the environments. Okavango, the most stable variety, was generally low yielding (4.28 t/ha) than other stable varieties such as ZM 305, ZM 501, ZM 621 and ZM 423. The later varieties had significantly ($p<0.05$) higher yields of between 4.46 t/ha and 4.97 t/ha. The highest yielding varieties, Pan 6479 (5.29 t/ha) and ZM 525 (4.87 t/ha), showed specific adaptations to high potential environments, while BR 993 (4.07 t/ha) and Afric 1 (4.24 t/ha) were low yielding, unstable and specifically adapted to low potential environments. New varieties, therefore, exhibited both specific and wide adaptation.

Qualitative and quantitative traits were evaluated to establish the morphological diversity of the 13 varieties. Ear height, plant height, days to 50% anthesis and grain yield contributed the most to variety diversity. Cluster Analysis discriminated varieties into four main clusters. The first cluster consisted of four CIMMYT varieties that were short in height and early maturing (ZM 305, ZM 423, ZM 501 and ZM 525), while hybrid Pan 6479 was placed into cluster two. Nelson's Choice and Okavango were grouped into the third cluster, while tall and late maturing varieties, ZM 621, ZM 627, Obatanpa, BR 993, Comp 4 and Afric 1, were placed in the fourth cluster. The segregation of the newly introduced varieties into two distinct groups shows that these varieties can be recommended into more than on cropping system and agro-ecology.

Differences in village agro-ecologies resulted in farmers selecting varieties differently. This diversity in agro-ecology also brought about variations on farmer perceptions in selection criteria and production constraints. Most of the new varieties were observed to be superior in yield performance when compared to local check OPVs, exhibiting either wide or specific adaptation. The study also demonstrated that, the study of morphological diversity can be used to suggest varieties to different environmental potentials and cropping systems. Multi-evaluation trials were able to give an insight on variety preferences and performance. These new varieties should, therefore, be introduced to selected farmers living in their respective environments on the basis of results obtained. However, varieties still need to be evaluated under farmer-managed conditions to determine whether they actually bring about yield improvement when compared with current varieties being used.

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LIST OF ACRYNONYMS

ANOVA	Analysis of variance
AMMI	Additive Main effects and Multiplicative Interaction
ARC	Agricultural Research Council
ASGISA	Accelerated and Shared Growth Initiatives – South Africa
ASI	Anthesis Silking Interval
ASV	AMMI Stability Value
CA	Cluster Analysis
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Centre
DEAET	Department of Economic Development and Environmental Affairs
DUS	Distinct, Uniform and Stable
EC	Eastern Cape
FGD	Focus Group Discussion
GEI	Genotype by Environment interaction
IBPGRI	International Board for Plant Genetic Resources Institute
IITA	International Institute of Tropical Agriculture
IPCA	Interaction Principal Component Analysis
KI	Key Informant
MFPP	Massive Food Production Program
OPV	Open Pollinated Varieties
PCA	Principal Component Analysis
SANSOR	South African National Seed Organization
TIA	Technology Innovation Agency
UPOV	Union for the Protection of New Varieties of Plants

1. GENERAL INTRODUCTION

Maize is South Africa's staple crop, and it is extensively grown in the Eastern Cape (EC) Province (PROVIDE, 2009). Coincidentally, the Province has one of the highest poverty and food insecurity incidences in South Africa, with more than 65% of the inhabitants living in rural areas (PROVIDE, 2009). According to Pauw (2006), a considerable number of rural dwellers survive on semi-subsistence agriculture, and are considered as resource-poor. Maize is the main summer crop grown by most, if not all, farmers (Sibanda, 2010). However, resource-poor farmers are currently unable to produce sufficient grain to meet their household consumption requirements (Bennett, 2002). Introduction of improved technologies, such as the use of hybrid maize varieties have failed to produce sustainable and increased crop yields among the resource-poor (Ngqangweni, 1999). There is a need, therefore, to increase the self-sufficiency of the resource-poor farmers so as to reduce dependency, and also to alleviate poverty. Like most developing countries, the biggest challenge to increasing maize yields has been numerous abiotic and biotic stresses, and the use of inappropriate maize varieties (Bembridge, 2000; Fanadzo *et al*., 2010).

The principal determinants for maize growth are bio-physical (abiotic) factors such as temperature and precipitation, in combination with soil and topographic features (altitude and gradient). The EC varies considerably for these determinants and has been described as having semi-arid to super-humid agro-ecologies (van Averbeke and Bennett, 2007). The amount of rainfall received in semi-arid areas (500 mm), such as the Amathole District Municipality, is not adequate for dry land maize production given that only 70%

of this falls in the summer season (van Averbeke *et al*., 2007). Furthermore, the actual amount received in summer is characterized by erratic patterns and dry spells, which are difficult to predict. In addition, this region has vast tracts of shallow soils which are unable to store water and restrict maize root growth and function. This further exacerbates the risk of drought and, in many cases, results in total crop failure (Monde, 2003). Low grain yields of less than one tonne per hectare are also being obtained in other areas of the province with deeper soils and higher rainfall.

Buhman *et al.* (2006) concluded that, although many emphasize on the amount and distribution of rainfall as factors largely affecting maize yield, poor soil conditions have an equal adverse impact on maize production. Areas in the O. R. Tambo District Municipality, for example, receive reasonably high amounts of rainfall. However, duplex and pseudo-duplex soils found in this region are generally very erodible (especially water erosion) and are poor in fertility (Fox and Rowntree, 2000). This, in turn, increases farmers' dependency on the use of soil amendments, such as organic and inorganic fertilizers. Other topographic and soil factors affecting maize production in this region are low soil pH, steep slopes as well as inherent and continual soil degradation.

In addition to poor soil and unreliable rainfall, farmers also have to cope with numerous other socio-economic constraints such as poor access to resources, rampant poverty and food insecurity (Buhmann *et al*., 2006). In view of these difficulties, resource-poor farmers in the EC are, left with the daunting task of selecting suitable varieties that responds well under marginal rainfall and soil fertility conditions (Buhmann *et al*., 2006).

However, suitable varieties for use by farmers in different agro-ecologies of the EC have not been identified.

According to Silwana (2000), less than 20.5% of farmers in selected villages in the EC used certified hybrid seed, while the majority (about 75.6%) used local landrace varieties. Contrary to this, Sibanda (2010) observed a larger proportion of farmers to be using hybrid seed as opposed to local landrace varieties. Others, however, retain hybrid seed for use in conjunction with open pollinated varieties (OPVs) and traditional varieties (Sibanda, 2010). The choice of seed type has always been linked with various benefits and yield penalties. In light of numerous constraints faced by resource-poor farmers in the EC, the use of hybrid seed might not be sustainable, and appropriate for maintenance of food security. To increase maize yields in environmentally challenged regions of Sub-Saharan Africa, various Consultative Groups on International Agricultural Research (CGIARs), such as the International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA), are focused on improving various aspects of maize production, seed development and distribution (Pixley and Banziger, 2001; Bänziger *et al*., 2005; Setimela *et al*., 2007). These organizations have revealed that replacing expensive maize hybrid seed and low yielding landrace varieties with inexpensive, improved OPVs may be more appropriate under marginal conditions since yields are stable under abiotic and biotic stress conditions (Muungani *et al*., 2007). Fortunately, these varieties are available for evaluation and use in agro-ecologies of the EC. Successful introduction of improved varieties into pre-existing agricultural systems requires involvement of farmers and other stakeholders during the evaluation phase.

The willingness of farmers to adopt varieties that they themselves have never grown is usually low (Ceccarelli and Grando, 1999). Many of the past strategies where researchers have tried to introduce new varieties evaluated in non-target sites have been faced with low adoption rates, for example, genetically modified maize introduced by Monsanto through the Massive Food Production Program in the EC Province (Siqwana-Ndulo, 2010). This has been attributed to the complex combinations of stresses experienced in resource-poor agricultural systems that necessitate farmers to alter their environment for the varieties to be successful (Joshi and Witcombe, 1996). Furthermore, the appropriateness of the technology, availability of required inputs and farmers' preferences and socio-economic conditions have mostly been overlooked during project implementation. This has brought about the use of the participatory variety selection (PVS), which involves the participation of farmers in the selection of suitable test varieties either on-station or on-farm.

Participatory variety selection has effectively been used to identify farmer-acceptable varieties, by providing them a range of varieties to choose from (Joshi and Witcombe, 1996). Moreover, participatory research has increased job efficiency of the scientists as it quickly addresses farmers' concerns using a more objective and realistic approach (Bellon, 2001). For a resource-poor farmer who has to deal with a variable environment, the choice of variety is important especially because it can be affected by genotype by environment interactions (GEI). However, apart from yield, other aspects need to be considered, such as adaptation of varieties to different agronomic management techniques and consumption purposes. Using PVS to identify farmers' preferences, in addition to establishing their agronomic performance, can facilitate fitting of new varieties in a multitude of target environments like those found in the EC province. The aim of the study, therefore, was to evaluate newly introduced maize OPVs in selected environments of the Amathole and O. R. Tambo districts in the EC. This was done through PVS, multi-locational adaptive trials and through on-station morphological characterisation of the varieties.

The specific objectives of the study were to:

1. Identify farmers' maize selection criteria and production constraints, and their implications towards maize variety selections.

2. Evaluate the agronomic performance of newly introduced maize OPVs in selected agro-ecological conditions of the EC.

3. Characterize newly introduced maize OPVs.

The null hypotheses that were tested were:

1. Farmers' maize selection criteria and production constraints in selected villages have no association with maize variety selections

2. Newly introduced maize OPVs are not superior in their performance when compared to some of the varieties that are used in the selected agro-ecological conditions of the EC province.

3. Morphological characteristics of newly introduced maize OPVs do not differ from those of varieties grown in the EC Province.

2. LITERATURE REVIEW

2.1 Introduction

This chapter is a review of literature published by various scholars pertaining to the study area. In the beginning of this review, a detailed elaboration of specific factors affecting maize production by local resource-poor farmers is given. This chapter also outlines the suitability of OPVs as a way of enhancing maize productivity in the smallholder sector. Furthermore, reviews of possible hindrances, such as farmer preferences, and GEI, towards correct recommendations of varieties is also given. Therefore, the importance of participatory research, and that of GEI when giving acceptable variety recommendations, in the context of the EC, is highlighted.

2.2 Factors affecting maize production in the Eastern Cape

2.2.1 Rainfall

The EC province is characterized as having a highly heterogeneous rainfall pattern (van Averbeke and Bennett, 2007). Rainfall received is primarily of cyclonic origin, from cold fronts from coastal high pressure systems, and orographic type in certain localities. The mean annual rainfall of the western half of the province is about 400 mm (van Averbeke and Marais, 1991; Bothma, 2004), thus exhibiting a semi-arid to arid climate. The eastern half, comprising the coast of the former Transkei (forming greater part of the O. R. Tambo District Municipality (ORTDM)) as well as the mountainous regions of the province, has a mean annual rainfall that exceeds 1000 mm (van Averbeke *et al*., 2000). These parts of the province exhibit a more temperate climate.

According to van Averbeke *et al*. (2006), the rainfall regime can be split into several facets. The northern and inland parts, such as the lowland areas of Amathole District, receive 75% of their annual rainfall of about 550 mm in summer, from October to April (Bothma, 2004). The coastal areas, from O. R. Tambo District Municipality (ORTDM) right through to the Port St. Johns coast, experiences a bi-modal rainfall pattern with early (October/November) and late (February/March) summer maxima (van Averbeke *et al*., 2006). The bimodal nature of the distribution of precipitation, which characterizes the low-lying inland zones, negatively affects the suitability of the climate for dryland cropping, because a significant portion of the precipitation falls outside crucial periods of plant life cycles (van Averbeke *et al*., 2006). In most parts of these coastal strips, winter rain adds approximately 40% to the total annual precipitation, but in the area around Port Elizabeth and Alexandria, the proportion of winter rain is even higher, and a real winter maximum occurs (van Averbeke *et al*., 2006). The rainy season in the ORTDM extends from October to mid-May, and 80% of the 1500 mm rainfall (1200 mm) is received between December and mid-May (Bothma, 2004). At a local level, rainfall is influenced by topography. Over a short distance, orographic effects may cause differences of several hundred millimeters in the annual amount of rain received, adding to the climatic diversity of the province (Bothma, 2004). Apart from the inherent factors affecting rainfall in the EC, there is also evidence that climate change has also had an effect on rainfall.

Changes in patterns of climate variables have been detected over South Africa since the 1960's (Warburton and Schulze, 2006; Davis, 2010). According to Gbertibouo and Ringler (2009), coastal provinces like the EC have recorded an increase in the frequency of extreme (floods and droughts) weather patterns over this period. To date, Warburton and Schulze (2006) have noted an overall increase in temperature (2^0C), which has been coupled with a reduction in rainfall inland of the province. This has reduced further, the provinces' agricultural potential as it has become more arid. Due to the large number of resource poor farmers found in the EC, the province has been rated by Gbertibouo and Ringler (2009) as the most vulnerable to the effects of climate change in terms of rural livelihoods. On the other hand, Schulze *et al*. (2005), as cited by Colvin *et al*. (2009), postulated that the future effects of climate change in the EC will not be as negative as the current recorded scenarios. It is believed that rainfall in and around the EC-Drankensburg region (inland areas of the EC) will increase (Schulze *et al*., 2005). Therefore, the increase in temperature and rainfall could mean an increase in the provinces' agricultural potential (more tropical) for maize production in this region. Schulze *et al*. (2005) also suggested that the coastal regions of the EC will experience an increase in temperature, but contrary to the inland areas, this will be coupled with a decrease in rainfall. However, similarly, the coastal regions will also become less temperate more tropical like the inland areas.

2.2.2 Topography

The topography of the Eastern Cape has been described as inconsistent by Laker (1982) while van Averbeke *et al*. (2006) described it as being generally steep. Over half (53.3 %)

of the province is covered in plateaus (areas of raised flat plains) with medium to large differences in local relief. The higher the altitude the cooler temperatures become (Shimono *et al*., 2008). Maize grown in high altitude tends to mature later than those grown in lower altitudes (Shimono *et al*., 2008). About a third of the Province (31.3 %) consists of mountain ranges with large differences in local relief and agricultural potentials; while a small part consists of relatively level plains (11.0 %) and river valleys (4.6 %). The valleys are usually deeply incised and the occurrence of level land of alluvial origin is generally limited and localized (Acocks, 1988).

The topographic position and degree of slope has a great influence on soil water content and soil fertility, two important factors affecting maize productivity (Laker, 2000). According to Andales *et al*. (2007) maize grain yield differences among landscape position on a hill slope can be attributed to differences in soil prolife characteristics and plant water availability. Van Averbeke and Marais (1991) reported that maize crops grown on steep terrains with a slope greater than 6% were more susceptible to drought regardless of the soil depth. Andales *et al*. (2007) observed a 52% yield difference between maize planted on middle slope (3 – 5% slope) and toe slope (base of the slope) (0 – 1% slope). An increase in slope gradient causes more rapid runoff and less infiltration, resulting in less water being stored by the soil regardless of depth (Craul, 1992). However, Laker (2004) reported that maize can be grown on a slope of 3.2% for clayey Lindley series (Valsrivier forms), 3.5% for shallow and 6.8% for deep (<50cm) Williamson series (Glenrosa form) soils, 7.8% for Jozini series (Oakleaf form) soils, and 11.3% for Shortlands soils, provided that there are contours. However, the absence of contours increases the risk of surface runoff, which increases the likelihood of erosion (Hoffman and Ashwell, 2005).

According to Le Roux (2007), 56% of the EC is eroded, while Kakembo *et al*. (2007) observed gully erosion (function of both rainfall and topography) as the most predominant form of erosion, especially on lower and middle position slopes (D'Huyvetter, 1985). Losing topsoil to erosion contributes to a loss of nitrogen, phosphorus, and potassium and a decline in potential crop yield and soil productivity (Craul, 1992). However, Mandiringana *et al*. (2005) observed better soil nutrient status on lower slope positions than on upper and middle positions.

2.2.3 Soil characteristics

Rainfall and temperature are the dominant climatic factors affecting soil formation and stability in the EC (D'Huyvetter, 1985; Laker, 2000). The unreliable and, in most cases, low rainfall in most areas of the province has resulted in poor soils, which are highly unstable and prone to erosion (Maswana, 2006). On the other hand, in areas of high rainfall and temperature, Laker (2000) observed deeper and more stable soils. The EC Province is underlined by rocks of the Karoo super group. The Sedimentary formation includes Dwyka, Ecca, Beaufort and Stormberg group. The majority of the province (approximately 85%) consists of Ecca and Beaufort series with intrusions of dolerite scattered within these groups (Catuneanu *et al*., 2005). According to van Breda (1991) and Maswana (2007), there is more of the Beaufort group than the Ecca. Sandstones, mudstones and shales constitute the main parent materials (for example Mt. Fletcher) in the Beaufort group. Soils from this series are normally poorly developed, eroded, shallow and duplex (rocky), and are mostly unsuitable for crop production. In valleys, however, deeper soils do occur and these normally belong to the Hutton, Oakleaf and Clovelly forms (South African soil binomial classification). These soil forms occur in the Keiskammahoek, Stutterheim, Tyume, Frankfurt, and Debe areas.

In areas of higher rainfall (<700 mm), such as Lusikisiki, Bizana, Butterworth and Stutterheim, Laker (2000) observed deep and stable soils, of the Ecca group. This series comprises of formations consisting of thick beds of whitish to yellowish, mostly coarse-grained sandstones and massive grits, often rich in feldspar (Catuneanu *et al*., 2005) and blue shales that were deposited under lacustrine conditions.

Dolerite, on the other hand, yields reddish brown clayey soils with well defined crumb-like structures. According to D'Huyvetter (1985), and van Averbeke and Bennet (2001), dolerite sills and dykes are resistant to erosion, primarily because of the cementing effect of iron oxide (Laker, 2004), and are chemically fertile. An example where these soils can be found is the Mdantsane area near East London. Furthermore, Maswana (2007) observed that dolerite soils are usually deeper and more porous, and therefore, have higher soil water content within the profile.

2.2.4 Soil depth

According to Laker (1982), Bembridge (1984), van Averbeke and Marias (1991) and van Averbeke (2006), the majority of soils in the Eastern Cape are shallow. Deep soils do not always develop in some places where the climate is too dry, while steep topography prevents the accumulation of a deep soil mantle (van Averbeke, 2006). Soil depth is an important property, especially in dry areas. Soil acts as a storage reservoir for water. The roots of plants growing in the soil tap this reservoir. The effective rooting depth of the soil, which is the depth to which plant roots can extend into the soil, determines the size of the reservoir. It was found that crops grown on deep soils yielded, on average, four times more than those grown on shallow soils (van Averbeke and Marias, 1991). Similarly, in a part of the central Eastern Cape with a mean annual rainfall of about 550 mm, the yield of maize was severely reduced when the effective rooting depth of the soil was less than 1 m (van Averbeke and Marais, 1991). At the level of the Province as a whole, the negative influence of shallow effective rooting depth and low water storage capacity within the soil profile is reduced as the climate becomes more humid. In the coastal regions of the former Transkei, for example, where the mean annual rainfall can exceed 1000 mm, maize can potentially produce acceptable yields on soils as shallow as 0.5 m or even less. Even in such areas, however, the availability of sufficient storage capacity remains important to enable the crop to meet its water requirements during the short periods of drought that may occur (van Averbeke *et al*., 2006).

In many instances, soil depth also influences soil drainage (rate at which excess water is removed from the soil profile). Shallow soils tend to fill-up with water quite rapidly during wet spells. When water continues to be added to the soil, excess water needs to be removed from the profile by means of deep drainage, but underlying rocky or clayey layers restrict this process. As a result, shallow soils tend to get saturated faster than deep soils. Plants growing in a saturated soil experience difficulties with the uptake of nitrogen, and can also be subjected to toxic substances, which develop as a result of the waterlogged conditions. Shallow soils are therefore limited in their ability to supply crops with water during dry seasons, and they are often too wet during seasons that are more favorable. Once the soil is saturated with water, additional rain can no longer infiltrate the soil and runoff occurs.

2.2.5 Soil fertility and acidity

The soils of the province have mainly aridic and ustic moisture regimes (Soil Survey Staff 1975 cited by van Averbeke *et al*., 2000). In the northwest of the province, where mean annual rainfall is less than 400 mm, soils are usually poorly developed and calcareous because of a lack of leaching. In the central part of the Eastern Cape, where the mean annual rainfall ranges from 400 to 600 mm, the soils usually have a neutral reaction but lime may still be present in the subsoil (van Averbeke, 2000; Maswana, 2007). In these soils, an abrupt increase in clay content from surface horizon to subsoil (duplex soils) and gradual increase in clay content from surface horizon to subsoil (pseudo-duplex soils) are common (van Averbeke, 2000). Where mean annual rainfall exceeds 600 mm, mainly along the coast and in the east, soils have surface horizons that react acid (Mandiringana *et al*., 2005).

The EC has one of the highest provincial indices of soil degradation and this is evident by the low soil fertility status (Mandiringana *et al*., 2005). Silwana (2001) reported that maize is usually grown under poor soil-fertility conditions in the EC, such as low nitrogen (N), phosphorus (P) and soil acidity. Low soil pH, which affects the availability of micro- and macro-nutrients, is a very important yield limiting factor in the EC province (Mandiringana *et al*., 2005; Gichangi, 2007). Acid soils are characteristic of soils that receive high rainfall, have soils with high levels of aluminium, manganese and iron. Such soils are deficient in phosphorus, calcium, magnesium, potassium, sulphur and zinc, all of which are important nutrients for maize growth (Mandiringana *et al*., 2005; Gichangi, 2007). These soils characteristically inhibit root development, leading to low water and nutrient uptake and low maize yields (Duque-Vargas *et al*., 1994). In such cases, aluminum toxicity and phosphorus deficiencies tend to be important factors affecting maize yields (Narro *et al*., 2001) in the EC.

2.2.6 Biotic factors

In the absence of abiotic constraints in maize production, biotic factors have an equally important role in the reduction of yield. It is estimated that, diseases like gray leaf spot (GLS) caused by *Cercospora zeae maydis*, various stains of rust and leaf blights, alone have resulted in a 15-75% yield reducing effect to maize grown in higher rainfall areas similar to those in the EC. Other biotic factors such as weeds, maize stem borer, maize pollen beetles, and vertebrate birds have also resulted in total yield losses (De Groote *et al*., 2004). According to Fanadzo *et al*. (2009), at post emergence stage, maize is highly susceptible to cut worm and vertebrate (rats and birds) pest damage. Fields prone to bird damages always have poor crop stands. During post anthesis, diseases, namely Diplodia cob and stem rot caused by *Stenocarpella maydis*, gray leaf spot have been seen to reduce yields along with maize stalk borer (Fanadzo *et al*., 2009).

2.2.7 Socio-economic factors

According to Witt *et al*. (2006), the failure of many initiatives to improve maize production was because of their inability to address socio-economic and bio-physical factors affecting farmers. Unlike commercial farmers who grow varieties based on market trends and yield, resource-poor farmers are bound by socio-economic and bio-physical factors (Balgah *et al*., 2010). Issues like gender, source of income, palatability, versatility in use, cultural practices and norms, accessibility of inputs and other prevailing production constraints are some of the factors that govern the rate and success of technology adoption (Balgah *et al*., 2010; Bucheyeki *et al*., 2011). Therefore, the use and adoption of improved varieties are often influenced by household objectives and household limitations, rather than profit maximization.

2.2.8 Choice of varieties

Not much information is known about the varieties grown in the EC. However, according to studies conducted by Silwana (2000) and Sibanda (2010), rural farmers in the province use a combination of varieties, including hybrids, improved OPVs and local landraces. According to results obtained by Silwana (2000), the majority of farmers use traditional landraces (75%), which tend to be highly heterogeneous and low yielding. Such varieties would either be grown alone or in conjunction with certified hybrid and retained hybrid seed. However, according to MEDTP (2010) and Matiwana (2011), donor organizations and agricultural support institutes such as Accelerated and Shared Growth Initiatives – South Africa (ASGISA) EC maize project, and the Massive Food Production Program

(MFPP), have been donating hybrid seed that is Genetically Modified (GM) or non-GM, and supplying agro-chemicals at subsidized prices, and on a loan basis. It is not clear whether these varieties have been evaluated for suitability in the Eastern Cape. However, results obtained by Matiwana (2011) and Fanadzo *et al*. (2009) suggest that, varieties currently in use may not be entirely adapted to the Eastern Cape.

Given the stressful condition in which maize is grown under in the EC, an adaptable variety should possess traits that allow it to be competitive in the event of such conditions. Results by Monneveux *et al*. (2008) suggest that leaf traits seem to be less important than variation in tassel parameters for increasing drought tolerance. Banziger *et al*. (2000) and Monneveux *et al*. (2008) suggested that varieties should have greater number of ears per plant, bigger kernel size and smaller tassels, which could help to increase grain yield in drought prone environments. Based on reports by Mwania *et al*. (2002), late maturing maize varieties with a lot of foliage (high number of leaves with a large surface area) are more suitable for high rainfall areas. According to Davis (1982), time to maturity, plant height, internode length and leaf width affect the suitability of maize varieties to intercropping and target populations. While Begna *et al*. (2001) observed that, small statured, early maturing plants were less affected (low decrease in yield) by higher levels of intra-specific plant competition (narrower rows and higher plant population densities) or inter-specific plant competition (weed pressure) than the conventional and late maturing varieties. Results by Zaidi *et al*. (2010) suggest that traits for good resistance to water logging are thick stems, low ASI interval of less than 5 days and early brace root development. Therefore, for farmers that have to contend with variable environments, the choice of variety is very important.

2.3 Participatory Variety Selection

Smallholder farmers have multiple production objectives and have to deal with variable environments, which greatly affect the choice and selection of maize varieties (Odendo *et al*., 2002). Other than yield, which in official release programs is by far the most important objective, yield stability, adaptation to agronomic management techniques and crop uses, are traits that many smallholder farmers consider (Witcombe, 2002; Odendo *et al*., 2002). According to Abebe *et al*. (2005) and Bucheyeki *et al*. (2011), this range of objectives often results in the use of a large number of varieties by individual farmers. In most cases, farmers are forced to spend more on maize production or forgo the benefits of other varieties to satisfy high order objectives. It becomes more difficult when farmers have to consider environmental factors as well.

According to Witcombe (2002), in order to encourage low-resource farmers to adopt higher yielding varieties, scientists initiated farmer participatory research to identify farmers' ideal plant varieties. The research was focused at the final stage of the plant breeding process which was the selection among released, or nearly released, varieties (Witcombe, 2002; Abebe *et al*., 2005 and Bucheyeki *et al*., 2011). During the research, the needs of farmers were established by identifying what varieties they could grow, and what traits they considered important (Ceccarelli *et al*., 1999; Witcombe, 2002). Interaction with farmers enables scientists to select new varieties that have the traits that farmer's desire and that match the farmers' landraces for important characters such as maturity, plant height and seed type. This method is termed Participatory Variety Selection (PVS).

Participatory Variety Selection underscores the importance of partnership between farmers and researchers, with the strong support of development workers for wider technology promotion (Ceccarelli *et al*., 1999; Witcombe, 2002; Abebe *et al*., 2005; Bucheyeki *et al*., 2011). Variety selections by farmers are an important starting point when introducing new varieties to diverse agro-ecologies (Nkongolo *et al*., 2008). Farmer participation in the selection of pre-existing crop varieties for low-resource conditions is regarded by some as necessary to help ensure acceptance and eventual adoption (Sperling *et al.*, 1993).

2.3.1 Methods of farmer participation

The involvement and/or interaction of farmers and researchers have given rise to two general types of classes of methods of PVS (Joshi and Witcombe 1996). The first class, termed as researcher managed PVS, usually restricts farmers' involvement to variety evaluation and selection. In all cases, the researcher incurs the expenses of trial establishment, and the primary evaluation method is yield data (Joshi and Witcombe, 1996). In researcher managed trials, experimental plots can either be on-farm or on-station. Examples of researcher managed trials include all coordinated projects and programs, and demonstration and adaptive trials. In the second classification, described as farmer managed PVS, most of the expenses are incurred by the participation farmer

(Degu *et al*., 2000). Trials are always on-farm and primary evaluations could either be yield data, farmer perceptions or both. Examples of farmer managed PVS include farmer participatory research (FAMPAR) trials of Nepal and India (Warner *et al*., 1999) and seed and fertilizer packages in Sidama and North Omo Zone, Ethiopia (Degu *et al*., 2000).

2.3.2 Data and analysis type in Participatory Variety Selection

What determines whether analysis will be formal or informal is the type of response variable. It is therefore important to understand exactly how the data were collected and what the numbers represent (Coe, 2004). For purposes of this research, scores and ranking were applied, and are the only issues that will be discussed in this section.

2.3.2.1 Scores or rating

When rating or scoring information, data will be recorded on a scale from poor to excellent, poor to bad, satisfactory to non compliant (Coe, 2004). The categories used are often given numerical labels, such as 1, 2, 3, 4, 5 (Coe, 2004). These are called scores or ratings and such a scale can also be described as ordered categorically. These labels are random. An observation of 3 will be higher than an observation of 2, but we cannot say that it is better by the same amount or that an observation of 5 is better than that of 4.

2.3.2.2 Ranks

In many investigations of preference, data are collected by asking respondents to rank alternatives (Coe, 2004). The options available are placed in order without any attempt to describe how much one differs from another or whether any of the alternatives are, for example, good or acceptable. We might have variety A ranked above B, which is ranked above C, yet none of the three are considered good (Coe, 2004). The data would look the same in the case where a respondent placed them in the same order, but one, two, or all three were acceptable. Other scales may be hybrids of these. The most common methods of ranking used in PVS are pair wise ranking and matrix ranking. During matrix ranking, factors with the highest frequency are considered important (Margolius *et al*., 1998). Pair-wise ranking, on the other hand, is used when communities and individuals need to determine the overall importance of factors. This is done by comparing each factor with the others and establishing which of the two is more important (see Appendix 1) (Margolius *et al*., 1998).

2.3.3 Lessons from participatory selection

Farmers' measure of satisfaction towards a variety cannot be measured by a researcher without their involvement. Farmers can give detailed information on desirable agronomic traits and post-harvest traits (Nkongolo *et al.,* 2008). It is feasible for a plant breeder to evaluate many of these traits without farmers, but it will be more expensive and yet not provide data on how the traits trade off against each other (Odendo *et al.,* 2002). Due to the different socio-economic differences exhibited by farmers within a single location, criteria for selecting different genotypes differ. It has been observed by numerous researchers that farmers evaluate varieties for multiple traits, and do not place an overriding emphasis on grain yield (Ceccarelli *et al*., 1999; Odendo *et al.,* 2002; Nkongolo *et al.,* 2008). Hence, the most preferred varieties are often not amongst those selected by breeders for grain yield alone. Despite scientists' uncertainty on the credibility of farmers' data, farmers are the ultimate judges of any new variety.

2.4 Genotype, environment and genotype by environment interaction (GEI)

A physical visible characteristic, for example yield, results from the interaction between the organism's genetic makeup and its immediate environment and is referred to as the phenotype (Samonte *et al*., 2006; Ma'ali, 2008). The environmental factors that affect the phenotypic response of maize include location, rainfall amount, growing season length, temperature, amount of precipitation per season, soil conditions, etc, and these can have either a collective positive or negative effect on the phenotypic response of a maize plant (Tigerstedt, 1997; Admassun *et al*., 2008). The association between the environment and the phenotypic expression of the genotype constitutes GEI. Therefore, GEI refers to the differential responses of different genotypes across a range of environments (Kang *et al*., 2004). GEI has been observed in many crops by numerous researchers, such as, Muungani *et al*. (2007) in maize varieties across Zimbabwe, Setimela *et al*. *(*2007) in maize OPVs across Sub-Saharan Africa, Asfaw *et al.* (2009) in soy bean across Ethiopia and Admassun *et al*. (2008) in maize across Ethiopia

Due to exposure to different environments, the same genotype may portray varied yield responses. This is termed as phenotypic plasticity (Kang *et al*., 2006). van Averbeke (1991) found that a single maize variety responded differently in different soil ecotypes in the same location (soil factors) and in different locations with the same soil ecotypes (environmental factors). In instances where more than two genotypes are being compared, GEI only becomes important when genotypes switch ranks from one environment to another. GEIs can therefore be grouped in to two categories: crossover and non-crossover interactions.

2.4.1 Crossover and Non crossover interaction

Crossover interaction is when two genotypes change in rank order of performance when evaluated in different environments (Kang, 2004). The main feature of crossover interaction can be represented by intersecting lines (Figure 2.1b) or diverging lines (Figure 2.1c) in a graphical representation (Kang, 2004)

The presence of crossing over has a strong implication on breeding for specific adaptation. According to results obtained by Yan (2001), crossover interactions observed between two barley genotypes suggested that the change in the rank for genotypes under the groups of environments could be used to select for specifically adapted genotypes. However, for non-crossover interaction (Figure 2.1a), the genotypes are in most cases genetically heterogeneous, while test environments are more or less uniform, or vice versa (Kang, 2004). Therefore, genotypes do no exchange rank positions when evaluated in different environments, however, the magnitude of change is intensified by environmental factors (Figure 2.1).

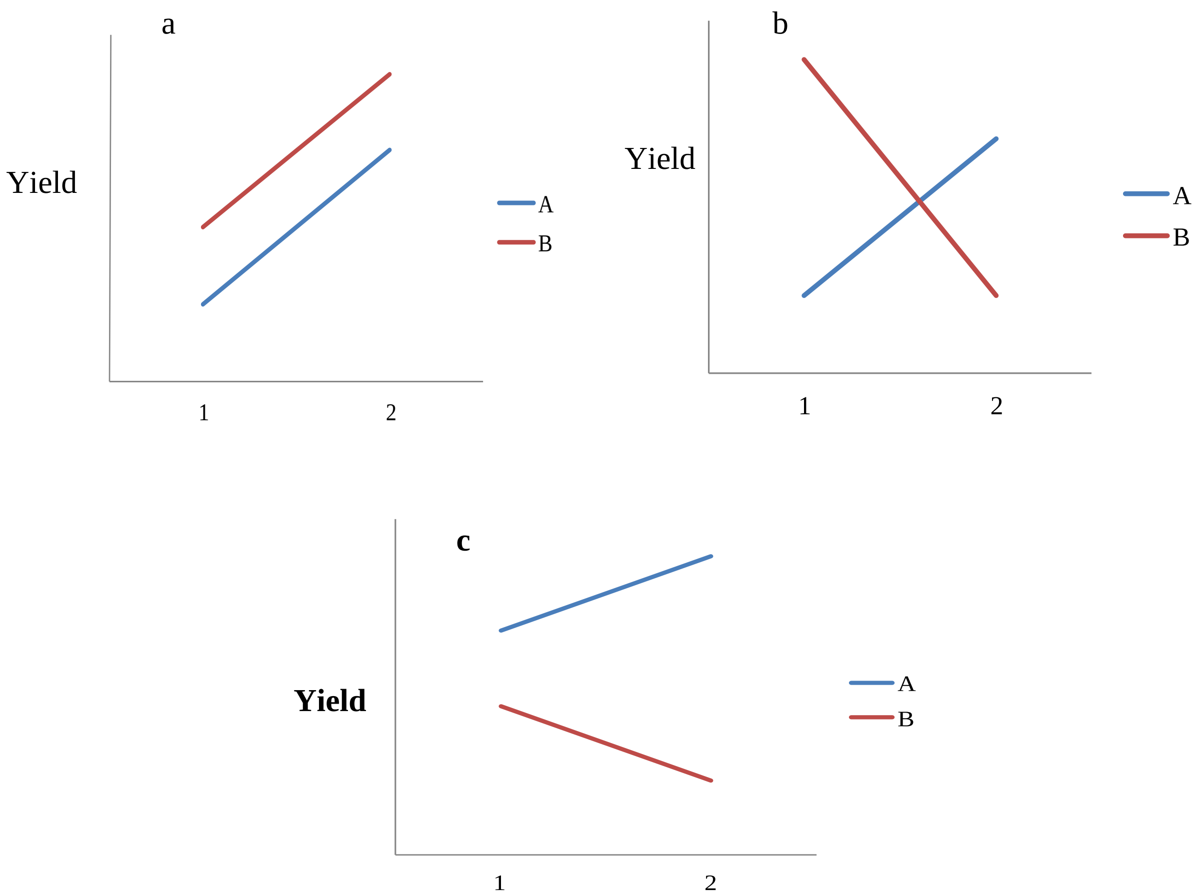

Figure 2.1 Schematic representation of performance of two hypothetical genotypes (A and B) evaluated in two environments (1 and 2) (a) no GEI, (b) GEI due to heterogeneity of variance between environments and crossover interaction, and (c) GEI due to heterogeneity of variance between the environments but no crossover interaction. (Adapted from Yan (2001))

2.4.2 Methods of measuring Genotype by Environment interaction

The GEI has been studied by different researchers, and several methods have been proposed to analyze it. Examples of such methods include, univariate methods such as Francis and Kannenberg's (1978) coefficient of variability, Plaisted and Peterson's (1959) mean variance component for pair-wise GEI, Wricke's (1962) ecovalence, Shukla's (1972) stability variance, Finlay and Wilkinson's (1963) and Perkins and Jinks's (1968) regression coefficient, and Eberhart and Russell's (1966) sum of squared deviations from regression. Usually a large number of genotypes are tested across a number of sites and years, and it is often difficult to determine the pattern of genotypic response across environments without the help of graphical display of the data (Yan, 2001). The biplot technique provides a powerful solution to graphically display data (Gauch, 1992).

Biplot analysis is a multivariate analytical technique that graphically displays the two-way data and allows visualization of the interrelationships among environments, genotypes, and interactions between genotypes and environments. Biplots are useful in summarizing and approximating patterns of response that exist in the original data (Gauch and Zobel, 1996). Two types of biplots, the Additive Main effect and Multiplicative Interaction (AMMI) biplot (Zobel *et al*., 1988; Gauch, 1992) and the GGE biplot (genotype main effect plus genotype x environment interaction; Yan *et al*., 2007) have been used to visualize genotype x environment two-way data. These display the "which-won-where" pattern of data that may lead to the identification of high-yielding and stable cultivars and the second is to identify discriminating and representative test environments (Yan *et al*., 2007). AMMI models were used in this research.

2.4.3 Additive Main effects and Multiplicative Interaction (AMMI) model

A combined analysis of variance (ANOVA) can be used to quantify GEI and describe the main effect. However, ANOVA does not fully explain the interaction between the two effects (Admassun *et al.,* 2008). Furthermore, ANOVA cannot distinguish varieties that have a potential of exhibiting specific or wide adaptation. To explain the interaction of the main effects beyond ANOVA, other statistical models can be employed. One such model is the Additive Main effect and Multiplicative Interaction (AMMI) model proposed by Zobel (1988). Ma'ali (2008) showed its usefulness in identifying the stable varieties that had been tested across eastern and western maize growing regions in South Africa. Asfaw *et al*. (2009) used it to identify the extent of specific variety-environment interactions in Ethiopia, while Mohammadi *et al*. (2007) used it to identify wheat varieties that had specific adaptations in specific environments in Iran. Furthermore, Yan and Tinkler (2006) also showed the usefulness of biplot generated by the AMMI model in the evaluation and identification of mega-environments and test environments.

The Additive Main effects and Multiplicative Interaction (AMMI) model combines analysis of variance (ANOVA) for the genotype and environment main effects with principal component analysis (PCA) of the genotype-environment interaction. It has proven useful for understanding complex GEI (Annicchiarico *et al*., 2002). They also provide visual representation, which can be graphed in a very informative biplot that shows both main and interaction effects for both genotype and environment (Annicchiarico *et al*., 2002). Also, AMMI can partition the data into a pattern and discard noise from residuals to increase accuracy. Additive main effects and multiplicative interaction thus provides better understanding of GEI, improving the accuracy of yield estimates, increasing the probability of successful selections of high yielding varieties, inputing missing data and increasing the flexibility and efficiency of experimental designs (Aina *et al*., 2007). A lot of researchers have successful used AMMI in the recommendation of varieties to appropriate target sites. Such efforts include those by Annicchiarico *et al*. (2002), Ebdon and Gauch (2002), Akcura *et al*. (2005), Aina *et al*. (2007), Admassan *et al*. (2008), Ma'ali (2008) and Balestre *et al*. (2009)

According to Yan and Tinker (2006), the purpose of evaluating environments is to identify 'ideal' test environments that effectively identify superior genotypes for a given set of mega-environments. Based on observations made by Yan *et al*. (2007), three classes of environments can be distinguished in an AMMI biplot. The first class consists of environments that are close to the abscissa (low principal component 1 and 2 scores), and are considered to be less discriminating. Therefore, these environments provide little information about different variety performances. Environments in the second class lay far from the abscissa (high principal component 1 and 2 scores), and are more discriminating, but are not representative of a mega-environment. The last class of environments, characterized by high principal component 1 scores and low principal component 2 scores, are considered as 'ideal' environments. According to Mohammadi *et al*. (2007), these environments should be used in selecting good performing varieties as they both, discriminate and are representative of the mega-environment.

2.4.4 Conclusions drawn from Genotype by Environment Interactions

For most GEI experiments, the aim is to fulfil two main objectives. The first is to establish whether there are varieties that will show performance stability throughout some, if not all, environments (wide adaptations). The second is to identify varieties that are suitable in some of the tested environments (specific adaptations) (Admassan *et al*. 2008). Therefore, GEI allows researchers to select for wide or/and narrow adaptation to an environment (Annicchiarico *et al*., 2002; Ebdon and Gauch, 2002). Varieties that are widely adapted tend to be generally low yielding, while those that exhibit narrow adaptation tend to be high yielding in a specific environment. According to Ceccarelli, (1999), breeding varieties for specific adaptation is important in the cases where crops are predominantly grown in diverse and unfavourable conditions. This is because unfavourable environments tend to be very different from each other as compared with favourable environments. Therefore, the use of unstable genotypes in low potential agricultural areas has been observed to be less favourable in terms of adaptation. Hybrids are generally more unstable (more susceptible to stress conditions) than OPVs.

2.5 The use of open pollinated varieties in marginal environments

Open pollinated varieties consist of plants of different genetic makeup (genotypes) that respond differently to environmental stresses such as moisture stress, diseases, temperature, etc. As a result, OPVs are more tolerant to stresses than hybrids (Pixley and Banziger, 2001). Maize hybrid plants support the concept of plant ideotypes. The reasons for dominance of these hybrid varieties include higher yields and uniformity (Donald, 1968 cited by Phillips and Wolfe (2006). There are vast restrictions, however, in the husbandry of these varieties. Maize hybrid production in marginal areas has been meeting with numerous challenges that include, high seed cost, abiotic and biotic problems and lack of adoption by resource-poor farmers (Ceccarelli *et al*., 1999). Many agronomic strategies have been experimented on, in an effort to improve yields of hybrids under smallholder farmers' conditions. However, Ceccarelli *et al*. (1999) reported that for resource-poor farmers, a more comprehensible solution does not include alteration of agronomic practices like planting time or location, but the growing of diverse genetic populations like OPVs.

The advantage of OPVs is that a high genetic diversity can lead to temporary yield stability in different environments (Phillips and Wolfe, 2006). These varieties are known to have wide adaptation as they are made from a population of different family genotypes. As OPVs are more variable in flowering dates, and peak drought stress (see section 2.2.1 for incidences of drought stress in the EC) tends to be most severe during flowering, this variation can at times offer more stable yields than uniformly flowering hybrid maize varieties. The cost of OPV seed is lower than that of hybrid seed, hence, money saved from their purchase can be re-channelled to buy more fertilizer and pesticides (Gadzirirayi *et al*., 2006).

Hybrid seed is more expensive because its production is technically more complex than that of OPV seed (van Wijk, 1994). Hybrid seed production can take up to three seasons, while OPVs only require one season (The maize program, 1999). Therefore, hybrids require more inputs to produce, and have a lower land output efficiency rate than OPV seed. In addition, the management (planting, detasseling and harvesting) of two different parent lines in the same field required to produce a hybrid variety, as compared with the uniform management practices in OPVs, increases the seed production costs of hybrid seed (van Wijk, 1994). This, in turn, increases the market price of hybrid seed as compared to OPV seed.

In the EC, a 25 kg packet of OPV seed costs about R405, whilst the same amount of hybrid seed costs, on average, R1160 (Umtiza Farmers' Co-op, 2011). Hybrid seed is therefore about one third more expensive than OPV seed. The current price of grain is approximately R1500/t (SAGIS, 2011). With average yields of less than 1.5 t/ha, this would suggest that farmers who purchase and grow hybrid seed yearly, to sell as grain, may not be able to break-even. This is especially true if the cost of labour is to be factored in and, fertilizers and agro-chemicals are to be purchased. Pixley and Banziger (2001) showed that in scenarios where farmers get yields of less than 1.5 t/ha, it becomes more profitable to use improved OPVs as opposed to purchasing hybrids annually or recycling hybrid seed. Furthermore, Sibanda (2012) observed that the use of OPV seed was more profitable than hybrid seed in low potential environments based on gross margin and gross profit margin analysis. Therefore, use of OPV seed represents an economically sound option relative to use of hybrid seed.

Seed of OPVs can be recycled (that is, retained after harvest for planting in the next season) thrice with minimal loss in yield (Pixley and Banziger, 2001). This is unlike recycled hybrid seed, which suffers as much as 30% loss in yield potential with just one year of recycling due to inbreeding (Pixley and Banziger, 2001). Farmers who cannot readily obtain seed can therefore maintain their own sources of seed. This is probably a viable socio-economic strategy only in extreme stress environments

To address numerous challenges faced by resource poor farmers located in marginal areas, the International Maize and Wheat Improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA), developed a range of stress tolerant open pollinated maize varieties (Pixley and Banziger, 2001; Bänziger *et al*., 2005; Setimela *et al*., 2007). These OPVs are known to have gone through a vigorous screening for tolerance to numerous stresses known to affect resource poor farmers, such as drought, low N, acidity, salinity and nutrient toxicity (especially aluminium toxicity) , all of which are major stresses affecting maize production in the EC province. The screening program has resulted in the production of numerous OPVs that are not only tolerant to diverse biotic and abiotic stresses, but are high yielding, such as ZM 621, ZM 305, ZM 521 and ZM 401 (Magorokosho *et al.*, 2008). However, these varieties need to be evaluated for their adaptation and acceptance by farmers in the EC.

2.6 Conclusion

Biotic and abiotic constraints, socio-economic factors and variety suitability, are the major parameters affecting maize productivity in EC. Introduction and adoption of OPVs could reduce the effects of these constraints. However, before these varieties can be made available for use, they have to be evaluated for overall agronomic performance and acceptability. Therefore, the broad objective of the study was to evaluate newly introduced stress tolerant OPVs in selected villages of the EC.

3. FARMERS' PERCEPTIONS ON MAIZE SELECTION CRITERIA AND PRODUCTION CONSTRAINTS

Abstract

Numerous biotic, abiotic and socio-economic factors affect maize production in the Eastern Cape, one of the poorest Provinces in South Africa. This study sought to identify farmers' production constraints and selection criteria for maize varieties, and their implications towards participatory variety selection (PVS). During the 2009/10 summer season, 41 farmers from Jixini and Mkhwezo villages, in O. R. Tambo District, participated in focus group discussions and participatory variety selection. This was followed-up by household interviews of 70 farmers using a semi-structured questionnaire in the 2010/11 summer season. Varieties evaluated during PVS included nine stress tolerant Open pollinated varieties (OPVs), ZM 305, ZM 423 (early maturing), ZM 501, ZM 525, Obatanpa (early to medium maturing), ZM 621, ZM 627, BR 993, and Comp 4 (late maturing). The first seven were obtained from the International Maize and Wheat Improvement Centre (CIMMYT), while the latter two were from the International Institute of Tropical Agriculture (IITA). Four locally grown varieties, Pan 6479 (a hybrid) and three OPVs (Okavango, Afric 1 and Nelson's Choice), were included as checks. The most preferred varieties were Okavango, ZM 305 and ZM 501, all of which are early to medium maturing varieties. In Jixini, Okavango was ranked first, while ZM 305 was ranked first in Mkhwezo. Agronomic yield data showed that these varieties were not significantly different from high yielding varieties. The predominant traits mentioned among farmers' selection criteria were long cobs, big kernels and taste, while other traits, such as, brace roots, strong stems, prolificacy, early maturity, retainability and dark leaves, were village specific. Elderly farmers dominated the studied farming community. Most farmers used local landrace varieties, because they were retainable and palatable. Maize yields were low, and were affected by shortages of labour and inadequate fertilizer use. Single farmers were the least productive farmer group. The main production constraints faced by farmers, in order of importance, were too much rain, pests and diseases, drought, climate change, and lack of fencing. Early to medium maturing OPVs, like Okavango, ZM 305 and ZM 501 could be recommended as a risk management strategy in light of farmer characteristics and the numerous constraints faced in both villages.

Key words: Focus group discussions (FDGs), participatory variety selection (PVS), production constraints, selection criteria

3.1 Introduction

Maize production in the EC province is characterized by resource-poor farmers growing the crop under stressful conditions. Production in the province is typically below household requirements, and marketing of surplus is rare. Use of stress tolerant OPV has been demonstrated to improve yields in Zimbabwe, Malawi and Limpopo province of South Africa, where maize is also grown under biotic and abiotic constraints (Bänziger *et al*., 2005; Gadzirirayi *et al*., 2006; Mphalala, 2007). Therefore, introduction of these low cost, highly adaptable, stress tolerant seed variety alternatives could help farmers in the EC's former homelands increase maize productivity. In turn, this could have a significant contribution towards improved rural livelihoods and alleviation of poverty.

The willingness of farmers to incorporate unfamiliar varieties into pre-existing cropping systems is often met with some resistance. To increase adoption of new varieties, researchers have incorporated various farmer participatory approaches (Witcombe *et al*., 2002). One such approach is participatory variety selection (PVS). Participatory variety selection has been successful in variety introduction and adoption in many areas, for example, rice in Nepal (Joshi *et al*., 1996), drought tolerant maize in Ethiopia (Abebe *et al*., 2005) and groundnuts in West Africa (Ntare *et al*., 2007). Failure to understand farmers' production constraints, variety preferences, and socio-economic situations results in rejection of improved varieties. Furthermore, this can pose as a hindrance towards the success of PVS of improved OPV. Due to the versatility of farmers' involvement in PVS, researchers have resorted to use of various participatory rural appraisal (PRA) tools and formal surveys, such as household questionnaires, to elicit vital information that could help in the introduction and adoption of new varieties.

Focus group discussions (FGD), coupled with activities such as matrix and pair-wise ranking, reduce the gap between the objectives of both the researchers and intended beneficiaries (Odendo *et al*., 2002). Furthermore, when there are significant agro-ecological and socio-economic differences across cropping systems, such information is extremely important in identifying factors that could affect adoption of new varieties (Witcombe *et al*., 2002; Joshi *et al*., 2007; Foti *et al*., 2008).

The type of varieties grown by resource poor farmers is mainly determined by socio-economic and bio-physical constraints being faced. Though, these factors also affect commercial farmers, this group of farmers generally grow varieties based on market trends and yield potential. (Balgah *et al*., 2010). Palatability, versatility in use, cultural practices and norms, accessibility of inputs and prevailing production constraints are some of the factors that influence the rate and success of variety adoption (Balgah *et al*., 2010; Bucheyeki *et al*., 2011). In other words, decisions to adopt new varieties are often influenced by household objectives and limitations rather than profit maximization. On the other hand, perceived attributes of a variety also influence behaviour of farmers towards a new variety (Uaiene and Arndt, 2009). This suggests that even if information regarding a variety is available, farmers have a tendency to subjectively evaluate it differently from scientists. Therefore, to estimate potential adoption of a new variety and facilitate its evaluation, an assessment of attributes preferred by farmers and the socio-economic environment under which they operate is an important starting point (Witt *et al*., 2006; Bucheyeki *et al*., 2011).

Gathering information on maize production constraints and farmers variety preferences helps in narrowing down the possible varieties to be introduced in a community. Introduction of appropriate varieties has been shown to increase rate of adoption, improve food security, reduce poverty and minimize food shortages (Witcombe *et al*., 2002). Therefore, the primary objective of this study was to investigate the effect of socio-economic factors and farmer perceptions on the evaluation of improved open pollinated maize varieties using participatory approaches.

The specific objectives of the study were to:

1. Compare farmer participatory evaluation of OPVs with selections based on agronomic criteria;

2. Determine the effects of socio-economic factors on maize productivity of different farmer-groups living in selected villages of the Eastern Cape; and

3. Identify farmers' maize selection criteria and production constraints in selected villages of the Eastern Cape.

The null hypotheses that were tested were:

1. Farmers variety selections do not differ from selections made by researchers;

2. Effects of socio-economic factors on maize productivity of different farmer groups living in selected villages do not differ from one another; and

3. Farmers' maize production constraints and selection criteria in selected villages, of the Eastern Cape do not differ from each other.

To address these objectives, a number of studies were conducted as follows, (i) establishment of yield trials in which farmers participated in evaluating improved maize OPVs (ii) assessing socio-economic factors affecting maize productivity of homogenous farmer groups (iii) assessment of farmer perceptions on maize preferred traits and production constraints. The latter study was designed around the PVS, and was conducted in selected areas that represented some of the maize growing areas in the EC.

3.2 Materials and Methods

3.2.1 District selection and characterization

The study was conducted during the 2009/10 summer season in the O. R. Tambo District Municipality (ORTDM) (located between longitude $33^0$34′S and latitude $28^0$46′E) of the EC, South Africa. The district was purposively selected because of its geographic, historic and ecological characteristics. It has an estimated population of 1.7 million, 82.2% of whom live below the poverty datum line (Mc Cain, 2005). In contrast to other districts, the majority of ORTDM's inhabitants, that is, 90.8% live in rural areas. Agriculture is mainly subsistence, with small scale farming and open grazed livestock

(Musemwa *et al*., 2008). Agricultural potential varies immensely across the district due to rainfall distribution, altitude, and soil characteristics, creating a highly heterogeneous agro-ecology. Mean rainfall of the district ranges from 600 to 1800 mm and this is highly dependent on altitude and distance from the Indian Ocean (AGIS, 2011). Most agricultural production in the district is rainfed. Altitude ranges from 0 to 1650 meters above sea level (AGIS, 2011), which allows a diversity of agricultural enterprises to be practiced.

3.2.2 Village selection

Jixini and Mkhwezo villages (Figure 3.1) were purposively selected to participate in the study. This was based on contrasting agro-ecologies and consultation with ward extension officers.

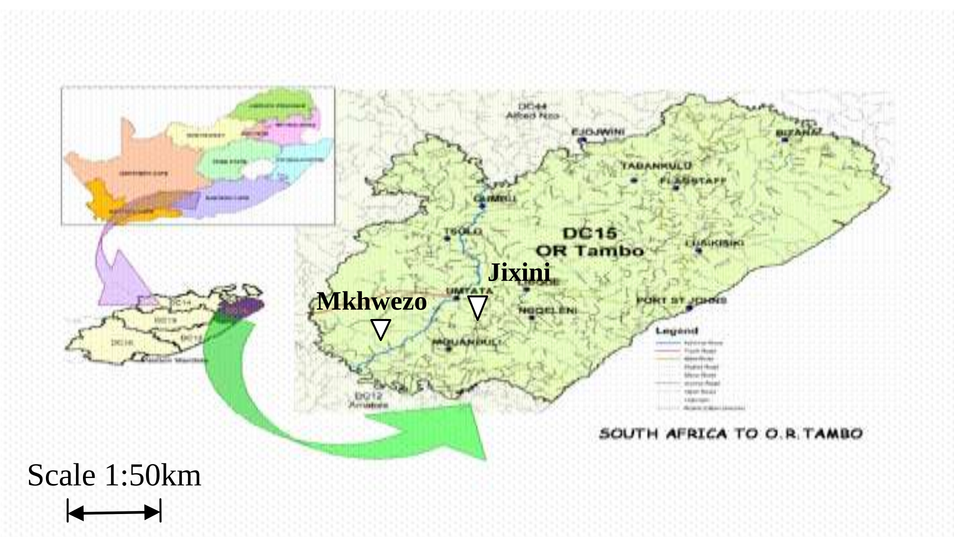

Figure 3.1 Map of O. R. Tambo district showing the location of study sites. Adapted from Mc Cain (2005).

Jixini ($31^{0}43$'S and $28^{0}50$'E) lies in a moderately high rainfall area with annual precipitation ranging from 800 to 1000 mm and an average altitude of 643 m above sea level (masl) (AGIS, 2011). According to agro-ecological classification, Jixini has a sub-tropical to semi-arid climate with clay loam black soils. It has a sparsely populated rural settlement, and covers approximately 5 km^2, with an estimated population of approximately 750 inhabitants (Water Service Report Tool, 2011). Mkhwezo ($31^{0}42$'S and $28^{0}30$'E), on the other hand, is located in a lower rainfall area with annual precipitation between 600 and 800 mm, with an average altitude of 942 masl (AGIS, 2011). This village has an arid to semi-arid climate, with light brown sandy loam soils. It is approximately 8 km^2 and has a population of about 1250 inhabitants (Water Service Report Tool, 2011). Mkhwezo is, therefore, densely populated (Water Service Report Tool, 2011). Most inhabitants from both villages have home gardens and out fields. Maize is the main summer crop grown within these fields.

Based on willingness to participate in the study and consultation with ward extension officers, a single farmer was identified in each village for the establishment of yield trials.

3.2.3 Participatory evaluation of stress tolerant maize open pollinated varieties

3.2.3.1 Treatments and experimental design

The trial evaluated thirteen varieties, seven OPVs from CIMMYT, two OPVs from IITA and four local checks as shown in Table 3.1. The experiment was laid out as a randomized complete block design (RCBD), replicated three times at each site.

Table 3.1 Characteristics of maize varieties included in the participatory yield trials conducted in Jixini and Mkhwezo

Code	Variety	Origin	Seed colour	Type	Maturity[1]	Yield potential (t/ha)
1	ZM 305	CIMMYT-Zim	White	OPV	E	2-4
2	ZM 423	CIMMYT-Zim	White	OPV	E	2-6
3	ZM 501	CIMMYT-Zim	White	OPV	E - M	2-6
4	ZM 525	CIMMYT-Zim	White	OPV	E - M	2-6
5	ZM 621	CIMMYT-Zim	White	OPV	M	3-6
6	ZM 627	CIMMYT-Zim[3]	White	OPV	M	2-5
7	BR993	IITA-Ghana	White	OPV	L	2-5
8	COMP 4	IITA-Ghana	White	OPV	L	2-5
9	Obatanpa	CIMMYT-Zim	White	OPV	M – L	2-5
10	AFRIC 1[2]	Nelson's Genetics-SA[4]	White	OPV	M	1.5-6
11	Okavango[2]	Capstone-SA	White	OPV	L	4-5
12	Nelson's Choice[2]	Nelson's genetics-SA	Yellow	OPV	M – L	4-5
13	Pan 6479[2]	PANNAR	White	HYBRID	M	5-10

[1]Maturity class in terms of days to 50% flowering in low altitudes, Early (E) 60-65; Medium (M) 65-70; Long (L) 70-75 (Magorokosho *et al*., 2008) [2]check varieties [3] Zim - Zimbabwe [4]SA – South Africa.

There was different randomization of treatments at each site. Gross plot size was 5 m by 4.5 m with a total of five, 5 m long rows. The net plots consisted of the three middle rows. The two outside rows were considered as discards or border rows. Plant spacing was 0.9 m between rows and 0.3 m within the row for a target population of 37 000 plants/ha.

3.2.3.2 Non-experimental variables

Land preparation involved an initial deep ploughing followed by disking using tractor drawn implements to obtain a fine tilth. Planting stations were opened using hoes and three seeds planted per station. These were later thinned to a single plant per station at two weeks after crop emergence (WACE). A basal fertilizer with an N: P: K ratio of

2:3:4 (30) was applied at a rate of 185 kg/ha at planting to give a nutrient ratio (kg) of 12.4 N: 18.5 P: 24.6 K. Lime ammonium nitrate (LAN) (28% N) was applied at a rate of 185 kg/ha 6 WACE. Therefore, N fertilizer was applied at 64 kg/ha. Weeds were controlled using pre-planting and post-emergence herbicides. Before planting, a pre-emergence herbicide alachlor 480CS was applied at a recommended rate of 5 l/ ha (a.i. chloroacetanilide 480 g/*l*). From two weeks after crop emergence to post-anthesis basagran (a.i. bendioxide 480 g/*l*) and atrazine 500SC (a.i. atrazine 500 g/*l*) was applied at a recommended rate of 2 *l*/ha every two weeks, until post anthesis, to control broad leafed weeds and nutsedge. Scouting for cut worms (*Agrotis segetum*) and maize stalk borer (*Buseola fusca*) was done and control was achieved by using dursban at 3 *ml*/5*l*. All agro-chemicals were applied using a knapsack sprayer. Harvesting of net plots was done at harvest maturity and cobs for each plot were hand shelled. A Protimeter Grain Moisture meter (Grainmaster®) was then used to standardize grain yield per plot to 12.5% moisture content.

3.2.3.3 Data collection

At physiological maturity, farmers from Jixini and Mkhwezo villages were invited by extension officers to attend a field day. Maize cobs from the outer rows of each plot were de-husked to allow farmers to assess varieties based on cob and other plant parameters. Farmers in each village were put into five groups of three people, and were asked to select three most preferred varieties. They were then asked to give reasons for their choices. The traits that were mentioned were considered as field-based selection criteria. Data on variety selections from each group were then consolidated to come up with the top five varieties for each village. At harvest maturity (when grain was fairly dry, such that it would not deteriorate in quality when harvested), net plots were harvested and shelled to obtain grain weight which was then used to calculate grain yield in t/ha. After determining moisture content, grain yield was adjusted to 12.5% using the following formular: Grain yield = [(100-moisture content)/87.5] * yield/ha.

3.2.3.4 Statistical analyses

Statistical analysis for grain yield was performed using GenStat Statistical Software, version 4.2 (GenStat®, 2002). A Bartlett's test (Gomez and Gomez, 1984) was performed to determine homogeneity of error variances before combining data of the two sites. This test showed homogeneity of error variances for both sites, allowing combined analysis to be done for grain yield. Duncan's mean test was used to separate significantly different means at $p<0.05$.

3.2.4 Farmer surveys

To identify selection criteria and maize production constraints, both informal (FGDs) and formal (involving distribution of questionnaires) surveys were used and these were conducted during the 2009/10 and 2010/11 seasons, respectively. Xhosa speaking enumerators collected the data. Enumerators were trained before they went into the field for data collection, to ensure uniformity in interpretation of the checklist and questionnaire. Qualitative data were collected from four focus groups, as shown in Table 3.2. Before the FGDs, the objectives were outlined and the purpose of meeting explained. During the discussions, a checklist was used to identify farmers cropping systems, preferred maize traits and maize production constraints (see Appendix 1). Key informants consisted of at least an experienced farmer (selected by the extension officer) and extension officer, who were interviewed using the same checklist used in the focus group discussions.

Table 3.2 Distribution of farmers who participated in focus group by gender

Village	Male(n)	Female (n)	Total
Jixini	10	8	18
Mkhwezo	10	13	23
Total	20	21	41

n – Number of participants

Key informants and each group of farmers assigned scores to each production constraint and selection criterion. The scores ranged from 1 to 5 (1 = never considered, 2 = considered but not important, 3 = moderately important, 4 = important, and 5 = very important). To come up with a final rank, production constraints and selection criteria equal to or above 3 were subsequently compared to each other in a pair-wise fashion.

A semi-structured questionnaire (Appendix 2) was then designed based on results of the informal survey with the objective of obtaining detailed information on specific issues and also testing some hypotheses formulated by researchers after FGDs. The formal survey was conducted in the same areas where FGDs were held, and involved interviews with70 individual farmers. The questionnaire was administered to maize growing farmers who were selected with the help of the extension workers. The semi-structured questionnaire covered household demographic characteristics (age, gender, marital status, source of income, education, household size, and household labour size), land characteristics and use, maize cropping systems, maize trait preferences and maize production constraints.

3.2.4.1 Statistical analysis

Data collected were coded and subjected to analysis of variance in Statistical Package for Social Sciences (SPSS) version 15 (SPSS Inc., Chicago IL). Descriptive statistics (means and percentages) that were generated provided insights into different socio-economic and bio-physical features of the households. Farmers were categorized into homogenous groups based on a selected set of criteria (Hoppe *et al*., 2000). Differences in perceptions, socio-economic and bio-physical features have been observed across gender (Odendo *et al*., 2001) and marital status (Nkongolo *et al*., 2008) and this has been attributed to the different roles played by in agriculture. Therefore, in this study, groups were constructed using gender and marital status.

3.3 Results

3.3.1 Participatory evaluation of stress tolerant maize open pollinated varieties

Farmers' variety preferences and ranking varied between the villages as shown in Tables 3.3. Three varieties were selected in both villages, and these were, Okavango, ZM 305 and ZM 501. Other varieties also selected included Nelson's Choice, Afric 1, ZM 621 and ZM 423. In Mkhwezo, ZM 305 was ranked first, while, Okavango ranked first in Jixini.

In general, traits desired by farmers, from the most to the least preferred, were short to medium plant height, long cob, kernel rows (≥12), prolific, good cob filling, big kernel size, flint kernels, and early maturity (Table 3.4). However, farmers also pointed out some weaknesses in varieties they selected.

Table 3.3 Rank positions of varieties selected by farmers in Mkhwezo and Jixini

Village	Rank				
	1	2	3	4	5
Jixini	Okavango	ZM 621	ZM 501	ZM 305	ZM 423
Mkhwezo	ZM 305	Nelson's choice	Okavango	ZM 501	Afric 1

Table 3.4 Presence or absence of preferred traits in varieties selected by farmers across the study sites

Traits preferred	Varieties selected									
	Jixini					Mkhwezo				
	ZM 423	ZM 621	ZM 305	ZM 501	OKA	ZM 305	ZM 501	OKA	AFRIC1	NC
Short to medium plant height	√	-	√	√	√	√	√	-	√	√
Long cob	√	√	√	-	√	√	√	√	-	√
Kernel rows (≥12)	√	√	√	√	+	√	√	+	-	√
Prolific	√	√	√	√	-	√	-	-	-	
Good cob filling	√	√	√	-	+	√	-	+	√	
Big kernel size	√	√	√	-	-	√	√	-	√	-
Kernel shape (flint)	√	√	√	-	-	√	-	√	-	√
Early maturity	√	-	√	-	-	√	√	-	-	-
Good husk cover	-	-	√	-	+	-	-	+	√	-
Thick stem	√	-	-	√	-	-	√	-	-	-
Kernel colour	+	+	-	-	√	+	-	√	+	-
low leaf number	√	-	-	-	-	√	-	-	-	-

√ indicates desirable traits that a variety was identified to have; - indicates trait was not mentioned for corresponding variety; + indicates a desirable trait that a variety was identified to be lacking; In the case of kernel colour, + refers to yellow kernels would be more preferred.

Though, Okavango was preferred mainly because of its yellow grain colour, farmers from both villages reported that it had few kernel rows, poor cob filling and poor husk covering (Table 3.4). Farmers also indicated that ZM 305, ZM 423, ZM 621 and Afric 1 would have been even more desirable if they were yellow.

3.3.2 Agronomic evaluation of stress tolerant varieties

There was a significant ($p<0.001$) interaction between variety and site (Table 3.5). Grain yield was higher (5.50 t/ha) in Jixini than of Mkhwezo (3.04 t/ha) (Table 3.5). In Jixini, Pan 6479 was the highest yielding variety with 6.68 t/ha, and showed no significant difference with ZM 525, which had a yield of 6.28 t/ha.

Table 3.5 Performance of varieties and ranking according to grain yield (t/ha) in Jixini and Mkhwezo

Variety		**Site**		
	Jixini	Rank	Mkhwezo	Rank
ZM 305	5.03 cdef[1]	9	3.49 ab	2
ZM 423	5.71 abcd	5	2.88 c	8
ZM 501	5.33 def	8	2.98 c	7
ZM 525	6.48 ab	2	3.31 b	5
ZM 621	5.60 bcd	6	2.52 de	12
ZM 627	5.65 bcd	7	2.47 e	13
BR 993	4.26 f	13	3.34 b	3
COMP 4	4.77 def	11	2.78 cd	9
OBA	4.69 ef	12	3.79 b	1
AFRIC 1	6.07 abc	3	3.33 b	4
NC	5.01 cdef	10	3.24 b	6
OKA	6.14 abcd	4	2.72 cde	10
PAN	6.68 a	1	2.65 cde	11
Mean	**5.50**		**3.02**	
$P_{0.05}$	*******		**NS**	
DMRT	**0.99**		**0.30**	
CV	**10.69**		**18.04**	

OBA – Obatanpa; NC – Nelson's Choice; OKA – Okavango; PAN – Pan 6479; [1] Means followed by similar letters are not significantly different at $p < 0.001$ based on DMRT test; NS - not significant. Interaction between Site and variety was also significant at $p< 0.001$; CV = 14.8 and $DMRT_{(0.05)} = 0.98$

The lowest yielding varieties in Jixini were Comp 4 (4.77 t/ha), Obatanpa (4.69 t/ha) and BR 993 (4.26 t/ha), which ranked 11th, 12th and 13th, respectively. Yields of these varieties were also not significantly different from each other. Obatanpa (3.79 t/ha) was ranked first in Mkhwezo, and this was followed by ZM 305 (3.49 t/ha) and BR 993 (3.34 t/ha), which ranked second and third, respectively. Low yielding varieties in this site were Pan 6479 (2.65 t/ha), ZM 621 (2.52 t/ha) and ZM 627 (2.47 t/ha), which ranked 11th, 12th and 13th, respectively. The highest yielding varieties in Mkhwezo, that is, Obatanpa (3.94 t/ha) and ZM 305 (3.47 t/ha), were also low yielding varieties in Jixini (4.64 t/ha and 4.69 t/ha, respectively). Interaction between varieties and site was, therefore, a result of changes in rankings of varieties within sites

3.3.3 Socio-economic characteristics of farmers

Table 3.6 shows the socio-economic characteristics of farmers who were interviewed. Across both sites, there were more male (55%) than female (45%) respondents, and the majority (65.7%) of farmers were in the age ranges of 56 - 65 (27.3%) and older than 66 years (38.4%). Fifty five percent of the interviewed farmers were single, while 17.5% were widowed. Divorced respondents were observed only in Mkhwezo and they constituted 5%.

Data on source of income are shown in Appendix 3 for interviewed farmers. Most of the respondents, that is 48% had old age pensions as their main source of income, while 16% obtained it from sale of agricultural produce and another 16% from family remittances. Only 14% obtained their main source of income from child support grants (14%).

Table 3.6 Demographic characteristics of farmers interviewed in Jixini and Mkhwezo

Variable		Jixini	Mkhwezo	X^2	$P_{(0.05)}$
Number of farmers interviewed (n)		34(49)[2]	36(51)	8.35	NS
Gender of farmers[1]	Male (%)	47	42	0.21	NS
	Female (%)	53	58		
Age range of farmers[1] (years)	< 35	14.7	8.3	3.73	NS
	36 – 45	2.9	11.1		
	46 – 55	17.6	13.8		
	56 – 65	32.4	22.2		
	> 66	32.4	44.4		
Marital status[1]	Married	52	58	3.98	NS
	Single	32	18		
	Widowed	16	19		
	Divorced	0	5		

[1] Percentage of respondents in each category; 2Number in parenthesis indicates percentage of interviewed farmers.

A household member was defined as an individual sharing an evening meal with the respondents. The average household size in Jixini was five, which was less than that of Mkhwezo whose household size was seven (Table 3.7). There were significant differences ($p<0.05$) between the villages for the number of family members below 15 years (Table 3.7).

In Jixini, the average number of family members below 15 years was 1.50, whereas in Mkhwezo it was 2.53 (Table 3.7). More family members residing at the homestead were in the age groups of 16 - 49 and older than 50.

The proportion of household members actively involved in agriculture for the age group below 15 years was generally low in both villages, with 38% in Jixini and 20% in Mkhwezo (Table 3.7). Respondents cited young age, school attendance and laziness as reasons for them not being involved. Significant differences ($p<0.01$) were observed between the villages in the age group older than 50 years. In Mkhwezo, more family members (87%) from this group were actively involved in farming than in Jixini (58%). Significant differences ($p < 0.05$) were observed between the two villages for years of schooling.

Table 3.7 Household characteristics of farmers interviewed in Jixini and Mkhwezo

Variable	Jixini	Mkhwezo	Aver	X^2	$P_{(0.05)}$
Average household size	5	7	6	11.01	NS
Demographic data per household					
Mean number below 15 yrs[2]	1.50	2.53	2.02*	10.81	NS
Mean number between 16 and 49 yrs	2.70	2.88	2.79	12.82	NS
Mean number above 50 yrs	1.05	1.38	1.22	5.15	NS
Labour data per household[1]					
Mean number below 15 yrs	38	20	29	8.75	NS
Mean number between 16 and 49 yrs	64	62	61	11.35	NS
Mean number above 50 yrs	58	87	68	8.77	*
Number of years in school	8.27	6.08	7.18	8.54	*
Livestock per household unit					
Mean number of cattle	2	5	3	9.52	NS
Mean number of sheep	13	15	14	12.56	NS
Mean number of goats	6	6	6	13.89	NS
Mean number of chickens	9	12	10.5	11.35	NS

[1] Data presented as percentages of family members within each age group who are actively involved in agricultural actives with respect to those living with the respondent; * and ** - significant difference between village, at $p< 0.01$ and $p<0.05$, respectively. [2] years

Farmers in Jixini were more educated (8.27 years) than their counterparts in Mkhwezo (6.08). On average, each family unit kept 14 sheep, 10.5 chickens, 6 goats and 3 cows (Table 3.7).

Farmer categories were constructed by grouping farmers by marital status and gender to produce eight groups of farmers. The first group was that of married male farmers, which constituted 36% of the interviewed farmers (Table 3.8). Twenty percent of the interviewed farmers fell into the second farming group, which was consisted of married female farmers. The third group was made up of single male farmers, and these made up 4% of the farmers who were interviewed. The fourth and fifth group comprised of single (19%) and widowed (16%) female farmers, respectively. Divorced male and female farmers and widowed male farmers had the least percentage of respondents, which were 1%, each. Therefore, results of these groups were not presented since sample size was too small.

Table 3.8 Selected demographic characteristics and livestock units possessed by different farmer groups

Variable	Farmer category				
	Married male (25)[1]	**Married female (14)**	**Single Male (4)**	**Single female (13)**	**Widowed female (11)**
Age [2]	59 (47 - 63)	46 (37 – 53)	42 (32 – 45)	49 (46 – 55)	66 (58 – 72)
Years in school	6.76 (0 – 12)	5.92 (0 – 12)	10.25 (6 – 12)	9.91 (9 – 12)	7.45 (5 - 10)
Household size	7.76 (4 – 14)	6.86 (1 – 9)	4.5 (1 - 9)	5.62 (1 - 9)	5.77 (2 – 9)
Available household labour (%)	59 (10 – 100)	55 (14 – 72)	31 (25 – 37.5)	51 (11 – 100)	65 (30 – 83)
Livestock units	6.08 (0 – 20.9)	4.99 (0 – 12.8)	3.68 (0 – 11.2)	1.62 (0.1 – 5.7)	3.05 (0 – 6.78)

[1] Number in parenthesis indicates percentage of farmers; [2] Numbers in parenthesis indicates range

Widowed females had the oldest (66 years) farmers and this was followed by married male farmers (56 years old). The youngest group (42 years) of farmers was that of single males. Single male and female farmers had the most years in school (10.25 and 9.91 years, respectively) as compared to the other farmer groups. Married male and female farmers had the widest range of years in school (0 – 12 years), which gave an average of 6.76 years for married male and 5.92 years for married female farmers.

Married farmers had the largest household sizes of 7.76 family members for male, and 6.86 for the female group. Available household labour was defined as individuals actively involved in agricultural activities. Forty nine percent of family members living with married male farmers, and 55% of those living with married female farmers were active participants in agricultural production. Household sizes for single female farmers and widowed female farmers were somewhat similar, with 5.62 and 5.77 family members, respectively. However, 65% of household members residing with widowed female farmers and 51% living with single female farmers were active in agriculture. Single male farmers had the smallest household size of 4.5, and even had a smaller percentage (31%) of family members who were actively involved in agriculture. Married male farmers had the most livestock units (6.08 LU), while single female farmers had the least (1.62 LU)

3.3.4 Land characteristics and use by farmers

All the respondents possessed and cultivated home gardens (Table 3.9). Ownership of outfields was based on four different types of tenure, which were; (i) possession of title deeds and Lease agreements, (ii) inheritance, (iii) communal holding, land allocated by chief and/or project manager and, (iv) purchase of land. The majority of respondents (46%) inherited their outfields (Table 3.9). An accumulative percentage of 61% of the farmers were in possession of outfields. Only 44% of these respondents cultivated outfields yearly, while 16.7% indicated that they no longer cultivate.

Some of the reasons cited by respondents why they stopped cultivating outfields were that outfields lacked fencing to keep stray animals out, were located far from the homesteads and, had been repossessed by the chief and/or project.

Table 3.9 Land characteristics and tenure for interviewed farmers from Jixini and Mkhwezo

Variable	Jixini (%)	Mkhwezo (%)	Ave.
Home gardens (HG)	100	100	100
Outfields (OF)			
Own and cultivates yearly	44.4	44.4	44.4
Own but does not cultivate	12	21.4	16.7
Used to own and cultivate	15	6.2	10.6
Never owned	29	28	28.5
Manner of land acquisition			
Purchase	22.5	14	18.3
Lease	6.5	3.5	5.0
Inherited	45	46.5	45.8
Allocated by chief	10	14	12
Allocated by project manager	16	21	19.5
Outfield size			
< 0.5 ha	4.5	11	7.8
0.6 – 2 ha	65	82	73.5
> 2ha	30.5	7	18.8*

*- significant difference between villages at $p<0.05$

Other farmers said that they no longer lived permanently at homestead, had become too old.

Overall, respondents with outfields less than 0.5 ha constituted 7.8%, while those in possession of outfields ranging between 0.6 – 2 ha were 73.5%. Significant differences ($p<0.05$) were observed between the villages for respondents having outfields bigger than 2 ha and these were 30.5% in Jixini, versus 7% in Mkhwezo (Table 3.9).

The study established that most of the land preparation (82.7%) was done using tractors, which farmers hired from other farmers living within the same village (Table 3.10). On average, there were two tractors per village. Across both villages, 4.3% of these farmers indicated that they augmented the use of tractors with animal draught power when ploughing their lands. Results from the investigations also revealed that 11.5% of farmers from both villages only used animal draught and hand hoes to till their lands (Table 3.10).

Table 3.10 Implement used for land preparation, and use of fertilizer and agro-chemicals by interviewed farmers in Jixini and Mkhwezo

Variable	**Jixini (%)**	**Mkhwezo (%)**	**Average**
Land preparation			
Tractor (Tr)	52.9	63.8	58.4
Animal draught (Ad)	11.8	11.1	11.5
Both Tr and Ad	23.5	25	24.3
Hand hoes and picks	11.8	11.1	11.5
Use of fertilizers (HG)			
Basal fertilizer (2:3:2/2:3:4)	50	91	70.5*
Top dressing (urea/LAN/CAN)	24	44	34.0
Farm manure	67	31	49.0*
Use of fertilizers (OF)			
Basal fertilizer (2:3:2/2:3:4)	43.2	36.8	38.5
Top dressing (urea/LAN/CAN)	28.7	34.5	32.1
Farm manure	36.67	0	18.4*
Agro-chemicals			
Insecticides	61.8	61	61.4
Herbicides	0	10	5

*Significant difference between villages at $p<0.05$; LAN – Lime ammonium nitrate; CAN – Calcium ammonium nitrate

Significant differences ($p<0.05$) were observed between the villages for the use of basal fertilizers and farm manure in home gardens, as well as for use of farm manure in outfields. More farmers in Mkhwezo (91%) used basal fertilizers in their home gardens as compared to Jixini (50%). However, the scenario was reversed for farm manure use, with 67% of the farmers in Jixini and 31% in Mkhwezo using farm manure in home gardens.

None of the interviewed farmers applied farm manure in their outfields in Mkhwezo, while 36.67% of the farmers applied it in Jixini (Table 3.10). On average, 34% and 32.1% of the interviewed farmers applied either, Urea, LAN or CAN in home gardens and outfields, respectively, while 38.5% applied basal fertilizers in their outfields (Table 3.10). The predominant agro-chemicals used by 61.4% of farmers who were interviewed were insecticides. Herbicides were only used in Mkhwezo by 10% of the farmers who were interviewed (Table 3.10).

More widowed female farmers (73%) cultivated outfields, and this was followed by 60% of married male farmers and 57% of married female farmer (Table 3.11). The percentage of single farmers cultivating outfields was slightly lower than the other groups with 50% male and 54% females.

Table 3.11 Land characteristics, method of land preparation and yields obtained for different farmer groups

	Farmer categories				
Variable	**Married male**	**Married female**	**Single male**	**Single female**	**Widowed female**
Cultivation of outfield (%)	60	57	50	54	73
Area under maize cultivation (ha)[2]	1.72 (1 – 7)	1.05 (0.5 – 2)	1.5 (1 - 2)	1.65 (1 – 3)	1.25 (1 – 2)
Land preparation	Tr and Ad	Tr	Tr and Hn	Tr	Tr
Yield (t/ha)[2]	0.68 (0.1 – 7)	0.53 (0.2 – 3)	0.4 (0.3 – 1.8)	0.11(0.1 – 1.2)	0.68 (0.1 – 2.5)

Tr – Tractor, Ad – draught animal, Hn – hand hoes; [2] Numbers in parenthesis indicate range.

Married male and single female farmer’s cultivated larger outfields of 1.72 and 1.65 ha, respectively, while married female farmers had the least (1.05 ha) (Table 3.11). The highest yields (0.68 t/ha) were obtained by married male and widowed female farmers.

The lowest yields (0.11 t/ha) were obtained by single female farmers (Table 3.11). The predominant tool for land preparation by female farmers was tractors, while male farmer augmented the use of tractors with animal draught and hand held hoes, respectively.

The majority of married male farmers used basal fertilizer in combination with top dressing fertilizer (40%) and also with farm manure (30%). Five percent of these farmers used only top dressing fertilizer, while 25% of them applied only animal manure in their outfields (Table 3.12).

Table 3.12 Percentage of farmers using different types and combination of fertilizers

Fertilizer type	Farmer category				
	Married male	**Married female**	**Single male**	**Single female**	**Widowed female**
Basal fertiliser (BF)	0	0	0	7	0
Top dressing fertilisers (TD)	5	0	0	0	0
Manure (M)	25	14	50	0	0
BF and TD	40	14	50	7	33
BF and M	30	21	0	0	0

Fourteen percent, each, of married female farmers used animal manure and a combination of basal and top dressing fertilizer. A larger percentage (21%) used animal manure in combination with basal fertilizer (Table 3.12). Fifty percent of single male farmers used a combination of basal and top dressing fertilizer, while 50% of these farmers used only animal manure (Table 3.12). Seven percent of single female farmers used only basal fertilizers, while another 7% used both basal and top dressing fertilizers. The latter fertilizer combination was also used by 33% of widowed female farmers.

3.3.5 Cropping systems

All the respondents in Jixini and 95% in Mkhwezo cultivated maize in their home gardens (Figure 3.2). An average of 45.5% of the respondents indicated that they practiced intercropping with pumpkin, beans or both, while 54.5% did not see the need to intercrop (Figure 3.2).

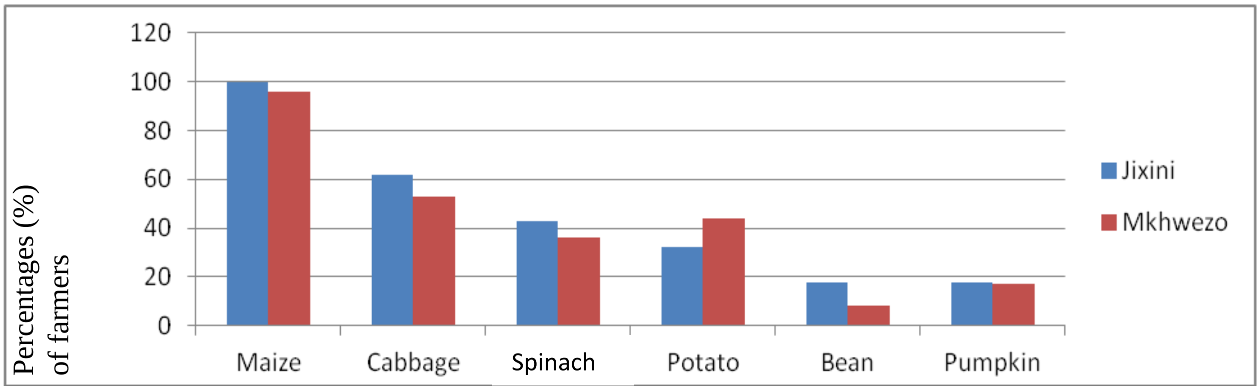

Figure 3.2 Distribution of interviewed farmers according to crops grown in Jixini and Mkhwezo

Respondents cultivating outfields only grew maize. Therefore, maize was the most important crop based on frequency of farmers producing it. Other crops grown by both villages included cabbage, spinach, potatoes, pumpkins and carrots (Figure 3.2).

In Jixini, land preparation for maize began in August right through to January, and planting started from October to January in both outfields and home gardens. The peak month for tillage operations and maize planting was November as shown in Figure 3.3.

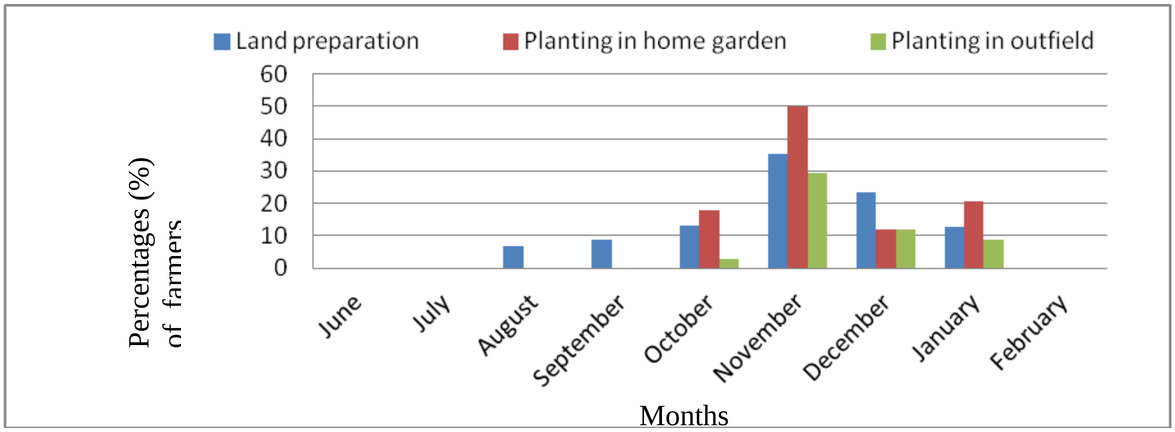

Figure 3.3 Distribution of respondents from Jixini according to month of land preparation and planting of home gardens and outfields

Land preparation in Mkhwezo also began in August but this stretched right through to February, after harvest of early planted maize (Figure 3.4). Similarly, the peak period for land preparation and planting was November. However, planting in both outfields and home gardens was done from October to December.

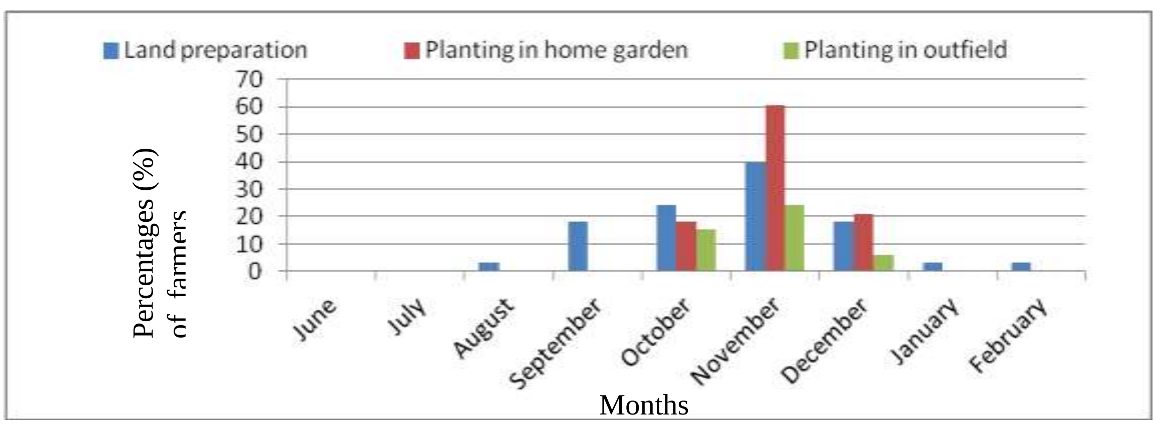

Figure 3.4 Distribution of respondents from Mkhwezo according to month of land preparation and planting of home gardens and outfields

3.3.5.1 Maize varieties grown by farmers

There were no significant differences in type of varieties used by farmers between the villages. The predominant varieties used were local landraces (53%) followed by hybrids (31%) and improved OPVs (11%) (Figure 3.5).

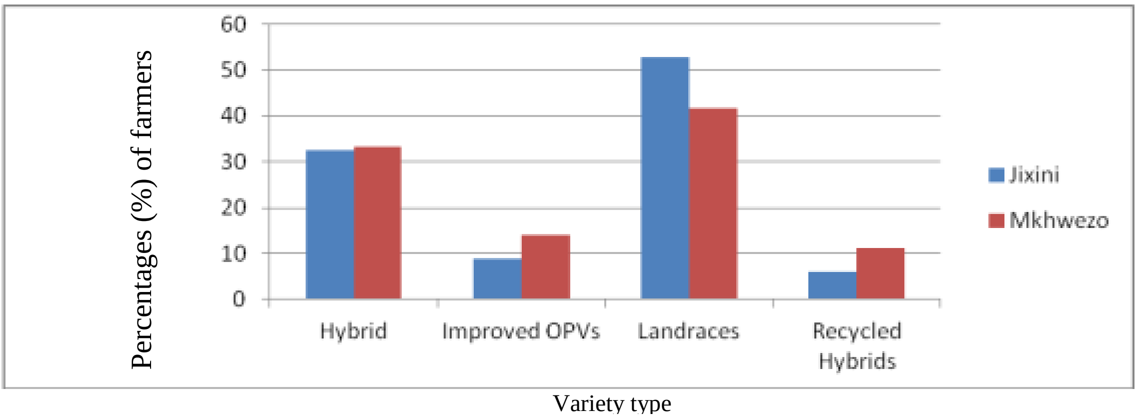

Figure 3.5 Percentage of farmers growing different types of maize varieties in Jixini and Mkhwezo

Seventy four percent of male married farmers used hybrid seed, while 16% and 10% used OPV and local landrace, respectively (Table 3.13).

Table 3.13 Types maize varieties grown in outfields for the different groups of farmers (%)

	Farmer category				
Type of variety	**Married male**	**Married female**	**Single Male**	**Single female**	**Widowed female**
Hybrid seed[1]	74	100	100	72	75
Open pollinated varieties	16	0	0	14	17
Local landrace	10	0	0	14	8
Knowing variety name	10	4	0	0	0

[1]Percentage of farmers within each group.

Seventy two percent of single female farmers used hybrid seed, while 14% used either OPVs or landrace (Table 3.13). Seventy five percent of widowed female farmers used hybrid seed, while 17% and 8%, of these farmers used OPVs and landrace varieties, respectively (Table 3.13).

Most married male farmers (50%) used hybrid seed in their home gardens, while fewer farmers in this group used local landrace varieties (36%) and OPVs (14%). On the other hand, 84% of married female farmers used local landraces, while hybrid or open pollinated varieties were used by 8% each, of these farmers (Table 3.14).

Table 3.14 Types maize varieties grown in home garden for the different groups of farmers (%)

	Farmer category				
Variety type	**Married male**	**Married female**	**Single Male**	**Single female**	**Widowed female**
Hybrid seed[1]	50	8	50	17	28
Open pollinated varieties	14	8	0	0	18
Local landrace	36	84	50	83	18
Recycled hybrid	0	0	0	0	36
Knowing variety name	10	7	2	0	0

[1] Percentage of farmers within each group.

Ten percentage and 4% of male and female married farmers, respectively, were aware of the names of varieties that they were using. The majority of single female farmers (83%) used local landrace, while a smaller proportion (17%) used hybrids in their home gardens. However, more widowed female farmers used recycled hybrid seed, followed by hybrid seed, and OPV and local landrace varieties (Table 3.14). A small proportion of married (both, male and female) and single male farmers were aware of the varieties they were using (Table 3.14).

An accumulative percentage of 82% of the farmers obtained yields less than 1 t/ha (Appendix 4), whereas yields above 1.6t/ha were obtained by only 3% of the interviewed farmers. Higher yields were obtained by farmers growing hybrid seed followed by improved OPVs, while lower yields were obtained by farmers growing landraces and recycled hybrids.

Farmers growing local landrace varieties indicated that seed of these varieties were cheaper, grain was more palatable, had a high kernel row number, were nutritious, retainable and adapted to their environment. However, farmers growing hybrids and improved OPVs indicated that these varieties produce high yields and are more marketable than local landraces.

Table 3.15 shows some of the maize varieties that are grown in the two villages, based on results from the informal survey. Nine out of thirteen varieties were yellow seeded and these were mainly grown in Jixini. Sahara, an improved OPV, was the only variety that was reported to be in use by both villages, with 76% of the participating farmers growing it. According to these farmers, Sahara was drought tolerant, adaptable to their environment, high yielding, and it is of multipurpose usage. However, like all the OPVs listed, Sahara was late maturing and had a tendency to lodge. Furthermore, OPVs currently being grown by farmers were reported as having a high fertilizer requirement, and seed was generally unavailable for purchase.

Table 3.15 Description of maize varieties grown, and distribution of farmers growing them in Jixini and Mkhwezo

Variety name	**Type**	**Seed colour**	**Jixini (18)**[1]	**Mkhwezo (23)**	**Total (%)**[2]
Sahara	OPV	Yellow	18	13	31 (76)
Silver king	OPV	White	-	5	5 (12)
Nelson's choice	OPV	White	-	6	6 (15)
Ungoyi	Landrace	Yellow	18	-	18 (44)
German yellow	Landrace	Yellow	18	-	18 (44)
Gastyeketye	Landrace	Various	10	-	10 (24)
Gambushe	Landrace	Various	10	-	10 (24)
PAN 6146	Hybrid	Yellow	-	13	13 (31)
PAN 6166	Hybrid	Yellow	-	10	10 (24)
PAN 6480	Hybrid	Yellow	8	18	26 (63)
PAN 6466	Hybrid	Yellow	8	13	21 (51)
PAN 6777	Hybrid	White	8	-	8 (20)
PAN 6966	Hybrid	Yellow	-	23	23 (56)

[1] Value in parenthesis indicates farmers, per village, who participated in the FGD; [2] Values in parenthesis indicates percentage of farmers who participated in the FGD; – indicates that farmers were not growing that variety

Contrary to the formal survey, results of informal surveys indicated that the production and use of traditional landraces was localized in Jixini, and they were grown by 23% of the participants.

3.3.5.2 Uses of maize

There were significant differences ($p<0.05$) for the use of maize by gender across the villages (Table 3.16). Generally, more female respondents used maize for household consumption, while more men used maize to feed livestock. A small percentage of the farmers sold their maize produce and this was within the village and in the district capital, Mthatha.

Table 3.16 Use of maize by gender, across Jixini and Mkhwezo

Use	Male (%)	Female (%)	Average
Household consumption	52[1]	68	60.0**
Feeding livestock	59	48	53.5
Sale	14	8	11.0

[1] Indicates percentage of interviewed farmers; ** indicates significant differences between gender for maize use at $p<0.01$

3.3.6 Farmers' selection criteria

Selection criteria used by farmers in both villages and the importance of criteria were different (Table 3.17). There was a highly significant difference ($p<0.01$) between the villages for farmers selecting varieties according to their ability to be retained (Table 3.17). More farmers in Jixini (26.5%) selected varieties based on their ability to be retained as compared to 5.6% in Mkhwezo. A higher percentage of farmers in Jixini (11.8%) selected varieties based on their adaptability to local environment as compared to Mkhwezo (8.33%). Farmers in Mkhwezo (15.62%) used prolificacy as selection criterion while farmers in Jixini did not (Table 3.17).

The overall importance of a selection criterion was computed based on the accumulative frequency of farmers mentioning it as being important across the two villages. Overall, the selection criteria, in order of their importance, were taste (36.5%), long cobs (33.75%), big leaves (17.25%), retainable seed (16.05%) and big kernels (15.7%).

Table 3.17 Farmers' ranking of traits used in selecting varieties

Source	Jixini	Mkhwezo	Mean
Big leaves	23.4 (2)[1]	11.1	17.25 (3)
Long cob	14.7 (5)	52.8 (2)	33.75 (2)
Big kernels	14.7 (5)	16.7 (4)	15.7 (5)
Medium kernels	0	5.5	2.75
Upright leaves	8.8	5.5	7.15
Yellow maize	0	11.1	5.65
Retainable seed	26.5 (1)	5.6	16.05 (4)**
Dark green leaves	5.8	25.0 (3)	15.40
Soft kernels	2.9	0	1.45
Lodging resistance	13.8	0	2.9
Brace roots	20.6 (3)	2.7	11.65
Taste	17.6 (4)	55.5 (1)	36.55 (1)
Drought tolerance	5.8	13.9 (5)	9.85
Tolerance to heavy rains	2.94	0	1.47
Matures early	14.7 (5)	8.33	11.50
High yield	8.82	8.33	8.56
Thick stems	14.7 (5)	2.82	8.76
Many kernel rows	0	8.33	4.17
Resistant to cob rots	2.9	5.62	4.26
Good husk cover	5.8	2.83	4.32
Adaptable to our environment	11.8	8.33	10.07
Prolific	0	15.62	7.81*

[1] Number in parenthesis represents overall rank position; *, ** - significant difference between village, at $p < 0.01$ and $p<0.05$, respectively; Bartlett's $X^2 = 20.0$, Degrees of Freedom (n-1) = 14; P = 0.130 ns

In Jixini, the top five important traits used in variety selection, in order of their importance, were retainable seed (26.5%), big leaf size (23.4%), presence of brace roots (20.6%), taste (17.6%), while big cobs (14.7%), big kernels (14.7%), early maturity (14.7%) and thick stems (14.7%) were all tied at fifth place (Table 3.17). In Mkhwezo, the top five traits mentioned were, taste (55.5%), long cobs (52.8%), dark green leaf colour (25.0%), big kernels (16.7%) and drought tolerance (13.9%) (Table 3.17).

3.3.7 Farmers' production constraints

Constraints faced by farmers during maize production in both villages were significantly different ($p<0.001$) from each other according to Bartlett's chi-squared test for homogeneity of variance (Table 3.18). Similar to selection criteria, the overall importance of a constraint was computed based on the accumulative frequency of farmers mentioning it as being important. Overall, too much rain was ranked first, with 36.1% of the respondents mentioning it as a constraint (Table 3.18). Occurrence of pests and diseases (30.07%), drought (28.8%), climate change (17.04%) and lack of fencing (15.36%) were ranked second, third, fourth and fifth, respectively.

In Jixini, too much rain (50%) was ranked first, followed by the occurrence of drought (32.4%). A high incidence of pests and diseases (26.8%) was ranked third, while attacks by birds, high fertilizer prices, climate change and weed infestation were all tied at fourth position (11.8%, each) (Table 3.18).

In Mkhwezo, a high incidence of pests and diseases (33.3%) was ranked first. Lack of fencing (27.8%) and occurrence of drought (25.2%) were ranked second and third, respectively. Too much rain and climate change was each ranked fourth (22.2% each) (Table 3.18). In contrast to the informal survey, FGD revealed that important constraints affecting both villages, in terms of the most to the least important, were lack of tillage equipment, high fertilizer prices, and high herbicide and insecticide prices (Appendix 9).

Table 3.18 Farmers perceptions and ranking of constraints to maize production

Source	Jixini	Mkhwezo	Mean
Too much rain	50.0 (1)[1]	22.2(4)	36.1 (1)
Storage pests	2.9	0	1.45
Storage facilities	8.8	11	9.95
Birds	11.8 (4)	8.3	10.05
Pests and diseases	26.8 (3)	33.3(1)	30.07 (2)
Drought	32.4 (2)	25.2(3)	28.8 (3)
High fertilizer price	11.8 (4)	8.3	10.07
Unavailable tractor	5.8	5.6	5.7
High tractor fees	0	11.1	5.55
High seed prices	5.8	11.1	8.45
High chemical prices	0	8.3	4.15
Inadequate land	5.8	0	2.9
Undesirable varieties	2.9	0	1.45
Cob rots	8.95	2.7	5.82
Climate change	11.8 (4)	22.2(4)	17.04 (4)
Lack of fencing	2.9	27.8(2)	15.36 (5)
Untimely operation	5.8	5.6	5.7
Weed infestations	11.8 (4)	2.7	7.27
Labour shortages	0	8.3	4.15
Low credit access	2.9	16.7	9.82
Strong winds	5.8	0	2.9
Poor production skills	2.9	2.7	2.8
Poor soil fertility	0	2.7	1.35

[1] Number in parenthesis represents overall rank position of constraint in each site; Bartlett's $X^2 = 79.3$, Degrees of Freedom (n-1) = 14 P = 0.001.

3.4 Discussion

The PVS methodology allowed farmers to select preferred varieties, objectively, from a range of local and newly introduced stress tolerant maize varieties. Selection of varieties by farmers in each village was observed to be different, but was consistent with high performing varieties according to agronomic yield data for each village. This could have been due to environmental effects on variety response, which caused some varieties to be more desirable to farmers in one village than the other, and vice versa. These results agree with Courtois *et al*. (2001) and suggest the presence of genotype and environment interaction effects on variety performance.

The observed field-based criteria used in the selection of varieties during PVS were somewhat similar for both villages. This could be because farmers have a tendency of rating varieties based on particular traits that they themselves want to see in their field (Louette and Smale, 2000). Use of the observed field-based criteria for breeding purposes could, however, be misleading. Results showed that, even if a variety had most of the desired traits mentioned by farmers, the presence of undesirable traits had a mixed effect on variety ranking. For example, Okavango, a variety chosen due to its yellow grain colour, was observed to have the highest number of undesirable traits, such as, a low kernel row number, poor grain filling and poor husk cover. In Jixini, it ranked first, while it ranked third in Mkhwezo. This would suggest that farmers in Jixini were not willing to trade-off other preferred traits (seed colour) because the variety possessed undesirable traits. Farmers in Mkhwezo were able to forgo Okavango for those that had more important traits like ZM 305. On the other hand, Okavango's selection and yield performance in both villages could also be an indication of its wide adaptation. The findings also suggested that differences in farmer characteristics and perceptions could have had a bearing on variety selection.

The observations that the white varieties selected by farmers would have been more desirable if they were yellow could affect potential adoption of these new varieties. This could also be supported by the observed large number of yellow varieties currently being grown by farmers who were interviewed. These results are consistent with those obtained in Limpopo, where the majority of smallholder farmers are growing yellow maize (Khumalo, 2007). It was observed that all farmers kept livestock. Maize was used for livestock feed and household consumption in both villages. Yellow maize is believed to have a high nutrient content than white maize (De Groote, 2008). According to Mapiye *et al*. (2009), most grazing fields in the province are eroded and poor in quality. Farmers, therefore, use yellow maize as a supplement. The introduction of QPM maize like Obatanpa could also play an important role in supplying the much needed nutrients to livestock.

The observation that the majority of farmers interviewed were old (above 60 years, which is the retirement age in South Africa), and could be regarded as inactive to pursue economic activities could be due to the lack of involvement of younger generations in maize production. These findings are consistent with those obtained by Musemwa *et al*. (2008) who reported that aging farmers dominate the Eastern Capes' agricultural sector. Age has a negative impact on the achievement of sustainable agriculture for smallholder farmers (Odoemenem and Adebisi, 2011). Young farmers are reported to be more responsive to new ideas and practices, while older farmers are more conservative, and less responsive to the adoption of new ideas and practices (Amaza *et al*., 2007). Although farmers were generally old, they were moderately educated having attained at least primary level education. According to Alam (2010), education enables a farmer to appreciate the advantages of new technologies. Therefore, in this regards, new varieties could be adopted by these aging farmers with little resistance. However, more should be done by the government and the private sector to encourage the involvement of youths in agriculture as they are the future farmers.

It was established that farmers used two maize based cropping systems, which were inter-cropping and mono-cropping. These findings agree with the cropping systems described by Bryndum *et al*. (2007) for farmers in Pepela village in the ORTDM. It was observed that, within these cropping systems, farmers obtained low maize yields in both outfields and home gardens. These results are also consistent with several reports on maize productivity in the EC province (MEDTP, 2010). The observed low yields in outfields could be due to farmers using inadequate amounts of fertilizers for hybrid varieties which require high input levels for them to their yield potential. Furthermore, some farmers were using landraces that are known to succumb to contamination from neighboring maize field, which could result in them losing their high yielding ability (Pixley and Banziger, 2001). An increase in the involvement of household members in agricultural activities was associated with an increase in maize productivity across farmer groups. These results could be attributed to the involvement of unemployed economically active household member (Okoye *et al*., 2008). Therefore, increasing the involvement of young adults in maize production could result in improved productivity.

On the other hand, low grain yields observed in home gardens could be attributed to the reduction of cob numbers due to respondents harvesting green mealies for household consumption. This suggests that observed yields would have been higher in home gardens than outfields if maize was grown solely for grain. Furthermore, it was observed that more farmers in the study used organic and inorganic fertilizers in home gardens than outfields. Mandiringana *et al*. (2005) observed high fertility levels in home gardens than outfields. Farmers were inclined at investing more inputs in home gardens due to improved security of crops grown next to the homestead. The use of cheap, improved stress tolerant OPVs is, therefore, more beneficial to female farmers who used lower levels of inputs since these OPVs exhibit better yield stability in low soil fertility soils when compared with hybrid varieties. Furthermore, since Banziger *et al*. (2005) observed that OPV yield better than landrace varieties, yield improvements could create an incentive for farmers to invest more in fertilizers.

Although farmers were aware of the benefits of using hybrid seed, the majority of them preferred to grow local landrace varieties. This could be explained by the large number of disadvantages that hybrid varieties possess as opposed to local landraces. Furthermore, farmers required the use of retainable seed as a trait used in variety selection. Ntare *et al*. (2007) reported that farmers reject better performing varieties if they do not possess desired traits.

It was observed that during the formal survey, most farmers were unable to state names of varieties they were using. It could be postulated that farmers' interactions within FGDs enabled them to brainstorm variety names, while key informants gave the necessary information, to add on to, and validate findings of the informal survey (Rabiee, 2004).

The observed constraints affecting maize production in the study were infrastructural, financial, biotic and abiotic (Fanadzo *et al*., 2010). Not all the constraints that ranked highly in the FGDs conducted in the 2009/10 season were considered important by farmers interviewed during the 2010/11 season. During the FGDs, more emphasis was placed on high cost of production operations, while results on farmer interviews emphasized biotic and abiotic stress factors. Focus group discussions revealed that a major constraint was the lack of tillage equipment. Key informants, however, highlighted that the real problem was the few service contractors and tractors available in each village. These results agree with Israel *et al*. (1999) and Bryndum *et al*. (2007) who also observed few tillage contractors in selected villages of the EC. Furthermore, these observations were substantiated by findings from the household survey, where there were two tractors per village, on average.

Though, heavy rains were mentioned in Mkhwezo, farmers put more emphasis on the occurrence of drought as a production constraint. According to Bothma (2004), rainfall received in many areas of the EC is strongly influenced by the relative distance from the sea. Amount and distribution of rainfall received becomes sporadic as distance from the sea increases. The high ranking of occurrence of drought in Mkhwezo was, therefore, expected. This could also explain why farmers in Jixini mentioned occurrence of floods as a constraint and desired more adaptive traits for heavy rains in their selection criteria such as varieties with brace roots, thick stems and tolerant to heavy rains. However, farmers in Jixini indicated that varieties that matured early were important. This could be due to the long mid season droughts that normally occur during flowering, throughout the

EC (Bothma, 2004). Therefore, the use of varieties that have been screened for biotic and abiotic stresses like these newly introduced OPVs could help lessen the impacts of unpredictable and extreme weather phenomena.

The observed selection criteria had a combination of yield component (rows per ear, kernel size and cob length) and adaptive traits. This was chiefly in response to prevailing agro-ecological conditions. Some traits were observed to be site specific. The high ranking of dark green leaves observed in Mkhwezo could be explained by the poor inherent soil fertility status of most sandy loam soils as compared to the clay soils found in Jixini, where such a trait was not mentioned at all. Furthermore, sandy loam soils are prone to leaching of nutrients when there is too much rain. The heavy rains experienced during the 2010/2011 season suggest that any amount of fertilizers added to the soil could have been leached away, resulting in pale green leaves. Therefore, farmers desire to have varieties with dark green leaves equates to having varieties that are tolerant to low soil fertility. The new introductions from CIMMYT and IITA were specifically screened for tolerance to low soil N (Magorokosho, 2008). This would suggest that their use can increase maize productivity in Mkhwezo. Farmers would still need to use good soil management practice to improve soil fertility.

The findings showed that maize had multiple uses which also included household consumption. Variety palatability (taste of a variety) was ranked highly by farmers during household surveys. The high ranking of taste agrees with Louette and Smale (2000) who identified taste as an important trait that is used to select maize varieties by resource poor farmers in Mexico. However, farmers were not given the opportunity to do organoleptic tests. Odendo *et al*. (2001) suggests that the improvement of rural livelihoods could be achieved if high yielding varieties, which possess desired traits, were selected and adopted by farmers. The organoleptic tests in the current study could have substantially changed the observed rankings of varieties.

3.5 Conclusions

Farmers' selections were different across the two villages. Varieties selected in Jixini were Okavango, ZM 621, ZM 501, ZM 305 and ZM 423, while ZM 305, Nelson's choice, Okavango, ZM 501 and Afric 1were selected in Mkhwezo. The most preferred variety was not statistically different from the highest yielding variety when agronomic yield data was considered. Maize productivity was different across different farming groups. Married farmers and widowed female farmers obtained higher yields when compared with single farmers as they had more resources available to them.

The most important farmer selection criteria and production constraints were different across the two villages. Differences in agro-ecological characteristics had an important effect on most differences observed in the study. Overall, the most important criteria, in order of their importance, were taste, long cobs, big leaves, retainable seed and big kernels. The most important constraints, in order of their importance, were too much rain, occurrence of pests and diseases, drought, climate change and lack of fencing.

Acceptable and adaptable varieties should be recommended to specific environments. Although the study demonstrated a number of constraints affecting maize production, the use of a single variety cannot mitigate against them all. It is recommended that, varieties tolerant to the most common stress factors should be used, and farmers should practice good crop husbandry to minimize the effects of other stress factors.

4. GENOTYPE-ENVIRONMENT INTERACTIONS FOR GRAIN YIELD OF OPEN POLLINATED MAIZE (*ZEA MAYS* L.) IN THE EASTERN CAPE PROVINCE OF SOUTH AFRICA

Abstract

Maize production in the Eastern Cape (EC) Province is characterized by low yields due to variation in climatic conditions, poor access to capital and numerous abiotic and biotic constraints. This has necessitated a shift from the use of hybrid seed to improved, stress tolerant Open Pollinated Varieties (OPVs) for sustainability. Before farmers can adopt OPVs, suitable varieties should be recommended. However, existence of Genotype by Environment Interactions (GEI) makes variety recommendations difficult. The objective of the study was to determine the yield performance and to assess the stability of maize varieties in selected environments of the EC province. Thirteen maize genotypes were evaluated during the 2009/10 and 2010/11seasons across eight sites. Genotypes evaluated included stress-tolerant OPVs, ZM 305, ZM 423 ZM 501, ZM 525, ZM 621, ZM 627 and Obatanpa from the International Maize and Wheat Improvement Center (CIMMYT), and BR 993 and Comp 4 from the International Institute of Tropical Agriculture (IITA). Locally grown check genotypes which comprised of a hybrid (Pan 6479) and three local OPVs (Okavango, Afric 1 and Nelson's Choice) were also included. Sites were Kieskammahoek, Mkhwezo, Burnshil, Gogozayo, Lenye, University of Fort Hare, Jixini, and Mqekezweni. These sites were purposely selected to differ in total annual rainfall, soil characteristics and altitude. All trials were set up in a randomized complete block design (RCBD), replicated thrice. Analysis of variance (ANOVA) for each site and a combined ANOVA across sites for grain yield data was done, followed by additive mean effects and multiplicative interaction (AMMI) analysis using GENSTAT 4.2 for Windows. Varietal and environment stability was determined by calculating AMMI stability values (ASV) for each variety and environment. Significant differences ($p<0.001$) where found for genotype (G), environment (E), season (S) main effects and S x E interaction, while G x E, S x G and G x E x S showed non-significant interaction. Although GEI was non-significant, varieties showed both crossover and non-crossover interaction. According to AMMI and ASV, Pan 6479 and ZM 525 (the best performing genotypes) showed high interactive responses to high potential environments, while BR993, Obatanpa and Afric 1 (least performing genotypes) showed high interactive responses to low potential environments. Okavango was the most stable variety, but yielded (4.28 t/ha) below the grand mean (4.45 t/ha). Varieties ZM 627, ZM 501, ZM 423 and ZM 305 had mean yields above the grand mean (4.46 – 4.67 t/ha), and were also stable across the environments. Therefore, varieties showed specific and wide adaptations to the environments. ZM 627, ZM 501, ZM 423 and ZM 305 can be recommended to several environments in the EC. ZM 525 should be recommended to resource-poor farmers in high potential environments, while Okavango was more suited

to environments with low yielding potentials, since improvement of environmental conditions did not improve its yield.

Keywords Additive mean multiplicative interaction (AMMI) model, AMMI stability values (ASV), genotype by environment interactions (GEI), open pollinated varieties (OPV), Stability,

4.1 Introduction

Maize is an integral component of most cropping systems practiced by resource-poor farmers in the EC as illustrated in section 3.4.3. The differential ranking of maize varieties during the agronomic yield trials in two contrasting environments in chapter 3 has suggested the presence of GEI. Therefore, much attention has to be given to determine the effect of GEI on variety stability, since it is known to affect variety performance in different target environments (Asfaw *et al*., 2009). Furthermore, it becomes essential to establish the pattern of yield response of any variety in diverse environments before they can be recommended to possible adopters.

According to Kang *et al.* (2004), a variety could either display broad adaptation and good yield stability (low GEI) or specific adaptation and high yielding potential in selected environments (large GEI). This implies that, if a range of varieties is to be tested in contrasting environments, high yielding varieties showing wide or specific adaptations can be identified. Therefore, to recommend appropriate varieties to resource-poor farmers living in diverse agro-ecologies, it is critical that the type and contribution of GEI is also understood. The AMMI model is effective in interpreting GEI, as well as increasing the precision of making variety recommendations to different target environments (Kang *et al.,* 2004). Therefore, this study sought to evaluate yield stability of newly introduced, stress tolerant maize OPVs in selected environments of the EC.

The specific objectives of this study were to: -

1. Determine the yield performance and stability of 13 maize varieties grown over two seasons in selected environments of the EC.
2. Identify the best test environment for evaluating maize varieties from selected environments in the EC.

The null hypotheses that were tested were: -

1. The yield performance and stability of 13 maize varieties do not differ from each other when evaluated over two seasons and across selected environments in the EC.
2. Environments' ability to discriminate among varieties does not differ in selected environments of the EC.

4.2 Materials and methods

4.2.1 Site selection and description

The study was conducted in two consecutive seasons, 2009/10 and 2010/11, in eight selected environments of the EC. Site names and codes are described in Tables 4.1 and 4.2. Environments were defined as site by season combination (Table 4.1). The sites were purposefully selected according to their heterogeneity, in terms of geographic location, altitude, soil characteristics and rainfall (Tables 4.2 and 4.3).

Table 4.1 Code names of environments (site in each season).

Code	2009/2010 season	**Code**	2010/11 season
E1	UFH	**E2**	UFH
E3	Burnshil	**E4**	Burnshil
E5	Lenye	**E6**	Lenye
E7	Mqekezweni	**E8**	Mqekezweni
E9	Mkhwezo	**E10**	Mkhwezo
E11	Jixini	**E12**	Jixini
E13	Gogozayo	**E14**	Gogozayo
E15	Keiskammahoek	**E16**	Keiskammahoek

4.2.2 Treatments and experimental design

All 13 varieties listed in section 3.2.3 were included in this evaluation. The trial was laid out as a RCBD replicated three times at each location described in section 4.2.1. Details of the experimental design for each site are as outlined in section 3.2.3.

4.2.3 Non-experimental variables

Trial management, which included fertilizer application, and control of weeds and insect pests were done as described in section 3.2.3

Table 4.2 Experimental Site description based on Geo-climatic data

	Site	Site code	Latitude	Longitude	Altitude (m)	Annual average rainfall[1] (mm)	STD[2] (mm)	Total precipitation (mm)	
								2009/10	2010/11
1	University of Fort Hare	UFH	32^{0}47’S	26^{0}50’E	503	523.7	109.9	627.7 (284)[3]	658 (90)
2	Burnshil	BURN	32^{0}45’S	27^{0}03’E	525	673.2	134.9	563 (256)	583 (35)
3	Lenye	LENY	32^{0}45’S	27^{0}03’E	528	673.2	134.9	528.7 (285)	789 (157)
4	Mqekezweni	MQEK	31^{0}42’S	28^{0}30’E	986	882.1	163.9	-	946
5	Mkhwezo	MKHE	31^{0}42’S	28^{0}30’E	842	882.1	163.9	-	996
6	Gogozayo	GOGO	31^{0}51’S	28^{0}44’E	1089	829.3	158.4	-	1656
7	Jixini	JIXI	31^{0}43’S	28^{0}50’E	643	918.7	174.1	-	832
8	Keiskammahoek	KK	32^{0}40’S	26^{0}8’E	459	481.4	107.1	401 (228)	638 (128)

[1]Annual averages and [2]STD Standard deviations quoted from South Africa’s’ rainfall atlas (2011); 3 Numbers in parenthesis indicate amount of water applied through irrigation in respective environments.

Table 4.3 Soil characterization of sites included in the study

Site name	S.A. system[1]	FAO system[2]	Soil texture	Soil colour	$pH_{(KCL)}$	So.C (%)	N (%)	P (g/kg)	K (g/kg)	Ca (g/kg)
UFH	Oakleaf	Luvisols	Sandy clay loam	Dark reddish brown	5.43	<0.5	0.08	67	175	1461
BURN	Valsriver	Lixisols	Clay loam	Black	5.37	<0.5	0.07	36	296	1066
LENYE	Oakleaf	Luvisols	Sandy clay loam	Black	5.49	<0.5	0.07	25	306	1750
MQEKE	Hutton	Lixisols	Sandy clay loam	Dark reddish brown	4.45	1.8	0.09	24	93	254
MKHEW	Hutton	Acrisols	Sandy clay loam	Dark reddish brown	4.39	<0.5	0.07	25	306	1750
GOGO	Valsriver	Lixisols	Sandy clay loam	Dark brown	5.24	<0.5	0.15	19	326	1476
JIXIN	Oakleaf	Luvisols	Sandy clay loam	Dark grayish brown	5.52	0.9	0.13	8	65	491
KK	Valsriver	Lixisols	Sandy clay loam	Grayish brown	4.87	<0.5	0.09	50	107	866

[1] South African soil classification system; [2] World Reference base soil classification systems. So.C – Soil Organic Matter. N – Nitrogen; K – Potassium; P – Phosphorus; Ca - Calcium

4.2.4 Statistical analyses

All statistical analysis for grain yield was performed using GenStat Statistical Software, version 4.2 (GenStat®, 2002). An initial ANOVA for each of the 16 sites was performed on grain yield data for each Genotype (G), expressed in t/ha. Yield data of genotypes were considered different at a significance level of 5%. Duncan's multiple range test (DMRT) was used to separate genotype means, and all means that were significantly different at $p < 0.05$ (Gomez and Gomez, 1984). The Bartlett's test (Gomez and Gomez, 1984) was then done to determine homogeneity of variances for grain yield before combining data of all sites across the seasons. This test showed homogeneity of variances for yield across both sites and seasons, allowing combined analysis to be done for grain yield. A combined ANOVA across sites and season was then conducted to estimate differences between the main effects G, E and S, and their interactions, on grain yields. The overall, G X E X S ANOVA was designed as three-way ANOVA, holding G as a fixed factor, while S and E were held as a random factor (Annicchiarico *et al*., 2002).

To explain the interaction between G and E, data on grain yield was then subjected to AMMI analysis (Zobel, 1988). The AMMI model equation (Gabriel, 1978) that was used is as follows:

$$Y_{ge} = \mu + \alpha_g + \beta_e + \Sigma_n \lambda_n \tau_{gn} \rho_{en} + \varepsilon_{ge}$$

where:

Y_{ge} = Observation of genotype *g* in environment *e*

μ = Overall mean

α_g = Mean genotypic deviation

β_e = Mean environmental variation

λ_n = Eigen value of the *n* axis in principal components analysis (PCA)

τ_{gn}, ρ_{en} = Genotypic and environmental unit vectors associated with λn

ε_{ge} = Random variable corresponding to the experimental error

Results of the analysis by the AMMI model were interpreted on the basis of two AMMI biplot graphs as follows:

(a) A graph that showed the main and first multiplicative term (IPCA 1) of genotype and environments (AMMI 1 biplot).

(b) A biplot that plotted IPCA1 against IPCA 2 scores of environments and genotypes (AMMI 2 biplot).

According to Ma'ali *et al*. (2010), genotypes falling within IPCA values of 1 and -1 are considered stable, while those falling outside these limits were specifically adapted to either low or high potential environments.

4.2.4.1 AMMI Stability Value (ASV)

Postulated by Purchase (1997), the ASV is the distance from the point of origin in the IPCA 1 vs IPCA 2 biplot. Since IPCA 1 contributed more to the GEI Sum of Squares (SS), a weight value was calculated according to the relative contribution of IPCA 1 and IPCA 2 to the interaction SS (Leeuvner *et al.*, 2005; Bantayehu, 2009). This weighted value is referred to as ASV, and was calculated as follows for genotypes (ASV_G), and environments (ASV_E).

$$AVS_G = ((IPCA1SS/IPCA2SS)*GIPCA1^2) + (GIPCA2^2))^{-1/2}$$

$$AVS_E = ((IPCA1SS/IPCA2SS)*EIPCA1^2) + (EIPCA2^2))^{-1/2}$$

4.2.4.2 Cluster analysis (CA)

Cluster analysis was used to group genotypes and environments based on yield (t/ha), IPCA 1, IPCA2 and ASV. This was done using the unweighted pair group method arithmetic average (UPGMA) technique (Wieslaw *et al*., 2011). Dendrograms were plotted to illustrate clustering of homogenous groups of genotypes and environments.

4.3 Results

4.3.1 Grain yields for the 2009/10 and 2010/11 season

Combined ANOVA for grain yield of the 13 genotypes evaluated across eight environments during the 2009/10 and 2010/11 summer season showed highly significant differences ($p<0.001$) for genotype (G), environment (E), season (S) main effects and S x E interaction, while G x E, S x G and G x E x S showed non-significant interaction (Appendix 10).

Overall, the highest yielding varieties were Pan 6479 (5.29 t/ha) and ZM 525 (4.87 t/ha), which ranked first and second, respectively. Grain yield of these genotypes were not significantly different from each other (Table 4.4). The lowest yielding varieties were Obatanpa (4.075 t/ha) and BR 993 (4.074 t/ha), and these also did not show any significant differences from each other. Though, GEI and GES interaction were statistically non-significant, genotypes performed somewhat differently across the environments. Pan 6479 was ranked first in UFH 1, UFH 2, Lenye 1, Burnshil 1, Mqekezweni 2, Jixini 1, Jixini 2, Gogozayo 1, Gogozayo 2, KK 1 and KK 2 while, it ranked lowly in Burnshil 2, Lenye 2 and Mqekezweni 1. ZM 525 was ranked first in Mqekezweni 1.

Yield advantages of the hybrid variety, Pan 6479, varied across environments, and also varied across the different OPVs that were tested (Appendix 15). Overall, Pan 6479 had the highest yield advantage in UFH 2 (40.30%), while it was out performed in Mkhwezo 2 by 18.59% (-18.59%) (Appendix 15). When comparing the varieties, Pan 6479 had the highest overall yield advantage (22.98%) over BR 993, while it had the least advantage (7.78%) over ZM 525.

Table 4.4 Grain means yields for varieties tested across 8 environments grown during 2009/10 and 2010/11 season

VARIETY	CODE	Environments[3]																AV.	RANK
		E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	YIELD	
ZM 305	G1	4.22	3.62	2.94	2.46	4.32	5.58	7.92	6.79	3.50	3.20	5.03	4.68	3.33	5.28	2.54	5.30	4.46 ab[1]	6
ZM 423	G2	4.25	3.87	2.15	2.75	5.26	6.56	7.73	6.39	2.88	4.15	5.81	5.11	4.01	4.03	2.03	6.69	4.60 bc	4
ZM 501	G3	4.00	4.35	3.04	4.41	4.66	5.16	8.00	6.21	2.98	3.84	5.17	4.69	3.62	5.35	2.49	6.72	4.67 c	3
ZM 525	G4	5.11	4.47	3.04	4.61	4.60	5.56	9.05	6.33	3.31	3.65	6.46	4.38	3.45	5.30	2.75	6.03	4.88 d	2
ZM 621	G5	4.19	4.42	3.52	1.74	4.11	4.16	7.33	6.62	2.53	3.72	5.77	3.50	3.37	4.66	2.93	6.58	4.32 ab	7
ZM 627	G6	4.39	3.83	2.72	1.83	4.58	5.36	7.93	8.12	2.47	3.55	5.64	4.67	3.43	5.51	2.62	6.64	4.58 bc	5
BR993	G7	3.52	2.59	2.34	4.27	4.26	6.45	5.91	5.98	3.34	3.58	4.26	4.73	3.09	3.99	2.07	4.81	4.07 a	13
COMP-4	G8	3.87	3.62	2.51	3.69	4.48	5.04	6.16	6.62	2.79	3.90	4.73	4.34	3.48	4.82	2.90	4.79	4.23 ab	10
OBATANPA	G9	3.09	3.40	2.59	2.11	3.45	5.76	6.42	6.35	3.79	3.19	4.71	4.86	2.91	4.42	2.88	5.28	4.08 a	12
AFRIC 1	G10	3.43	3.89	3.48	2.25	4.85	3.30	5.45	7.13	3.34	3.30	6.02	4.84	4.27	4.57	1.67	5.98	4.24 ab	9
NELSON'S CHOICE	G11	3.39	3.90	2.22	2.86	4.25	3.82	8.34	6.85	3.24	3.39	5.00	3.39	4.04	4.29	2.23	5.98	4.20 ab	11
OKAVANGO	G12	4.40	4.25	2.87	2.90	4.76	5.34	6.45	6.58	2.72	3.08	5.85	4.65	3.64	4.36	1.71	4.96	4.28 ab	8
PAN 6479	G13	5.63	6.45	3.56	3.51	5.86	4.54	7.21	8.57	2.66	2.99	7.03	5.28	5.04	5.95	3.31	7.11	5.29 d	1
Means		4.11	4.05	2.87	3.03	4.57	5.12	7.22	6.81	3.04	3.05	5.50	4.54	3.67	4.81	2.47	5.91	4.45	
$P_{(0.05)}$		***	**	NS	NS	**	NS	NS	NS	**	NS	***	NS	**	NS	NS	NS	***	
$LSD_{(0.05)}$		1.05	1.34	1.1	2.19	1..22	3.02	1.65	1.67	0.83	1.39	0.89	2.39	0.89	1.86	1.34	1.75	0.430	
CV		14.6	19.9	33.7	34.1	26.5	35.1	22.0	14.7	20.4	23.7	11.9	31.3	14.8	23.1	27.7	23.5	24.10	

Highlighted figures represent those genotypes with the highest yield in respective environment; [1]Means followed by the same letter indicate that they were not significantly different ($p < 0.05$) from each other; Overall mean yield = 4.45 t/ha, genotype CV% = 24.10, $R^2 = 0.753$, and DMRT $_{(0.05)}$ = 0.430; AV. Yield – Average yield; [3]Environment names for code are give in Table 4.1.

Obatanpa ranked first in Mkhwezo 1, while ZM 501 ranked first in Burnshil 1 and Mkhwezo 2 (Table 4.4).

The mean grain yield for 2010/11 season (4.723 t/ha) was higher than that of 2009/10 season (4.178 t/ha) (Table 4.5). In 2009/10, the highest yielding environment was Mqekezweni 1 (7.22 t/ha), while the lowest yielding environments were KK 1 (2.47 t/ha) and Burnshil 1 (2.84 t/ha), which ranked seventh and eighth, respectively. In the 2010/11 season, Mqekezweni 2 (6.81 t/ha) was the highest yielding environment, while Mkhwezo 2 (3.05 t/ha) and Burnshil 1 (3.03 t/ha) had the lowest grain yield (Table 4.5). Jixini was ranked second during the 2009/10 season but ranked fifth during 2010/11 season. On the other hand, Keiskammahoek ranked eighth in 2009/10 season and ranked second in 2010/11 season.

Table 4.5 Overall grain yield performance and rank for 16 environments during 2009/10 and 2010/11 seasons

Environment	2009/10	Rank	2010/11	Rank	Overall Mean	Overall Rank
MQEKE	7.22 a[1]	1	6.81 a	1	7.02 a	1
JIXI	5.50 b	2	4.54 de	5	5.03b	2
LENY	4.57 c	3	5.12 c	3	4.85b	3
GOGO	3.67 e	5	4.81 d	4	4.24c	4
KK	2.47 fg	8	5.91 b	2	4.19c	5
UFH	4.11 d	4	4.05 e	6	4.08c	6
MKHW	3.04 f	6	3.05 ef	7	3.05d	7
BURN	2.87 f	7	3.03 f	8	2.94d	8
Mean	4.18		4.72		4.45	
DMRT	0.4022		0.5108		0.3812	
CV%	21.48		25.97		25.01	
$P_{(0.05)}$	***		***		***	

[1] Means followed by similar letters are not significantly different at 0.05 probability based on DMRT test; Environment codes see Table 4.2

Across both seasons, Mqekezweni was consistently ranked first, while Burnshil and Mkhwezo were consistently ranked lowly. Low and insignificant ($r = 0.125$, $p>0.05$) correlation co-efficient between annual precipitation and amount of rainfall received during the study.

4.3.4 Additive main effects and multiplicative interaction analysis

The AMMI ANOVA for grain yield (t/ha) of 13 genotypes tested in 16 environments is presented in Table 4.6. The analysis showed that maize yield was significantly ($p<0.01$) affected by G and E however, there was no significant GEI.

Table 4.6 Additive Main effects and Multiplicative Interaction analysis of variance for grain yield of 13 varieties tested across 16 environments

Source	DF	SS	%SS	Explained% of GEI SS	MS
Total	623	1934.4			3.11
Treatments $^{(G+E+G\ X\ E)}$	207	1440.9			6.69
G	12	70.2	3.6%		5.85***
E	15	1146.0	79.5%		76.40***
Block	32	77.9			2.44***
G X E	180	224.7	15.6%		1.25^{NS}
IPCA 1	26	82.5	4.3%	36.7%	3.17***
IPCA 2	24	43.4	2.2%	19.3%	1.81*
Residuals	130	98.8			
Error	384	415.6			

*, *** Significant F-test at probability levels 0.05 and 0.001, respectively; NS - not significant.; DF - Degrees of freedom; SS – Sum of squares; MS – mean square error

Environmental effects explained 79.5% of the total G+E+GEI Sums of Squares (SS). Only a small proportion of the G+E+GEI total SS, which is 3.6%, was contributed by genotypic effects, while GEI explained 15.6% of the treatment variation in grain yield. The first two Interaction principal component axis (IPCA) generated from the application of the AMMI model were highly significant (IPCA 1 – $p<0.001$ and IPCA 2 – $p<0.05$). The first IPCA and second IPCA explained 36.7% and 19.3%, respectively, of the GEI sum of squares, with a combined total of 55.0% (Table 4.6).

4.3.4.1 AMMI biplot analysis

The AMMI biplot provides a visual expression of the relationship between the first interaction principal component axis (IPCA 1) and means of G and E (Fig. 4.1). The main effects accounted for 83.1%, while the IPCA 1 accounted for 4.3% of the total variation of the GE data. This gave a model fit of 87.4% for the AMMI 1 biplot. Genotypes falling into sections B and D of the biplot had average grain yields higher than the grand mean.

Genotypes in sections A and C had average grain yields lower than the grand mean. Any genotypes falling close to the point of origin of the multiplicative axis (IPCA 1) had lower interaction with most of the environments, and were stable. Genotypes located beyond 1 and -1 showed a high interactive behavior with environments close to them and were generally unstable. Similarly, environments with IPCA 1 scores near zero had little interaction with genotypes, and also had low discrimination of genotypes, while those with IPCA scores beyond 1 (+/-) discriminated genotypes more effectively.

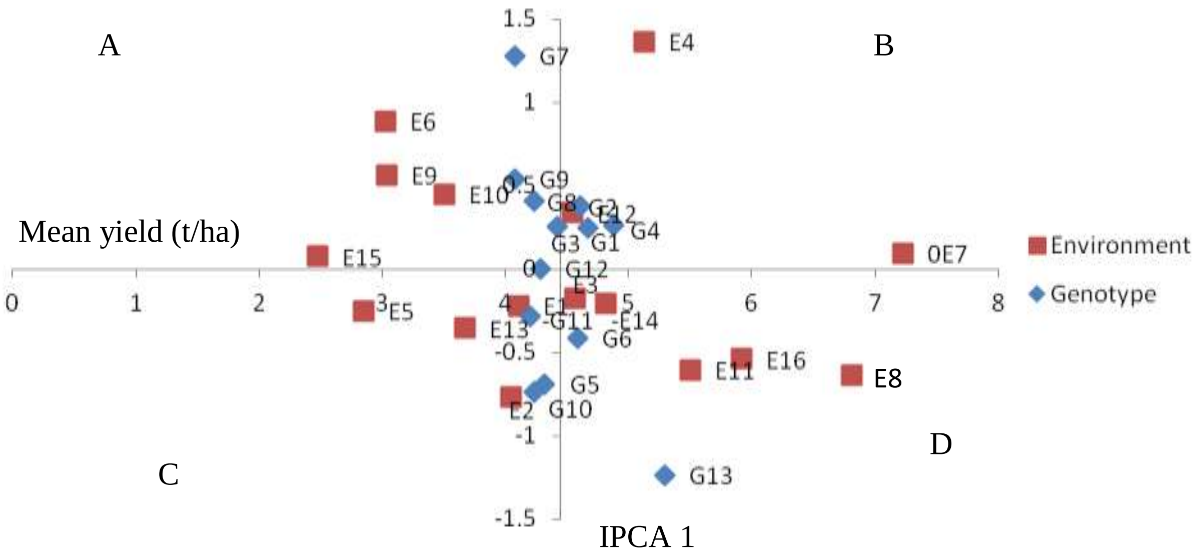

Figure 4.1 Additive Main effects and Multiplicative Interaction 1 biplot for IPCA 1 scores of 13 genotypes and 16 environments against mean yields (t/ha) for both genotypes and environments

Genotype and environment names for codes given in Figure 4.1 have been described in Table 4.1 and 4.4, respectively. Most genotypes had IPCA 1 scores of less than 1 (+/-). Pan 6479 had a large negative IPCA score of -1.23, while BR 993 had a large positive IPCA 1 score of 1.28. Okavango had a near zero IPCA 1 score of 0.001. Other genotypes that had the low IPCA 1 scores, in their decreasing order, included Nelson's Choice (-0.28), ZM 525 (0.27), ZM 305 (0.25) and ZM 501 (0.25) (Appendix 12).

Similar to genotypes, all environments except Lenye 2 (1.36) had IPCA 1 scores of less than 1 (+/-). UFH 2 had a large negative IPCA 1 score of -0.77. KK 1 and Mqekezweni 1 had IPCA 1 score that were close to zero while, Lenye 1 (-0.17), Gogozayo 2 (-0.21), UFH 1 (-0.22) and Burnshil 2 (-0.25) had the least IPCA 1 scores (Appendix 11). Afric 1 and ZM 621 showed high interactive behavior with UFH 2, while BR 993 interacted strongly with Burnshil 2.

4.3.4.2 Cluster analysis for environments

Cluster analysis based on Euclidean distances between 16 environments enabled the identification of four major stability clusters at a similarity index of 0.90 (Figure 4.2). This was based on grain yield; IPCA 1, IPCA 2 and ASV (see Appendix 11). The first group was comprised of Mqekezweni 1, and was characterized by a mean (7.22 t/ha) which was above the grand mean and also had a very high ASV (1.62) (Appendix 11). The second group, was also characterized by a high ASV of 1.82 and moderately high grain yield (5.125 t/ha) consisted of Lenye 2. Group three comprised of UFH 2, Mqekezweni 2, Jixini 1 and KK 2, which had mean grain yields between 4.02 and 6.811 t/ha and ASV of between 0.807 and 1.02 (see Appendix 11).

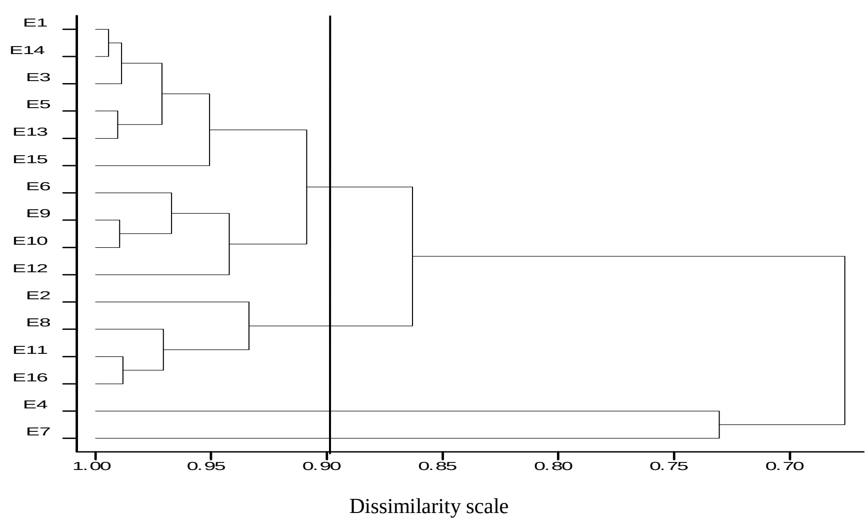

Figure 4.2 Dendogram showing clusstering of environments based on yield (t/ha), IPCA 1, IPCA2 and ASV

The rest of the environments fell into the last cluster, and these were characterized by moderately low to high means of between 2.472 and 4.81 t/ha, and low ASVs ranging from 0.12 to 0.79.

4.3.4.3 Cluster analysis for genotypes

Cluster analysis based on Euclidean distances between 13 genotypes enabled the identification of five major stability clusters at a similarity index of 0.90 (Table 4.3). Generally, there were, three single variety clusters (cluster 1, 2 and 4), one, two variety cluster (cluster 3) and one eight variety cluster (cluster 5). Cluster 1 comprised of the hybrid variety Pan 6479 (Table 4.3), and it was characterized by a high grain yield (4.93t/ha) which was above the grand mean, and a large ASV of 1.83 (Appendix 12).

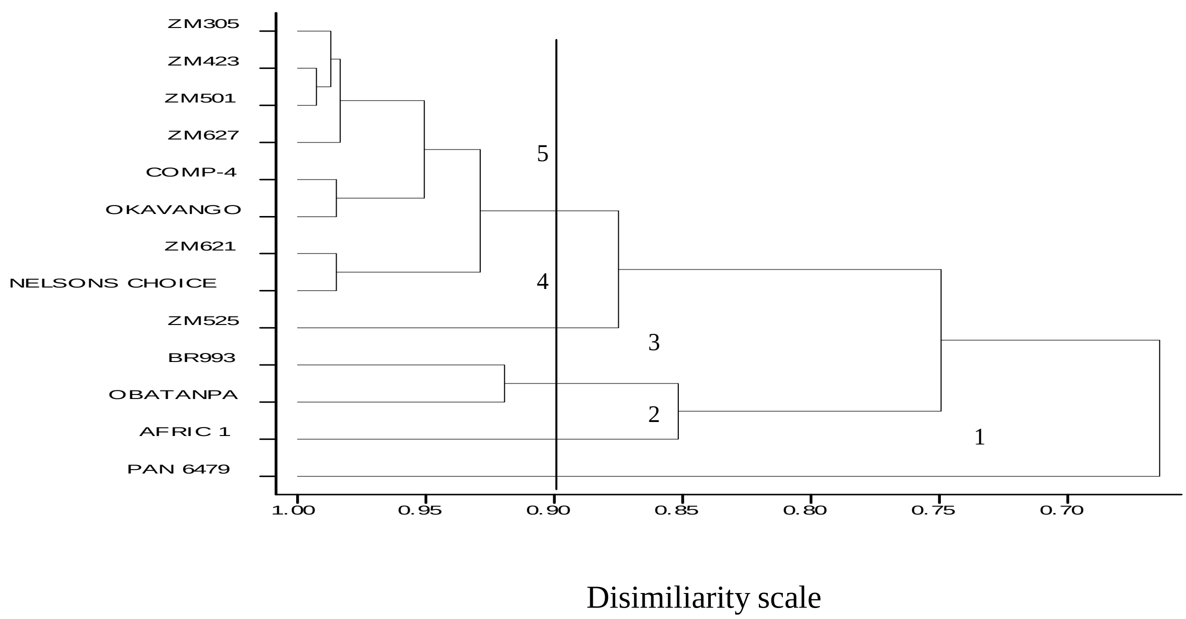

Figure 4.3 Dendogram showing variety clustering based on yield (t/ha), IPCA 1, IPCA2 and ASV

The second cluster comprised Afric 1, and its grain yield was not very different from the grand mean, but also had a large ASV of 1.64. Genotypes in the third cluster, BR 993 and Obatanpa, were characterized by grain yields (3.77 and 3.89 t/ha, respectively) below the grand mean, and moderately high ASV (1.003 and 1.43, respectively) (Appendix 12). ZM 525 was discriminated into the fourth cluster (Figure 4.4), and this discrimination was because this genotype had a mean yield higher (4.53 t/ha) than the grand mean. Furthermore, ZM 525 had a moderately low ASV of 1.028. The final cluster, cluster 5, which was also the largest, comprised ZM 305, ZM 423, ZM 501, Nelson's Choice, ZM 621, ZM 627, Comp 4 and Okavango. Generally these genotypes had means that were either lower or higher than the grand mean (4.08 - 4.67 t/ha) though all exhibited relatively low ASVs (0.268 – 0.781) (Figure 4.4). Three distinct subclusters could also be observed at a similarity index of 0.95 in Cluster 5 (Figure 4.4). The first sub-cluster containing ZM 305, ZM 423, ZM 501, ZM 627, designated 5a, had means above the grand mean (4.46 – 4.67 t/ha) and moderately low ASV (0.4385 – 0.6184). The second sub-cluster 5b, contained Comp 4 and Okavango, and these genotypes had means below the grand mean (4.23 and 4.28 t/ha, respectively) and low ASV (0.682 and 0.444, respectively), while the last sub-cluster 5c, comprised ZM 621 and Nelson's Choice, which also had means (4.20 and 4.32 t/ha, respectively) below the grand mean but moderately high ASV (0.98 and 0.781, respectively) (Appendix 12)

4.3.4.4 Which variety won in which environment?

An AMMI 2 biplot was plotted using 1PCA 1 and IPCA 2 scores for both genotype and environments (Figure 4.4). The results of the biplot showed that genotypes, Afric 1, Pan

6479, BR 993, ZM 525, Nelson's Choice and ZM 621 were the furthest from the origin, and expressed a highly interactive behavior (positive or negative) with specific environments. Connecting the extreme genotypes with lines formed a polygon. Lines perpendicular to the sides of the polygon were also drawn and these formed five sectors of which three had environments assigned to them. (Figure 4.4).

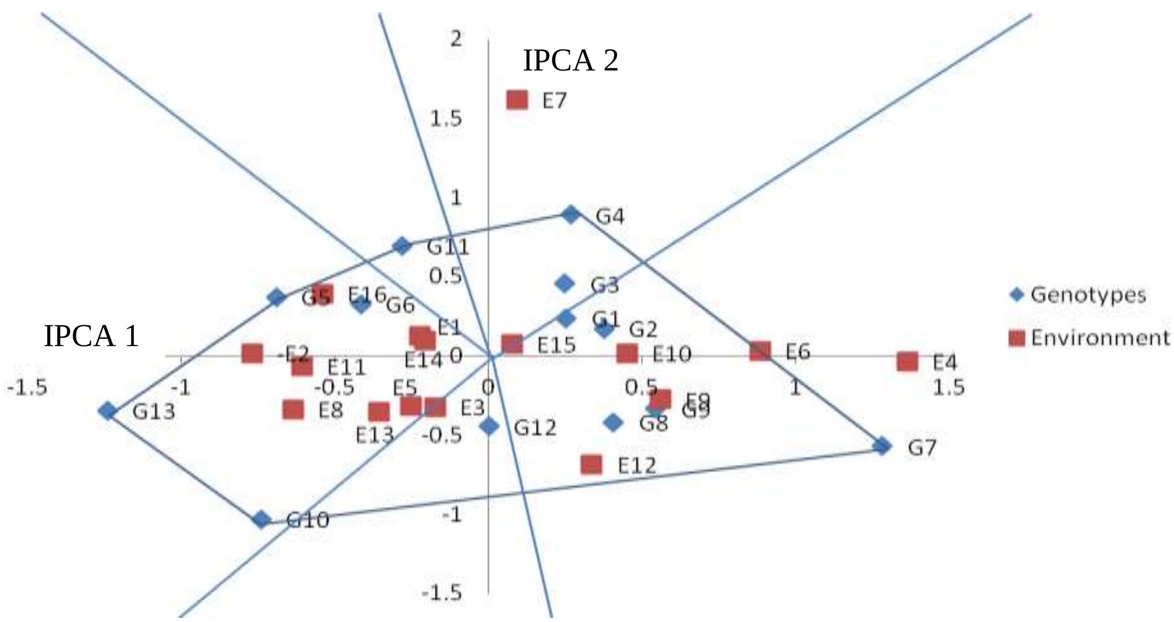

Figure 4.4 Additive Main effects and Multiplicative Interaction 2 Biplot for IPCA 1 vs IPCA 2 scores for environments and genotypes

Mqekezweni 1 fell into sector one and the summit genotype was ZM 525, which was the highest yielding variety in this environment (Figure 4.4). Pan 6479, Afric 1and ZM 621 were the summit genotypes in the second sector, containing environments UFH 1, UFH 2, Burnshil 1, Lenye 2, Mqekezweni 2, Jixini 2, Gogozayo 1, Gogozayo 2 and KK 2. The last sector containing environments consisted of Burnshil 2, Lenye 2, Mkhwezo 2, Jixini 2 and KK 1, and these had BR 993 as their summit variety (Figure 4.4).

4.3.4.5 AMMI variety recommendation for environments

The first choice selection based on AMMI estimates, in 11 out of 16 environments, was Pan 6479 (Table 4.7). This was followed by BR 993 in three environments and ZM 525, each in two environments. ZM 525 and Pan 6479 had the most appearances, (12 out of 16 environments) in the top four variety recommendations, while Comp 4 and Afric 1had the least appearances (once out of 16).

Table 4.7 AMMI 2 genotype recommendations for each environment and yield improvements brought about by first recommendations

Environment	Mean yield	IPCA 1 score	First four AMMI Genotype recommendations				Yield of 1st recom.	Yield improvement (%) based on first recom.[1]
E1	4.10	-0.221	G13	G4	G6	G3	5.63	37
E2	4.05	-0.768	G13	G6	G5	G10	6.45	59
E5	4.57	-0.173	G13	G10	G6	G4	5.86	28
E6	5.13	1.361	G7	G4	G2	G3	6.45	25
E3	2.85	-0.251	G13	G10	G6	G4	3.56	25
E4	3.03	0.885	G7	G4	G2	G3	4.27	40
E7	7.22	0.093	G4	G3	G11	G6	9.05	25
E8	6.81	-0.635	G13	G10	G6	G5	8.57	25
E9	3.04	0.561	G7	G4	G2	G13	3.34	10
E10	3.50	0.449	G4	G3	G2	G13	3.65	4
E11	5.50	-0.608	G13	G6	G10	G5	7.03	28
E12	4.55	0.336	G13	G7	G10	G8	5.28	16
E13	3.67	-0.356	G13	G10	G6	G4	5.04	37
E14	4.81	-0.208	G13	G4	G6	G3	5.95	24
E15	2.47	0.075	G13	G4	G3	G2	3.31	34
E16	5.91	-0.539	G13	G4	G6	G5	7.11	20

[1] Yield improvements calculated by comparing the grain yield of the genotype recommended as the top performer by AMMI 2 for each environment and the environment mean, and obtaining the percentage increment; Names of genotype and environment codes are presented in Tables 4.1 and 4.4, respectively.

Yield improvements by AMMI 2 recommendations were calculated by finding the percentage change of yield for an environment mean when the first recommended genotype was used. Recommending genotypes brought about differential yield improvements that ranged from 4% to 59.3% (Table 4.7). Recommending Pan 6479 to UFH 2 gave the highest yield improvement of 59.0%. Recommending BR 993 to Mkhwezo 1 and ZM 525 to Mkhwezo 2 gave the lowest yield improvements of 4% and 10%, respectively.

4.4 Discussion

Supreme varieties of maize need to be adapted in specific or broad environments of the EC so as to ensure that yield stability and economic profit are realized by farmers. Yield performance of different maize genotypes is often affected by environmental conditions (Nakitandwe *et al*., 2005). The study of GEI can be used in identifying suitable varieties for resource-poor farmers growing maize in diverse environmental conditions based on stability.

The observed non significant GEI could have been due to the low contribution of the genotype SS to the total variation in grain yield. This suggests that change in rank position by most genotypes might not have been as pronounced. Results observed are contrary to numerous findings on GEI in maize (Mohammadi *et al*., 2007; Akpalu *et al.*, 2008). However, differential yield performance of genotypes across seasons could be explained by the differences in the seasonal climatic conditions. Overall, the better yields observed in the 2010/11 season, and this was probably due to higher rainfall amounts received in this season as compared to the 2009/10 season. These findings, therefore, emphasis the importance of recommending genotypes with good yield stability to farmers producing maize in fluctuating weather patterns.

The observed crossover GEI was due to the differential ranking of genotypes like ZM 525 (G4), which ranked first at Mqekezweni (E7) but ranked seventh in Jixini (E11) during 2009/10, and ranked first in Burnshil (E3) and eighth in Mqekezweni (E8) during 2010/11. These results agree with Asfaw *et al*. (2009) and Mohammadi *et al*. (2007) who also highlighted that, such change in genotype ranking was largely due to differences in environments, which were also exacerbated by seasonal effects. This was also substantiated by the large contribution by environments to the total variation of grain yield. However, non-crossover GEI was also evidenced in this study since some varieties ranked consistently throughout some environments across the two seasons.

The low, and insignificant, correlation obtained between annual precipitation and long term averages suggests that other environment factors such as soil type and depth also have a bearing on the availability of soil moisture to growing maize plants. These findings are consistent with van Averbeke and Marais (1991) and Akpalu *et al.* (2008) who observed that yielding potential of maize is strongly linked with available soil moisture rather than seasonal precipitation. Therefore, genotypes can be recommended based on crop simulation models that factor in long term climatic data and current soil characteristics rather than just historic ecological classifications (Yan and Hunt, 2000).

The observed findings demonstrated that most environments were generally stable, which could suggest that these environments had more than one limiting factor affecting different genotype performance. These findings were in line with those obtained by Muungani *et al*. (2007) and Yan *et al*. (2007), who reported that no meaningful information on genotype performance can be obtained in such environments. On the other hand, the observed large interaction scores for environments like Lenye 2 (E6) and Burnshil 2 (E4) could suggest the presence of fewer stress factors allowing effective discrimination of genotypes (Yan *et al*., 2007).

Environment potential determines the threshold to which a variety can perform (Ceccarelli *et al*., 1994). Environment clustering, AMMI 2 biplot and environment grain yields suggested that environments could be grouped into three different potentials that is low (Burnshil and Mkhwezo), medium (UFH, Jixini, Gogozayo, Lenye and Keiskammahoek) and high (Mqekezweni). When soil properties were considered, those in low potential environments were characterized by low soil fertility due to inadequate major nutrients and carbon content, while high potential environments were generally fertile. These results agree with Ndufa (2001) who showed that maize yields are low if grown in soils depleted of nutrients and soil organic matter. In such environments, farmers should change current strategies for management of soil fertility to obtain the full benefits of stress tolerant genotypes with high yield potentials (Nakitandwe *et al*., 2005)

High yield attained by Pan 6479 (G13) was because of hybrid vigor, by nature hybrids are genetically stable, possess hybrid vigor, and modern breeding programs of such varieties have screened such varieties for improved stress tolerance. These results agree with those obtained by Muungani *et al*. (2007). These results are in agreement with findings by Pixley and Banziger (2001), who reported that hybrid varieties outperform OPVs by at least 18% under sub-optimum and optimum conditions. Furthermore, this hybrid variety was developed in South Africa; hence, it would naturally perform better in comparison to the exotic OPVs. However, yield fluctuations by this hybrid variety were more pronounced than some CIMMYT OPVs across the environments showing yield performances of between -42.07% and 50.43% when compared with these OPVs. On the other hand, the observed poor performance of Obatanpa could be due to poor adaptation of this genotype in environments that were tested in the EC. Therefore, the recommendation of selected OPVs to resource-poor farmers could still show better yield stability in diverse agro-ecologies than the use of hybrid varieties.

The differences in yield performance and stability observed in the genotypes could have been due to the difference in their genetic structure and morphological characteristics. Okavango, a locally grown long season genotype, was the most stable genotype among all the genotypes studied but was low yielding. This suggests that this variety has been bred for environments in the EC, but has a low yielding potential. On the other hand, the observed stable performance of early maturing (ZM 305, ZM 501, ZM 423), and medium maturing (ZM 627) varieties could be attributed to the intensive screening for tolerance to various stress conditions that they received making them stable across different environments. The findings of this study agree with Worku *et al*. (2001) and Muungani *et* *al*. (2007) who observed better stability with early maturing CIMMYT OPVs across stress induced environments.

4.5 Conclusions

Genotype by environment interaction was not significant, but varieties were able to show specific and wide adaptations to the environments. The best performing genotypes were Pan 6479; confirming superiority of hybrids over OPVs, and ZM 525, while the least performing genotypes were BR 993, Obatanpa and Nelson's choice. Pan 6479, BR 993, ZM 525 and Afric 1 were unstable genotypes. Okavango was the most stable variety but was low yielding. ZM 627, ZM 501, ZM 423 and ZM 305 all yielded above the grand mean, and these genotypes were stable. Pan 6479 showed specific adaptations to high to medium potential environments, while ZM 525 showed specific adaptations to Mqekezweni 1 which was also a high potential environment. Okavango was more suited to environments with low yielding potential such as Burnshil and Mkhwezo, since improvement of environmental conditions did not improve its yield.

Most environments were generally stable. UFH, Gogozayo, Jixini, Mkhwezo and Keiskammahoek were the most representative environments, while Mqekezweni could be used to discriminate stable and unstable varieties. The 'ideal' environments for discriminating genotypes were Lenye and Burnshil. These environments could be used in future GEI trials. Varieties should be evaluated for morphological uniformity as a possible cause of variety stability or instability, taking in to account GEI.

5. ASSESSING PHENOTYPIC DIVERSITY OF OPEN POLLINATED MAIZE VARIETIES BY EVALUATING QUALITATIVE AND QUANTITATIVE TRAITS

Abstract

The suitability of a variety to a particular cropping systems and environments is often influenced by morphological traits that it possesses. It was therefore important to characterize the new varieties to determine their suitability of use in different cropping systems and agro-ecologies of the EC. The objective of the study was to assess agro-morphological diversity of newly introduced stress tolerant maize open pollinated varieties (OPVs). Using maize descriptors from the Union for the Protection of New Varieties of Plants (UPOV) and International Board for Plant Genetic Resources Institute (IBPGR), seven varieties from the International Maize and Wheat Improvement Center (CIMMYT-Zimbabwe), two from IITA-Ghana and four locally grown varieties (a hybrid and three local OPVs) were characterized for 21 quantitative and 11 qualitative traits. This was done at the University of Fort Hare, Alice, South Africa, during the 2010/11 summer season. Analysis of variance was performed on quantitative traits and results of descriptive statistics were used to quantify the variability among the varieties. Qualitative variables were also tabulated in their nominal classes. A standardized data matrix of quantitative trait mean values was constructed so as to perform principal component and cluster analysis (PCA and CA). Significant variations among genotypes ($p<0.05$) were observed for days to anthesis, days to silk emergence, chlorophyll content, plant height, number of kernel rows per ear, stem thickness, ears per plant, ear height, cob length, grain yield, ear position and 1000 kernel weight. According to principal component analysis, ear height, plant height, days to 50% anthesis and grain yield contributed more to variety diversity. Cluster Analysis discriminated varieties into four main clusters. The first cluster consisted of four short, early maturing CIMMYT varieties, ZM 305, ZM 423, ZM 501 and ZM 525. The second cluster had the hybrid Pan 6479, while Nelson's Choice and Okavango were grouped into the third cluster. Tall late maturing varieties that is, ZM 621, ZM 627, Obatanpa, BR 993, Comp 4 and Afric 1, were placed in the fourth cluster. Newly introduced varieties could be grouped into two main groups according to maturity range and plant height. In each group, there was low diversity among varieties, while diversity was large across the groups. Varieties in the first cluster (group one) possessed traits desirable for low potential environments, while newly introduced varieties in cluster four (group two) were more suitable for environments with long seasons, and high management levels.

Key words: Agro-morphological traits, open pollinated varieties (OPVs), principal component analysis (PA), and cluster analysis (CA)

5.1 Introduction

Maize (*Zea mays* L.) is described as one of the most diverse agricultural crops, and its diversity occurs at both phenotypic and molecular levels (Magorokosho, 2001). Despite its highly adaptive nature and diversity, results obtained in chapter three, suggest that multiple stress factors have had a negative impact on maize yields in the EC province. Chapter 3 and chapter 4 have based the appropriateness of stress tolerant varieties on farmer-preference and yield performance. Moukoumbi *et al*. (2011), however, suggest that suitability of a variety also depends on the interaction of a given set of traits, which makes it competitive in any given environment and for specific applications. This suggests that different varieties could be matched to different agronomic practices, environmental conditions and socio-economic factors on the basis of plant attributes (Moukoumbi *et al*., 2011). Therefore, the efficient utilization and management of a range of newly introduced varieties requires an evaluation for genetic diversity to establish traits suitable for specific applications (Coetzee, 2004).

By definition, variety diversity consists of inherited variation among and between populations (Moukoumbi *et al*., 2011). Diversity of maize is normally studied to determine crop variability of existing germplasm, variety classification and to detect needed morphological and agronomic traits (Angelo *et al*., 2008). Morphological and molecular markers, or both, have been successfully used in recent years in the evaluation of rice (Caldo *et al*., 1996), cowpeas (Musvosvi, 2006), maize (Hamblin, *et al*., 2007), sorghum (Lasalita-Zapico *et al*., 2010) and finger millet (Moukoumbi *et al*., 2011). In this study, agro-morphological characterization was used because of its simplicity and low cost (Musvosvi, 2006).

The morphology of a plant is an outward expression of a few or many genes that a plant carries (Wattoo *et al*., 2009). This expression can be regarded as a qualitative or quantitative trait. Quantitative traits are normally measured on a numerical scale (measured and counted); while qualitative traits are differentiated in their nominal classes (Hallauer *et al*., 2010). Therefore, quantitative traits show continuous variation, with phenotypic values of a population having a normal distribution. When measured under a range of environments, quantitative traits will generally show multiple expressions (Hallauer *et al*., 2010). On the other hand, phenotypic expressions of qualitative traits fall into different categories, which do not show a certain order (Christensen, 2003). Unlike quantitative traits, qualitative traits are seldom affected by environmental factors (Hallauer *et al*., 2010).

According to Bänziger *et al*. (2000) and Monneveux *et al*. (2008), morphological characterization has been used successfully in recommending adaptable maize varieties into different agro-ecological zones. Results by Monneveux *et al*. (2008) suggest that leaf traits seem to be less important than variation in tassel parameters for increasing drought tolerance. Bänziger *et al*. (2000) and Monneveux *et al*. (2008) suggested that varieties should have a greater number of ears per plant, bigger kernel sizes and smaller tassels if they are to have better grain yields in drought prone environments. Based on reports by Mwania *et al*. (1990), late maturing maize varieties with a lot of foliage (that is, a high number of leaves with a large surface area) are more suitable for high rainfall areas. According to Welcker *et al*. (2007), leaf growth and anthesis–silking interval (ASI) are the main factors affecting source and sink strengths of maize via their relations with light interception and yield, respectively. Based on results by Maddonni *et al*. (2001), time to maturity, plant height, internode length and leaf width affect the suitability of maize varieties to intercropping, and also determine target populations that should be used for them. Therefore, plant morphology can play a significant role in recommending varieties in various cropping systems as those described in chapter 3.

Various researchers have studied the diversity of morphological traits to establish baseline information needed for various applications, such as variety registration, recommendation and furthering crop improvement. The aim of the study was, therefore, to evaluate morphological diversity of stress tolerant OPVs by using UPOV and IBPGRI guidelines.

The specific objective of the study was:-

1. To assess the morphological diversity of newly introduced, stress tolerant maize OPVs, with respect to qualitative and quantitative traits.

The null hypotheses that were tested were:-

1. Newly, introduced stress tolerant OPVs of maize do not differ, morphologically, when compared with local varieties.

5.2 Materials and methods

5.2.1 Site description

The experiment was carried out at the University of Fort Hare's experimental farm in the Amatole district of the EC, during the 2010/11 summer season. More details about this site were provided in Chapter 4, section 4.2.1.

5.2.2 Treatments and Experimental design

All thirteen varieties listed in section 3.2.3 were used in this diversity study. The trial was laid out as a randomized complete block design (RCBD) replicated three times at each location. Further details on the experimental design are outlined in section 3.2.3.

5.2.3 Non-experimental variables

Details of agronomic practices, fertilizer quantities, and management of weeds and insect pests were the same as described in section 3.2.3.

5.2.4 Data collection and statistical analysis

Plants were characterized for 32 (21 quantitative and 11 qualitative) morphological and agronomic traits using maize descriptors outlined by CIMMYT, IBPGR and UPOV (see Table 5.1 below and Appendix 13 for a detailed description) (IBPGR, 1991; UPOV, 2000). Data on quantitative traits were averaged for 10 plants randomly selected in each net plot while qualitative traits were obtained from visual scoring on a plot basis.

Table 5.1 Quantitative traits used during morphological characterization of 13 maize varieties

Quantitative traits		Acronym
1.	Anthesis date (days)	AD
2.	Silking date (days)	SD
3.	Anthesis Silking Interval (days)	ASI
4.	Stem Lodging (%)	SL
5.	Root Lodging (%)	RL
6.	Tassel length (cm)	TL
7.	Venation index	VI
8.	Leaf number	LN
9.	Leaf area (cm^2)	LA
10.	Leaf chlorophyll	CHL
11.	Plant height (cm)	PH
12.	Ear height (cm)	EH
13.	Ear position	EPO
14.	Stem thickness (cm)	ST
15.	Ear per Plant (No.)	EPP
16.	Grain yield (tha^{-1})	GY
17.	Ear length (cm)	EL
18.	Ear diameter (cm)	ED
19.	Number of rows per ear	NRE
20.	Number of kernels per row	NKR
21.	1000 kernel weight (g)	KW
22.	Rachis width (cm)	RW

Adapted from IBPGR, 1991. Descriptors for Maize. International Wheat and Maize Improvement Center, Mexico City/International Board for Plant Genetic Resources, Rome

Therefore, quantitative data were determined on a metric scale while qualitative data were scored using an arbitrary scale. Table 5.2 and Appendix 13 gave detailed description traits that were recorded.

An initial analysis of variance (ANOVA) was performed on quantitative data to determine if there was significant variation among traits that were measured. Descriptive statistics generated from this initial analysis such as ranges for each trait (minimum and maximum values), means, standard deviations and coefficients of variations, were tabulated to explain variations of quantitative data. Qualitative variables were also tabulated in their nominal classes. Analysis of variance and descriptive statistics were done using GenStat Statistical Software, version 4.2 (GenStat®, 2002).

Table 5.2 Qualitative traits used during morphological characterization of 13 maize varieties

Qualitative traits	Acronym
1. Tassel branching type (1=primary, 2=secondary, 3=tertiary)	TB
2. Tassel bushiness (1=sparse, 3=medium, 5=dense)	TBU
3. Leaf pubescence (1=sparse, 3=medium, 5=dense)	PUB
4. Husks cover (1=good, 3=intermediate, 5=poor)	HC
5. Stem coloration (1=none, 2=weak, 3=medium, 4=strong, 5=very strong)	SC
6. Brace root coloration (1=none, 2=weak, 3=medium, 4=strong, 5=very strong)	BC
7. Leaf sheath coloration (1=none, 2=weak, 3=medium, 4=strong, 5=very strong)	LSC
8. Tassel coloration (1=none, 2=weak, 3=medium, 4=strong, 5=very strong)	TC
9. Grain texture (1=flint, 3=semi-dent, 5=dent)	GT
10. Leaf attitude (1=straight, 3=slightly curved, 5=curved, 7=strongly curved, 9=recurved)	LAT
11. Leaf angle (1=<25^0, 3= 26^0-50^0, 5=50^0-90^0, 7=>90^0)	LANG

Adopted from IBPGR, 1991. Descriptors for Maize. International Wheat and Maize Improvement Center, Mexico City/International Board for Plant Genetic Resources, Rome

A data matrix of the mean values of quantitative traits was constructed and standardized (mean = 0, standard deviation = 1) so as to perform principal component and cluster analysis (PCA and CA) (Lasalita-Zapico *et al*., 2010). Principal component analysis was used to identify characteristics that contributed significantly to the variability among varieties. Cluster analysis was employed for grouping together varieties that showed similarity in several traits or response patterns. Clustering was carried out using UPGMA technique (Lasalita-Zapico *et al*., 2010). The standardized data matrix was then used to generate similarity indices based on Euclidean distances. Both PCA and CA were done using JMP, version 9.0.2 (SAS, 2010). The dendrogram resulting from CA of quantitative data was then plotted to illustrate variety homogeneity. Finally, an analysis of variance was performed on data of grouped varieties to determine if there was variation among traits measured among the groups generated by CA.

5.4 Results

5.4.1 Quantitative traits

Results of ANOVA showed highly significant differences at different probability levels for 14 of the 21 quantitative traits that were measured (Table 5.3 and Appendix 14). Highly significant variations ($p<0.001$) were observed among the varieties for AD, SD, CHLO, PH, NRE, ST, EPP and 1000KWT. Moderately high and significant differences ($p<0.01$) were observed for EH, CL and GY, while EPO showed significant differences at $p<0.05$. Variability of each trait was expressed by standard deviation (STD) and the coefficient of variance (CV%) (Table 5.3). The lowest cases of STDs were recorded for 1000KWT (0.036), EPO (0.055), EPP (0.085), and ST (0.245). The highest STDs were LA (37.1), PH (31.61) and EH (28.64). The lowest CV% was observed for CW (5.1%) followed by SD (5.7%), AD (6.6%), CHLO (7.3%) and ST (7.5%). High CV% were assigned to SL (133.9%) and RL (138.4%) while ASI (26.06%), GY (21.7%) and EH (19.74%) had moderately high CV% (Table 5.3).

Table 5.3 Descriptive statistics and F. probability for quantitative traits measured in the 13 varieties

TRAIT	Minimum	Maximum	CV%	Mean±STD	F. prob (p<0.05)
Anthesis date (AD)	74	95	6.59	83.72 ±5.52	***
Silking date (SD)	80	97	5.74	89.03 ±5.11	***
Anthesis silking interval (ASI)	1	12	26.06	5.308 ±3.29	***
SPAD chlorophyll content (CHLO)	50.6	68.2	7.33	59.74 ±4.38	***
Plant height (PH)	218	336	11.3	279.4 ±31.61	***
Ear height (EH)	91.5	200	19.74	144.98 ±28.64	**
Ear plant position (EPO)	0.42	0.629	10.61	0.5157 ±0.055	*
Leaf number (LN)	12	17.33	9.5	13.92 ±1.32	NS
Venation index (VI)	10	17	13.73	12.79 ±1.76	NS
Tassel length (TL)	32.33	50.33	10.66	41.85 ±4.47	NS
Leaf area (LA)	383.7	562.9	7.7	488.3 ±37.7	NS
Cob width (CW)	3.9	4.8	5.05	4.4.16 ±2.23	NS
Cob length (CL)	14.4	21.7	8.14	19.258 ±1.57	**
Number of kernel rows per ear (NRE)	11.2	17.6	9.46	14.174 ±1.34	***
Number of kernels per row (NKR)	34.2	46.3	7.8	37.9±1.04	NS
Ears per plant (EPP)	0.714	1.46	7.95	0.983±0.085	***
Stem thickness (ST)	2.40	3.40	7.45	2.989±0.245	***
Stem lodging (SL)	0	14.55	133.9	1.80±3.23	**
Root lodging (RL)	0	21.15	138.36	1.87±3.903	NS
Grain yield (GY)	1.792	6.756	21.7	4.042±1.07	**
1000 kernel weight (1000KW)	0.256	0.334	10.79	0.334±0.036	***
Rachis width (RW)	0.660	1.960	15.82	1.204±0.332	NS

*, ** and*** indicates significance at 0.05, 0.01 and 0.001, respectively; levels of probability. NS – not significant (p>0.05)

5.4.2 Qualitative traits

There were considerable variations among varieties for traits such as LSC, BRC, TC, TB, TBU and GT. Varieties with tassels that were lax in bushiness (ZM 305 and Afric 1) were of primary branching type while those that were of medium bushiness had either primary or secondary tassel branches (Table 5.4).

Table 5.4 Nominal results for 11 qualitative traits measured in 13 maize varieties

Variety	PUB[1]	LSC	HC	GT	SC	BRC	LANG	TC	LAT	TB	TBU
ZM 305	Sparse	Medium	Intermediate	Semi dent	Medium	Medium	25^0-50^0	Weak	Slightly curved	Primary	Lax
ZM 423	Sparse	Strong	Good	Flint	Medium	Strong	25^0-50^0	Weak	Straight	Primary	Medium
ZM 501	Sparse	Weak	Intermediate	Flint	Medium	Strong	25^0-50^0	None	Slightly curved	Primary	Medium
ZM 525	Sparse	Medium	Good	Flint	Weak	Strong	25^0-50^0	Weak	Slightly curved	Secondary	Medium
ZM 621	Medium	Weak	Intermediate	Flint	Medium	Weak	25^0-50^0	Medium	Straight	Secondary	Medium
ZM 627	Medium	Weak	Intermediate	Dent	Weak	Medium	25^0-50^0	Weak	Slightly curved	Secondary	Dense
BR993	Medium	None	Intermediate	Semi dent	Medium	Strong	25^0-50^0	Weak	Slightly curved	Secondary	Medium
COMP4	Sparse	Weak	Intermediate	Flint	None	Medium	25^0-50^0	Medium	Slightly curved	Secondary	Medium
OBATANPA	Medium	Strong	Intermediate	Flint	Weak	Medium	25^0-50^0	Weak	Slightly curved	Primary	Medium
AFRIC 1	Sparse	Medium	Intermediate	Semi dent	Strong	Strong	25^0-50^0	Weak	Slightly curved	Primary	Lax
NC	Sparse	Strong	Intermediate	Flint	Medium	Medium	25^0-50^0	None	Slightly curved	Secondary	Medium
OKAVANGO	Sparse	Medium	Poor	Flint	Strong	Strong	25^0-50^0	Medium	Slightly curved	Secondary	Dense
PAN 6479	Sparse	Weak	Intermediate	Semi dent	Medium	Strong	25^0-50^0	Medium	Slightly curved	Secondary	Medium

[1]PUB – pubescence, LSC – leaf sheath coloration, HC – husk cover, GT – grain texture, SC – stem coloration, BRC – brace root coloration, LANG – leaf angle, TC – tassel coloration, LAT – leaf attitude, TB – tassel branches and TBU – tassel bushiness

Varieties with tassels that were dense in bushiness had secondary tassel branches (ZM 627 and Okavango). All varieties had leaves with leaf angle between 25^0 and 50^0 with the majority being slightly curved at the tip (Table 5.4).

5.4.3 Correlation co-efficiencies between quantitative traits

Table 5.5 presents correlations of 14 pairs of traits which were found to be significantly different among the varieties. Very strong, and positive, correlations that were highly significant were found between AD and SD ($p<0.001$, $r = 0.756$), PH and EH ($p<0.0001$, $r = 0.956$), and EH and EPO ($p<0.001$, $r = 0.904$) (Table 5.5). There was a moderately strong, positive and significant correlation between 1000KWT and SL ($p<0.05$, $r = 0.539$). However, very strong, and negative correlations which were significant, were observed for GY and EH ($p<0.05$, $r = -0.705$), GY and EPO ($p<0.05$, -0.802), and EPP and AD ($p<0.01$, -0.731), while EPP and SD ($p<0.001$, $r = -0.721$), EH and CL ($p<0.01$, $r = -0.857$) were highly significant (Table 5.5). Moderately strong and negative, but significant, correlations were observed for PH and 1000KWT ($p<0.05$, $r = -0.578$), PH and SL ($p<0.05$, $r = -0.564$), EPP and EPO ($p<0.05$, $r = -0.581$), and EPP and ST ($p<0.05$, $r = -0.443$).

Table 5.5 Correlation co-efficients (r) of qualitative traits that were found to be significantly different

	AD[1]	SD	ASI	CHLOR	PH	EH	EPO	CL	NRE	EPP	1000KWT	SL	ST
AD	1												
SD	0.756***	1											
ASI	-0.471	0.220	1										
CHLORO	0.076	-0.048	-0.180	1									
PH	0.554	0.508	-0.141	0.154	1								
EH	0.584	0.608	-0.050	0.133	0.956***	1							
EPO	0.512	0.675	0.146	0.079	0.743*	0.904***	1						
CL	-0.245	-0.195	0.102	-0.049	-0.857**	-0.789	-0.586	1					
NRE	0.628	0.406	-0.389	0.477	0.552	0.502	0.333	-0.359	1				
EPP	-0.731**	-0.721**	0.118	-0.198	-0.270	-0.427	-0.581*	-0.035	-0.425	1			
1000KWT	-0.669	-0.29	0.606	-0.026	-0.578*	-0.476	-0.220	0.347	-0.380	0.362	1		
SL	-0.207	-0.003	0.304	-0.026	-0.564*	-0.352	0.029	0.500	-0.486	-0.239	0.539*	1	
ST	-0.048	0.317	0.500	0.333	-0.085	0.056	0.273	0.281	-0.070	-0.443*	0.376	0.429	1
GY	-0.553	-0.664	-0.070	0.109	-0.582	-0.705*	-0.802*	0.576	-0.317	0.592	0.221	-0.134	-0.002

, ** and indicates significance at 0.05, 0.01 and 0.001 levels of probability; [1] AD – anthesis date, SD – silking date, ASI – anthesis silking interval, CHLOR – SPAD chlorophyll content, PH – plant height, EH –ear height, EPO – ear position, CL – cob length, NRE – number of kernel rows per ear, EPP – ears per plant, 1000KWT – 1000 kernel weight, SL – stem lodging and ST – stem thickness.**

5.4.4 Principal Component Analysis

The first two principal components gave Eigen values greater than three and explained 38.7% and 22.2% (total of 60.9%) of the total variation among the varieties for traits that were significantly different (Table 5.6).

Table 5.6 Principal Component Analysis showing the contribution of each quantitative maize trait towards observed variability

Trait	**PC1**	**PC2**
AD	0.3635	0.00646
SD	0.3073	0.30051
ASI	-0.1277	0.3958
CHLO	0.0838	-0.0544
PH	0.1933	-0.3496
EH	0.3812	0.0541
EPO	0.3355	0.2572
CL	-0.2756	0.146
NRE	0.3068	-0.1571
EPP	0.2887	-0.2567
1000KWT	0.2764	-0.2612
SL	0.1552	-0.4151
ST	0.0008	-0.3929
GY	0.3177	0.2276
Eigen value	**5.4173**	**3.1057**
% contribution	**38.7**	**22.2**
Cumulative%	**38.7**	**60.9**

Traits such as AD, SD, EH, EPO and GY, were the most discriminating traits associated with the PC1 while ASI, PH, SL and ST were traits associated with PC2 (Table 5.6).

5.4.5 Cluster Analysis

Cluster Analysis grouped the varieties into four distinct clusters at a similarity index of 0.85 (Figure 5.1). In the first cluster, four CIMMYT varieties, ZM 305, ZM 423, ZM 501 and ZM 525 were grouped together, while the second cluster comprised the hybrid variety, Pan 6479.

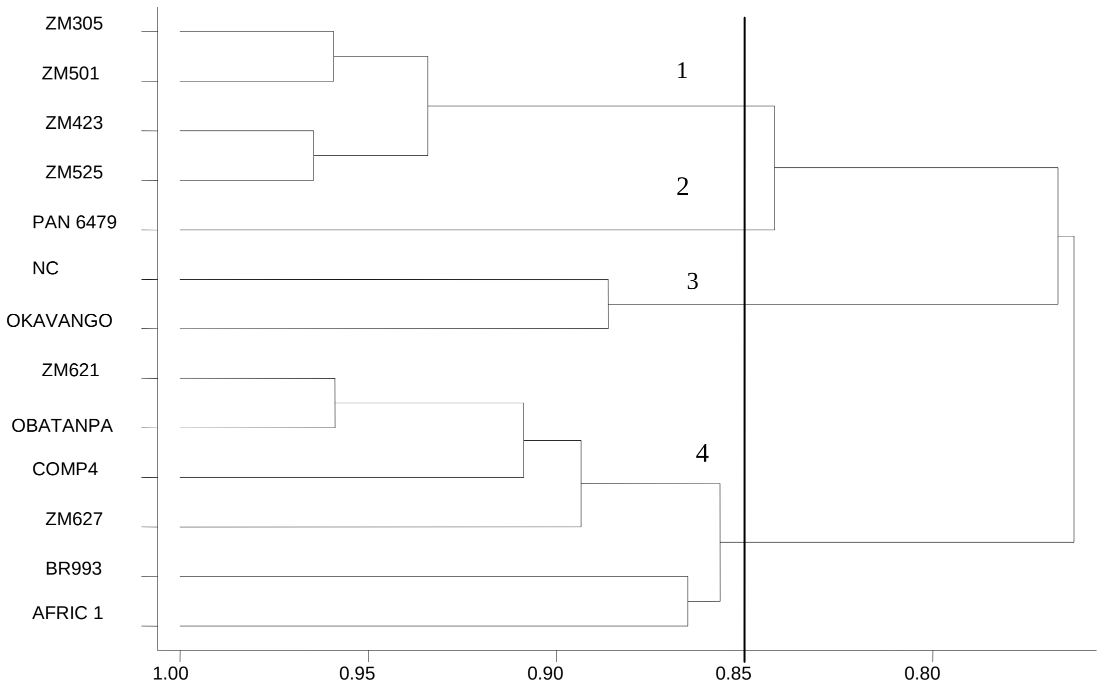

Figure 5.1 Cluster dendrogram illustrating morphological diversity between the thirteen varieties characterized using 14 qualitative descriptors that were significantly different from each other

Two local OPVs, NC and Okavango, were grouped into the third cluster, while ZM 621, ZM 627, Obatanpa, BR 993, Comp 4 and Afric 1 were placed in the fourth cluster. Contrary to the first and third clusters, cluster four consisted of the two IITA varieties, three CIMMYT varieties and one local variety.

Distinguishing features of the first cluster were that varieties matured early (AD = 78 days), were not prone to stem lodging (0.3%), that were short (237.9 cm), and prolific, but had small cobs (18.1 cm) (Table 5.7).

Table 5.7 Means for each trait for the four clusters of maize varieties

Trait	CUSTER 1	CLUSTER 2	CLUSTER 3	CLUSTER 4
AD (days)	78[a1]	80.3[b]	82.5[c]	88.5[d]
SD (days)	83.7[a]	83.7[a]	90.1[b]	93.1[b]
ASI	5.7[a]	3.3[a]	7.7[b]	4.6[a]
CHL	60.2	58.6	58.2	60.1
PH (cm)	237.9[a]	231.1[a]	245.0[b]	296.6[b]
EH (cm)	135.5[bc]	100.2[a]	118.4[ab]	161[c]
EPO	0.5[ab]	0.43[a]	0.5[ab]	0.54[b]
CL (cm)	18.1[a]	21.3[c]	21[bc]	19.13[ab]
NRE	13.8[ab]	13.6[ab]	12.7[a]	15[b]
EPP	1.26[c]	1.05[b]	0.95[a]	0.93[a]
1000KWT	0.34[b]	0.35[d]	0.38[c]	0.33[a]
SL (%)	0.312[a]	0.7[a]	6.5[b]	1.42[a]
ST (cm)	2.78[a]	2.97[ab]	3.1[b]	3.08[b]
GY (t/ha)	4.0[a]	6.4[b]	4.1[a]	3.7[a]

Numbers followed by the different letter indicates significant differences in mean for trait according to DMRT $_{(0.05)}$

Pan 6479, placed in the second cluster matured relatively early (80.3 days) in comparison to the other clusters. Furthermore, this cluster had the highest grain yield (6.37 t/ha), and could be considered as a short (231.1 cm) plant. It also had the narrowest ASI (3 days), the lowest ear position index (0.45) and long cobs (21.3 cm) when compared with the other clusters (Table 5.7).Varieties in the third cluster were characterized as intermediate in maturity (82.5 days), prone to stem lodging (7%), medium height (245.0 cm) with a large ASI (7 days). Cobs had few kernel rows (12.7) but these varieties had the highest 1000 kernel weight (0.38kg) (Table 7). Varieties in cluster 4 were later maturing (88.5 days), tall (296.6 cm) with a high cob position index (0.54) (Table 5.7). Cobs from this cluster had a high number of kernel rows (15). However, 1000 kernel weight and grain yield were the lowest compared with other clusters (0.33 kg and 3.72 t/ha, respectively).

5.5 Discussion

Morphological characterization is a classic method of distinguishing variations based on the observation of external differences such as size and shape of leaf, plant stature and characteristics of fruit (Coetzee, 2004). Knowledge of existing variation and association between various agro-morphological traits is vital for any evaluation experiment (Khayatnezhad *et al*., 2011). Varieties evaluated in the study showed considerable variations in most of the evaluated agro-morphological traits, which was also substantiated by PCA. This is in agreement with Barcaccia *et al*. (2003) and Beyene (2005) who obtained variations in similar agro-morphological traits they studied.

The study observed insignificant association between grain yield and many yield components such as ears per plant, cob length, number of kernel rows per ear and 1000 grain weight. These results are contrary to those obtained by numerous researchers who found consistencies in the interactive behaviour for the above mentioned traits and grain yield (Barcaccia, *et al*. 2003; Beyene, 2005). These observations could be because grain yield in this study was a function of many traits interacting together as suggested by the variety grouping generated by cluster analysis (Beyene, 2005). Furthermore, the sample of only 13 varieties is small, making it difficult to compare with other studies that had large numbers of varieties.

A large variation was observed with respect to the extent to which colour was expressed in tassels, stems, leaves and brace roots. These results were similar to reports by Moukoumbi *et al*. (2011), who suggested that the extent of anthocyanin coloration could be used as a morphological marker in diversity studies of rice varieties, and this too could apply for maize. Anthocyanin coloration of different maize parts ranges from green, red, purple to brown (IBPGR, 1991). However, a limitation to the use of colour in population diversity studies is the presence of a mixture of colours within one population.

The observed tassel characteristics aided in the identification of two extreme tassel sizes, small and large. According to Bodi *et al*. (2007), the morphology of tassel components is important to crop breeders as it is to maize producers. In theory, smaller tassels utilize less assimilates during development and this results in more assimilates being available for ear formation. Furthermore, smaller tassels mean less shading of the flag and upper leaves of the maize plant, resulting in increased photosynthetic efficiency of leaves since more assimilates are channeled towards grain formation. On the other hand, selections of small tassels might cause problems during production and maintenance of seed due to low pollen production and shedding duration. Therefore, varieties like ZM 627 and

Okavango could be better pollinators but have more shading of flag and upper leaves, when compared with ZM 305 and Afric 1.

Similarities observed in leaf characteristics (leaf area, length, angle and attitude) could be due to the fact that modern plant breeding is aimed at creating varieties based on ideotypes (Maddonni *et al*., 2001). This suggests that varieties evaluated might have the same photosynthetic efficiency as suggested by Ku *et al*. (2010). This also supports the findings presented in Chapter four were the majority of varieties were clustered around the grand mean in Figure 4.4.

The observed crop canopy architectures (plant height, leaf orientation and area) and maturity ranges suggested that varieties under study will have different responses to inter-specific and intra-specific plant competition. Hypothetically, early maturing varieties could be less affected by high levels of inter-specific and intra-specific plant competition, and weed competitions. Therefore, results from this morphological study suggested that varieties in cluster one and two could be used by farmers practicing intercropping, and those with poor weed management strategies. On the other hand, one of the goals in maize breeding is to produce maize varieties with the ability of suppressing or smothering weeds (Williams *et al*., 2006). One such strategy is to use tall varieties like those in the fourth cluster, while using appropriate spatial arrangements and plant populations can also help. However, yield penalties can be expected in drought prone, nutrient depleted soils as high levels of intra-specific competition could be expected.

The observed expression of certain traits, such as days to maturity, suggested that varieties might have adaptation to specific and/or a wide range environment. These results agree with Ogunbodede and Ajibade (2001), and agree to results obtained in chapter four that the adaptations of current maize varieties under study were either specific or broad. When plant stature (mainly height) and days to 50% anthesis were considered, three plant types emerged, that is, tall and early maturing, short and early maturing and tall and late maturing. In a similar study of characterizing maize populations in India, Sharma *et al*. (2010) identified days to anthesis and plant stature as major factors contributing to the clustering of maize landraces according to agro-ecological zones where they were collected. This suggested that, members of cluster two and three were candidates for short growing seasons in low potential environments due to their relative early maturity. However, according to Bänziger *et al*. (2000) varieties suitable for low potential areas that are prone to drought should have an ASI less than 4. Varieties in the third cluster had a higher ASI than those in the third cluster, indicating that they may not be suitable in drought prone areas. Varieties in the fourth cluster could be grown in areas with a longer growing season, in high potential environments as they were late maturing and tall. It should be noted, however, that maturity ranges were longer, while plant heights were taller, for most of the CIMMYT stress tolerant varieties as compared with results obtained by Magorokosho *et al*. (2008). This could be because the varieties under study were bred for tropical and sub-tropical climates, while the experiment was conducted in a temperate environment (Laker, 1978). According to Coles *et al*. (2010) tropical maize varieties are better adapted to shorter day lengths, and will increase in plant height and days to maturity when planted in temperate climates with less than 11 hours of daily dark periods (The sunrise times, 2012)

Genotypic variations between hybrid varieties and OPVs were also re-emphasized by these results since Pan 6479 was clustered into its own group. These findings are similar to those obtained by Jaradat *et al*. (2010) and substantiate observations in chapter 4. Pan 6479 was also from a different source of origin from the OPVs that were bred by CIMMYT and IITA.

The observed clustering of varieties could be explained from two different angles. Clusters one and three were grouped by country of origin, and suggest that variety diversity could be described in the context of geographical origin. On the other hand, the grouping of varieties from different countries of origin in to cluster four suggested that diversity was a function of genetic constitution than geographical origin. In this regard, emphasis can be directed at variety level rather than environmental level as a source of variety diversity. However, Afric 1, which was clustered together with varieties of tropical origin from CIMMYT and IITA, is known to have been synthesized from lines with tropical descent. Nevertheless, phenotypic evaluation is easily influenced by the environment which makes distinguishing related varieties difficult (Moukoumbi *et al*., 2011). Therefore, molecular characterizations could be done on these varieties to obtain more conclusive diversity trends.

5.6 Conclusions

There was high diversity among newly introduced OPVs based on the study of qualitative and quantitative agro-morphological traits. Large variations being observed in plant coloration and tassel type and bushiness as opposed to the other qualitative traits that that showed small variations. Ear height, plant height, days to 50% anthesis and grain yield contributed more to variety diversity. Four variety groups were identified and these were:

(i) Short, early maturing CIMMYT varieties (ZM 305, ZM 423, ZM 501 and ZM 525).

(ii) High yielding, short maturing hybrid variety which was short in stature (Pan 6479)

(iii) Locally grown OPVs that were short in stature (Nelson's choice and Okavango) and had a wide ASI

(iv) A mixture of tall, late maturing varieties from CIMMYT, IITA and a local OPV (ZM 621, ZM 627, Obatanpa, BR 993, Comp 4 and Afric 1).

Varieties from clusters 1 and 2 can be recommended to environments with high risks of drought. Furthermore, the same varieties possess traits suitable for intercropping. On the other hand, varieties in cluster 4 could be used in high potential environments where farmers practice high levels of management. Further studies aimed at testing the suitability of clusters 1 and 2 varieties for intercropping is recommended.

6. GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The review of literature showed that cropping systems for resource poor farmers in the EC province experience low maize yields averaging 1 - 3 t/ha. The major challenges faced by these farmers include limited access to capital, low and sometimes excessive summer rainfall, poor soil fertility, and use of inappropriate varieties. Various stress tolerant maize OPVs are being promoted as a seed technology for increasing maize production for resource-poor farmers. However, before the "ideal" varieties can be recommended to farmers for use, they should be evaluated by both farmers and researchers, for suitability. Overall, the study demonstrated the importance of variety evaluations before the introduction of new varieties across diverse agro-ecologies. This chapter, therefore, consolidates the major findings, conclusions and recommendations of the study, and discusses their implication towards recommending the ideal varieties for adoption in the EC.

6.2 General discussion

The initial evaluation by farmers showed that varieties selected did not differ from those that would have been selected by researchers. Farmers were able to visually assess varieties for some of the maize yield components such as cob length, kernel row numbers and kernel size, of which researchers have shown strong correlations of such traits to grain yield. Participatory variety selection was an effective strategy used in selecting acceptable varieties through field based selection criteria which confirms previous studies (Witcombe *et al*., 2000). Similarities observed for field based selection criteria indicated homogeneity in expected variety out puts or performances by farmers. However, results obtained on variety selections suggest that farmers farming in different agro-ecological zones will select varieties differently. This shows that farmer' selections can easily be influenced by external factors, and one such factor is socio-economic characteristics.

The observed characteristics of maize growing farmers in the study were somewhat different, with age, marital status, household sizes and gender, having the most obvious differences across the villages. Although maize production by farmers in the study was generally low, results observed showed that married farmers (both male and female) produced better yields. This could be explained by them having a larger number of family members available for agricultural activities and use hybrid seed that should respond positively to higher use of fertilizers. Therefore, the adoption of appropriate stress tolerant varieties will be more beneficial for single farmers that had smaller households and limited access to fertilizers and hybrid seed, and could be considered as the most vulnerable. However, projected yield improvements cannot be based on current yields obtained from agronomic yield trials. These trials were researcher managed. Farmer fields are known to possess numerous production constrains, such as low fertility status, that affect variety performance. Furthermore, such farmers have limited access to resources. Therefore, to get a clearer insight on factors affecting maize production, constraint analysis within the study villages was done.

Constraint analysis gave an insight to factors affecting maize production in the studied villages. In general, observed constraints highlighted by farmers were similar, but differed in their importance. Extreme weather conditions were the most important constraints, and according to Rosenzweig *et al*. (2000), such events are associated with an increase in the prevalence of insect pests and diseases. This could explain why this constrained ranked highly in both villages. Therefore, more than one stress tolerant variety could be used as risk management strategy. This becomes very necessary especially when farmers are faced with multiple stresses as shown by the differential weather patterns experienced during the 2009/2010 and 2010/2011 summer seasons, and low levels of input-use. As a result, recommending varieties should be guided by the most common constraints affecting maize productivity in a specific location rather than variety availability.

In addition to the field-based selection criteria, the selection criteria generated from household surveys provided an insight on traits that could not be easily distinguished by farmers during field evaluations. Traits for stress adaptations were frequently mentioned, and this suggested weakness to current varieties being used by farmers. This could explain why traits mentioned as selection criteria were in response to the stressful climatic conditions. In this regard, the selection of traits linked with flood tolerance in Jixini and drought tolerance in Mkhwezo suggested that modifications of current varieties being grown will result in better performing varieties. The observed results of differences in selection criteria and variety performance suggest that even more variations can be observed with farmers in other environments.

Genotype by environment studies in Chapter 4 gave an insight on the yield response patterns of newly introduced varieties. The observed results indicated that there were some differences to variety performance and stability. For example, high yielding varieties like ZM 525 and Pan 6479 showed significant differences with low yielding ones like Afric 1 and BR 993, but all these varieties were regarded as unstable. Similarly, stable varieties were either high yielding or low yielding. Differences in annual rainfall, temperature and soil characteristic across the environments most likely influenced the observed performance. However, the stability of ZM 305, ZM 501, ZM 423 and ZM 627 suggested that plants had mechanisms that allowed them to adapt to variations in climatic conditions. As suggested by differences in the importance of some selection criteria outlined by farmers in chapter 3, variety performance in different environments and even cropping systems, can also be influenced, to an extent, by differences in variety morphology.

Morphological diversity of the varieties included in this study was assessed using qualitative and quantitative agro-morphological traits. Morphological analysis suggests that varieties diversity was largely influenced by maturity range and plant height, which were observed to differ from previous descriptions (Magorokosho *et al*., 2008). Therefore, the study of morphological diversity in a different agro-ecology, other than the ecology used for its breeding, allows the re-classification of varieties for some traits. Therefore, appropriate varieties can be recommended to farmers living in the stress prone areas of the EC, based on suitable attributes. Furthermore, the suitability of varieties to different cropping systems can be established.

6.3 General conclusions and recommendations

- Varieties selected by farmers were different across the two villages, but were not significantly different from the best performing variety, in terms of yield, in each village. Farmers were able to select acceptable high yielding varieties based on visual assessment of maize traits. ZM 305 and ZM 501 could be recommended to farmers in low and high potential environments, respectively.

- Farmers' selection criteria and production constraints were different for farmers living in different agro-ecologies. Variety recommendations should be guided by agro-ecological differences. Obtaining a variety that conforms to farmer selection criteria can result in the mitigation of some production constraints.

- Performance of newly introduced maize OPVs showed insignificant differences across selected agro-ecological conditions. However, variety stability was different. ZM 525, ZM 423, ZM 501, ZM 305, and ZM 621 had better yields as compared to ZM 627, Comp 4, Obatanpa and BR 993. The most unstable varieties were ZM 525, ZM 627, Obatanpa and BR 993, and these varieties showed specific adaptation to selected environments. ZM 423, ZM 501, ZM 305, Comp 4 and ZM 621 were stable across several environments. ZM 525 should be used by farmers growing maize in high rainfall areas, characterised by deep fertile soils (high potential). On the other hand, ZM 423, ZM 501, ZM 305 and ZM 621 can be used across a wider range of environmental potentials.

- ZM 305, ZM 423, ZM 501 and ZM 525 were similar in maturity ranges and plant height but differed greatly from ZM 621, ZM 627, Comp 4, Obatanpa and BR 993, which also had similar maturity ranges and plant height. Varieties in the first group can be used by farmers practicing intercropping, while those doing mono-cropping in high potential areas should used varieties in the second group of varieties

6.4 Recommendations for future studies

- The administration of FGDs and household surveys should be done concurrently with in the same season to reduce any sources of variation in data.
- Participatory variety selection should be done at different stages of crop growth, including organoleptic tests, to increase the precision of farmer evaluation.
- Information on farmer wealth status, availability of advisory services, accessibility and quantity of inputs should be collected so as to categorize farmers according to availability of resources.
- Varieties need to be evaluated in farmers fields under farmer managed conditions to determine whether they actually bring about yield improvement when compared with current varieties being used.
- Varieties selected by farmers should be converted from white to yellow grain colour so as to increase their desirability and possible adoption.
- There is need to do a detailed characterization of these OPVs in major agro-ecological zones to establish environmental effect on plant morphology.

- These varieties should also be characterized with molecular tools so as to refine conclusions on morphological variation.

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APPENDICES

Appendix 1 Check list for the Focus Group Discussion

Recording sheet number……………………
Number of participants………………..
Date..

Name of Recorder………………..…..........
Name of Community/Farm...................
Name of facilitator.............................

- Introductions
- Norms (do's and don'ts during the discussion)
- Specifying the objectives of the research and meeting.

Activity 1
Grouping of farmers into groups of 10-15 people. This, however, will depend on attendance.

Activity 2 (this will be done according to the guiding questions that follow)

1. What crops do you grow

	Crops	**No/ of Farmers**
1		
2		
3		
4		
5		

2. How important is maize?

	Very important	**Important**	**Average**	**Not all the time**	**Not important**
No/ of Farmers					

3. Where do you grow your maize?

Land type	**Home gardens**	**Fields**
No/ of Farmers		

4. Do you consider your land as being fertile? (For each response, write down the frequency)

	No/ of Farmers	**Reasons**
Yes		
No		

5. Is the rainfall that you receive adequate for maize production? If not, how do you overcome this?

	No/ of Farmers	**How it is overcome**
More than adequate		
Adequate		

Inadequate		

6. Do you practice intercropping? (For each response, write down the frequency of farmers)

Yes	**Sometimes**	**No**

7. For those that practice intercropping, which crops do you intercrop maize with?

Crops	**No/ of Farmers**

8. Do you intercrop in the main field, home garden, or both?

	No/ of Farmers
Main field	
Home garden	
Both	

9. Why do you grow maize?

	Purpose	**No/ of farmers**
1	Food	
2	Fodder	
3	Sale	
4	Feed	
5	Others (specify)	

10. What types of maize varieties have you been growing and for what purposes? How long have you been growing them?
What type of maize variety is it (hybrid, landrace or improved OPV) and where did you get it from?
What colour is the seed?
What do you normally use it for?

	Variety name	**Type**	**No/ farmers**	**Source**	**Seed colour**	**How long it has been grown**	**Where do you normally grow this variety? (Home garden/field)**
1							

2							
3							
4							
5							

1 = Improved Open-pollinated varieties: maize varieties with a **broad population** of **many related plants**. The **pollination** of the plants in the seed field is **not controlled**. The seed is, therefore, genetically diverse, but related. These types of **varieties** have been **developed** through **modern breeding** and can be bought in general dealer shops. Farmers can **retain the seed** for up **to three seasons** without having to purchase new seed. Examples of Open pollinated varieties are Nelson's choice, Okavango and Zama star.
2 = Hybrid varieties: maize varieties that are **uniform** in all their **characteristics** and are **generally high yielding**. Seed **cannot be re-used** (retained), therefore, it is bought every year and tends to be **expensive**. These varieties are **products of modern breeding programs**. Examples of hybrid varieties are Sahara, SR52 and SC701
3 = Landrace: a maize variety that evolved with and has been genetically **improved by traditional farmers**, but has not been influenced by modern breeding practices. These varieties are **passed down from generation to generation** and farmers normally **swap with their neighbors**. Examples of landrace **Gambushe and Gastyeketye.**

11. How did you get to know about these varieties?
For each answer write down the frequency of farmers.

Variety name	**Extension**	**Supplier**	**Neighbours**	**Others specify**
1				
2				
3				
4				
5				

12. What are the strengths and weaknesses of these varieties?

Variety name	**Strengths**	**Weaknesses**
1		

2		

13. Do you produce enough maize for the whole year?
For each answer write down the frequency of farmers

Yes	Yes but need more	Not all the time	no

14. If not yes, why are you unable to produce enough maize? (Farmers will be required to score using colored stones provided)
(Score 5= very important, 4= important, 3 = average, 2 = not all the time and 1 = not important)

	Constraint	**Score**	**No/ of Farmers**
Pre-planting	Land is too small		
	Poor performance of varieties		
	High seed price		
	Lack of capital to hire tillage equipment		
	Inadequate tillage equipment		
	High fertilizer price		
	High chemical prices		
Crop establishment	Drought		
	Lack of Irrigation equipment		
	Hail		
	Soil is too poor		
	Bird damage		
	Labor is too scarce		
	Weed control		
	Stalk borer damage		
	Occurrence of Diseases		
Pre-harvest	Bird damage		
	Theives		
Post harvest	Lack of or adequate Storage facilities		
	Storage pests		
	Lack of storage chemicals		
	Markets availability		
	Low price offered for maize grain		
Other (Specify)			
Others (Specify)			
Others (Specify)			

15. What are the criteria that you would use to select a suitable maize variety? How important is this criteria.
(*It is important to appreciate farmers understanding of the termers below)*
(Score 5= very important, 4= important, 3 = average, 2 = not all the time and 1 = not important)

	Reasons	**No/ of Farmers**	**Score**
Drought tolerant			

Adapted to heavy rains			
Adapted to poor soils			
Good response when planted late			
Resistant to pests			
Resistant to diseases			
Lodging resistant			
Low fertilizer requirements			
Others (specify)			
Others (specify)			
Others (specify)			

Physiological characteristics		**Reasons**	**No/ of Farmers**	**Score**
Height	Short			
	Medium			
	Tall			
Maturity	Short			
	Medium			
	Long			
Leaf structure	Up-right			
	Horizontal			
	Both			
Stem thickness	Thin			
	Thick			
Cob size	Short			
	Medium			
	Big			

Cob number	One			
	Many			
Kernel size	Small			
	Medium			
	Large			
Kernel colour	White			
	Yellow			
	Red			
	Purple			
Grain yield	Low			
	Medium			
	High			
Taste	Sweet			
	Medium			
	Tasteless			
Others (specify)				
Others (specify)				
Others (specify)				
Others (specify)				
Others (specify)				

16. Do you think there is need for development of a new variety?

	No/ of Farmers
YES	
NO	

16a. If yes, why

16b. If no, why

Activity 3
Pair wise ranking
Constraints and Characteristics highlighted by farmers will be compared in a pair wise rank fashion to come up with the most important. *Fill in table on page 10 and 11.*
The description below will show the discussion recorders how to carry out pair-wise ranking
How to carry out pair wise ranking
Each box in the matrix represents the intersection (or pairing) of two criteria. If your list has five criteria, the pair-wise matrix would look like the diagram below:

5		2			*
4				*	*
3	3	3	*	*	*
2	1	*	*	*	*
1	*	*	*	*	*
	1	**2**	**3**	**4**	**5**

For each pair, the whole group (using a consensus-oriented discussion) will determine which of the two criteria is important. Then, for each pair, write the number of the preferable criteria in the appropriate box. Repeat this process until the matrix is filled.

Comparing 1 and 2, 1 is better, In this case enter one in the box where constraints one and two intersect.
Comparing 2 and 3, 3 is better, In this case enter three in the box where constraints two and three intersect.

Comparing 1 and 3, 3 is better, In this case enter three in the box where constraints one and three intersect.
Comparing 2 and 5, 2 is better, In this case enter two in the box where constraints two and five intersect.

The alternatives will be ranked by the total number of times they appear in the matrix thus showing the order of importance

alternative	1	2	3	4	5
Rank	2nd	3rd	1^{st}		

Appendix 2 Questionnaire used in the formal survey

UNIVERSITY OF FORT HARE

FACULTY OF SCIENCE AND AGRICULTURE

Department of Agronomy

QUESTIONNAIRE FOR PROJECT- FARMERS' PERCEPTIONS ON MAIZE SELECTION CRITERIA AND PRODUCTION CONSTRAINTS: IMPLICATIONS ON PARTICIPATORY VARIETY SELECTION OF OPEN POLLINATED VARIETIES

All information provided will be treated as STRICTLY CONFIDENTIAL

Date…………………………………………………Interviewer………………………
Name of respondent (Optional) …………………….Location……………………….....

1. HOUSEHOLD CHARACTERISTICS

1.1 Gender of respondents: 1.Male 2. Female
1.2 Age …………………….yrs
1.3 Marital status (*Circle the correct option)*
1. Married 2. Single 3. Widowed 4. Divorced 5. Other: *(Specify*)….……
1.4 Highest education level for respondent?
…………………………………………………………………………………………=
1.5 Household size…………………
1.6 How many dependents actually share a meal with the respondent at night?

	Below 15yrs	Between 16 and 49	Above 50
Male			
Female			

1.7 How many are actively involved in farming activities?

	Below 15yrs	Between 16 and 49	Above 50
Male			
Female			

1.8 **The people that are not involved, why are they not**?... .... ……
…………………………………………………………………….
1.9 **What is your main source of income**?……………………………………………………
2. LAND CHARACTERISTICS AND USE
2.1 Do you have a home garden? 1. Yes 2. No
2.2 If yes, do you cultivate it? 1. Yes 2. No
2.3 If no, why……………………………………………………………………………...
If yes, answer questions 2.4 and 2.5
2.4 Which are the major crops that you cultivated last year?
2.5 W hat month of the year did you plant?

2.6 Could you rank the importance of each crop for household consumption?

No	**2.4** Crop name	**2.5** Month of the year planted	**2.6** Rank household importance
1			
2			
3			
4			
5			

For rankings, start by asking the least important to the most important. Assign more weight (4) to the least and lower weight to the most important (1).

2.7 Do you have an outfield? 1. Yes 2. No

2.8 If no, have you ever cultivated an outfield? 1. Yes 2. No

2.9 If yes, when was it and why did you stop……………………………………………….
………………………………………………………………………………………………

If yes to question 2.7, answer questions 2.10 – 2.12

2.10 How did you acquire the land?

Bought(Title deed)	Rent	Lease	Inherited	Other (specify)
1	2	3	4	5

2.11 What is the area of your outfield?

1	Less than 0.5 ha	2	Between 0.6 and 2 ha	3	More than 2 ha

2.12 What are the 4 major crops that you cultivated and harvested last year?
2.13 How much land did you allocate to each crop?
2.14 Could you rank the importance of each crop for household consumption?
2.15 Could you rank the importance of each crop as a source of income?
2.16 What month of the year do you plant this crop?

No	**2.12** Crop name	**2.13** Land allocation	**2.14** Rank household importance	**2.15** Rank as a source of income	**2.16** Month of planting
1					
2					
3					
4					

For rankings, start by asking the least important to the most important. Assign more weight (4) to the least and lower weight to the most important (1).

2.15 Do you own any livestock 1. Yes 2. No

If yes, how many

	Animal	Number
1	Cattle	
2	Sheep	
3	Goats	
4	Chickens	
5	Pigs	
6	Donkey/horse	
7	Others	

3. MAIZE CROPPING SYSTEM

3.1 What do you use to till your land?

1	Tractor	2	Animal draught	3	Both

3.2 Do you own or hire any of these assets?

	Tractor	Oxen/donkey/horse	Tractor drawn plough	Ox-drawn plough
Own				
Hire				
Others specify				

3.3 If farmer does not own, how many tractors are available in their village.

1	None	2	Between 1 and 3	2	More than 4

3.4 What month of the year do you normally finish land preparation for your maize field? ……………………………………..

3.5 Do you practice intercropping? 1. Yes 2. No

3.6 If yes, which crops do you intercrop with maize?

1	Beans	2	Pumpkins	3	Butter nuts	4	Others, specify……………..

3.7 If no, why…………………………………………………….

3.8 Did you use any fertilizer? 1. Yes 2. No

3.9 If yes, what types of fertilizer (organic/inorganic) did you use and how many bags did you apply in the maize fields? *Fill in table below.*

	Name	**Number of bags**	
		Home garden	**Outfield**
1	Lime Ammonium Nitrate (LAN)		
2	Urea		
3	Compound specify…………		
4	Compound specify…………		
5	Cattle manure		

3.10 If no, why ………………………………………………………………………………

3.11 Are there any other chemicals that you used during last season's maize production? List them below

	Type	**Name**	**Quantity**
1			
2			
3			
4			

3.12 If no, why………………………………………………………………………………

Fill in table below on space allocated for each corresponding question

3.13 What maize varieties did you grow last season?
3.14 What type of varieties? *Indicate whether 1. Hybrid 2. OPV 3. Landrace*

3.15 Why did you grow these varieties?
3.16 What is the size of land that each cultivar of the maize is planted?

3.17 And how many bags of grain did you harvest last season?

3.13 Variety	**3.14** Type (1, 2, or 3)	**3.15** Reason for growing variety	**3.16** Area allocated to variety	**3.17** Bags harvested (50kg)

3.18 Do you sell you maize produce? 1. Yes 2. No
3.19 If yes, where do you sell your maize? ……………………………………………….
3.20 If no, why……………………………………………………………………………..
…………………………………………………………………………………………

4. FARMERS' MAIZE PREFERENCES

What are the FIVE maize traits that you would consider for a maize variety to be highly desirable to you?

1………………………………. 3..................................

2………………………………. 4....................................

5. FARMERS' PRODUCTION CONSTRAINTS

What were the FIVE major production constraints that you faced when producing last season's maize crop?

1………………………………. 3..................................

2………………………………. 4....................................

Appendix 3 Sources of income for interviewed farmers in Jixini and Mkhwezo

Marital status	**Jixini**	**Mkhwezo**	**Average**
Old age pensions	52	44	48
Child support grants	16	12	14
Family remittance	14	18	16
Sell of agricultural produce	15	17	16
Wages	3	9	6
Total	**100**	**100**	**100**

Appendix 4 Interaction of yield (t/ha) attained and variety type used by interview farmers (%) from Jixini and Mkhwezo.

Variety type	Yield (t/ha)				**Total% of farmers**
	0.1-0.5	**0.51-1.0**	**1.1-1.6**	**1.61-2.4**	
Hybrid	20	7	3	3	33
Improved OPVs	2	6	3	0	11
Local landraces	40	6	0	0	46
Retained hybrid seed	8	0	0	0	8
Total	72	19	7	3	70
Accumulative% of farmers	72	91	98	100	

Appendix 5 Estimates of land sizes allocated to different types of maize varieties grown by interviewed farmers from Jixini and Mkhwezo

Land size (ha)	**Variety type**				
	Hybrid seed	Improved OPVs	Local landraces	Recycled hybrid seed	Total
< 0.5 ha	8	4	28	1	41 (60)
0.6 – 2 ha	12	5	5	6	28 (41)
2.1 – 4 ha	5	3	0	0	8 (12)
> 4.1 ha	1	0	0	0	1 (0.1)
Total	26 (38)	12 (18)	33 (49)	7 (10)	

Appendix 6 Agronomic trait data for varieties grown in Jixini

VARIETY	Grain yield (t/ha)	Rank	Anthesis date	ASI	Plant height	Prolificacy	Cob length	Number of kernel rows (<12)	Husk cover	1000 grain weight
ZM 305	5.03	13	72.0	4.4	236.8	0.89	16.6	13.8	1.6	0.301
ZM 423	5.79	5	77.1	4.7	285.3	1.08	18.1	14.2	3.6	0.303
ZM 501	5.22	8	78.5	1.4	276.0	0.99	17.4	13.5	2.4	0.300
ZM 525	6.54	2	77.5	2.9	261.3	0.99	18.3	14.1	3.5	0.300
ZM 621	5.73	7	87.9	6.6	288.8	0.99	17.4	14.8	2.1	0.334
ZM 627	5.65	6	77.0	3.7	291.6	1.04	17.3	14.3	4.3	0.332
BR 993	4.26	10	94.6	2.1	295.6	0.84	16.7	14.7	2.2	0.308
COMP 4	4.70	11	90.7	3.0	296.8	1.01	16.6	14.7	5.4	0.361
OBA	4.69	12	76.8	6.8	304.2	0.82	18.4	13.1	2.9	0.299
AFRIC 1	6.06	3	77.8	5.0	267.4	1.00	16.6	14.2	4.4	0.296
NC	5.02	9	78.8	2.6	288.1	0.93	19.0	14.1	2.8	0.303
OKA	5.91	4	77.9	2.6	303.5	0.90	20.3	11.9	6.7	0.407
PAN	6.93	1	79.0	2.3	280.1	1.06	20.0	13.3	2.3	0.334
Mean	**5.50**	**7**	**80.4**	**3.7**	**282.7**	**0.96**	**17.9**	**13.9**	**3.4**	**0.321**
LSD (0.05)	**-**	**4**	**2.7**	**3.3**	**27.6**	**0.22**	**2.5**	**1.6**	**1.9**	**0.049**
CV	**10.77**		**1.9**	**50.2**	**5.8**	**12.89**	**8.3**	**6.7**	**35.0**	**9.361**
P	ns		***	*	**	ns	*	*	***	**
Min	**4.26**	**1**	**72.0**	**1.4**	**236.8**	**0.82**	**16.6**	**11.9**	**1.6**	**0.296**
Max	**6.93**	**13**	**94.6**	**6.8**	**304.2**	**1.08**	**20.3**	**14.8**	**6.7**	**0.407**

Appendix 7 Agronomic data for varieties grown in Mkhwezo

VARIETY	Grain yield (t/ha)	Rank	Anthesis date	ASI	Plant height	Prolificacy	Cob length	Number of kernel rows (<12)	Husk cover	1000 grain weight
ZM 305	3.47	2	79.2	4.4	249.2	1.12	18.6	14.1	1.6	0.303
ZM 423	2.71	8	77.1	5.1	231.2	1.07	18.2	14.1	3.1	0.306
ZM 501	3.20	6	79.5	5.9	234.5	1.17	18.8	14.0	2.5	0.327
ZM 525	3.44	3	76.2	6.6	246.3	1.16	18.4	13.6	2.0	0.325
ZM 621	2.28	13	81.2	5.0	239.2	1.03	17.9	14.6	4.6	0.346
ZM 627	2.53	12	77.1	2.2	267.0	1.04	16.5	14.8	6.3	0.347
BR 993	3.44	4	96.2	7.3	238.4	0.96	18.8	14.1	5.5	0.311
COMP 4	2.66	9	88.7	6.3	250.8	0.85	19.9	13.7	6.8	0.329
OBA	3.94	1	87.9	5.8	260.6	0.98	20.2	13.3	4.4	0.332
AFRIC 1	3.27	5	77.0	6.4	239.7	1.19	19.6	13.9	3.3	0.316
NC	3.19	7	76.0	5.7	256.6	0.97	19.2	15.2	2.2	0.332
OKA	2.53	11	75.8	5.7	275.0	1.07	18.5	12.9	8.7	0.405
PAN	2.58	10	79.8	5.1	256.6	0.91	19.5	13.4	5.2	0.351
Mean	**3.02**	**7**	**80.9**	**5.5**	**249.6**	**1.04**	**18.8**	**14.0**	**4.3**	**0.333**
LSD (0.05)	**0.83**	**4**	**1.2**	**1.9**	**33.9**	**0.19**	**2.9**	**-**	**2.3**	**0.019**
CV	**10.77**		**1.9**	**50.2**	**5.8**	**12.89**	**8.3**	**6.7**	**35.0**	**9.361**
P	**	-	***	**	ns	***	ns	ns	***	***
Min	**2.28**	**1**	**75.8**	**2.2**	**231.2**	**0.85**	**16.5**	**12.9**	**1.6**	**0.303**
Max	**3.94**	**13**	**96.2**	**7.3**	**275.0**	**1.19**	**20.2**	**15.2**	**8.7**	**0.405**

Appendix 8 Key criteria desired by farmers and the relative importance according to rank position for farmers in Mkhwezo and Jixini.

Rank	Mkhwezo		Jixini	
	Male	Female	Male	Female
1	Low fertilizer requirement	Drought tolerance	Yellow kernels	Drought tolerance
2	Disease tolerance	Lodging resistance	Palatable	Disease tolerance
3	Insect pest resistance	Medium height	High yielding	Low fertilizer requirement
4	Prolific	Insect pest resistant	Prolific	Lodging resistance
5	Palatable	Prolific	Large kernels	High yielding

Appendix 9 Maize production constraints and the relative importance according to rank position for farmers in Mkhwezo and Jixini.

Rank	Mkhwezo		Jixini	
	Male	Female	Male	Female
1	Lack of tillage equipment	Poor performing varieties	Lack of tillage equipment	Lack of irrigation equipment
2	High fertilizer price	High fertilizer price	High chemical prices	Lack of tillage equipment
3	Poor storage facilities	Lack of tillage equipment	High fertilizer price	Drought
4	Drought	High seed price	Weeds	High fertilizer price
5	High seed price	Poor storage facilities	Storage pests	High chemical prices

Appendix 10 Analysis of variance for grain yield obtained by 13 varieties tested across 8 sites during 2009/2010 and 2010/2011 season

Source	**DF**	**SS**	**MS**	**VR**	**F. Pr**
Site (St)	7	857.79	122.54	42.24	***
Blocks	36	77.94	2.90	2.60	
Seasons (S)	1	46.35	46.36	41.47	***
Genotypes (G)	12	70.19	5.85	5.23	***
St X S	7	241.86	34.55	30.91	***
St X G	84	103.36	1.23	1.10	NS
S X G	12	8.39	0.69	0.63	NS
St X S X G	84	112.92	1.34	1.20	NS
Residual	384	415.60	1.08		
Total	623	1934.42			

Appendix 11 Means (t/ha), IPCA 1, IPCA 2 and ASV for 16 environments included in the study

Code	Environ ment	Grain yield	IPCA1	IPCA2	ASV	Correlation coefficient
UFH 1	UFH1	4.108	-0.2216	0.12929	0.320439	0.8302***
UFH 2	UFH2	4.05	-0.7682	0.01819	1.016784	0.8100***
Lenye 1	LENY1	4.566	-0.1728	-0.3208	0.393919	0.7337**
Lenye 2	LENY2	5.125	1.36092	-0.0353	1.801383	-0.009
Burnshil 1	BURN1	2.847	-0.2505	-0.3164	0.458201	0.4524
Burnshil 2	BURN2	3.03	0.88485	0.03236	1.171455	0.3074
Mqekezweni 1	MQEK1	7.224	0.0932	1.62082	1.625506	0.5131
Mqekezweni 2	MQEK2	6.811	-0.6351	-0.3377	0.905753	0.5494
Mkhwezo 1	MKHW1	3.042	0.56078	-0.2741	0.791132	-0.2957
Mkhwezo 2	MKHW2	3.502	0.44899	0.01657	0.594423	-0.052
Jixini 1	JIXI1	5.5	-0.6082	-0.0627	0.807313	0.7629**
Jixini 2	JIXI2	4.547	0.33593	-0.6823	0.814389	0.4319
Gogozayo 1	GOGO1	3.668	-0.3559	-0.3525	0.588337	0.6668*
Gogozayo 2	GOGO2	4.81	-0.2082	0.09662	0.291919	0.7729**
KK 1	KK1	2.472	0.07547	0.07543	0.12516	0.4337
KK 2	KK2	5.912	-0.5399	0.39248	0.815156	0.7431***
	Mean	4.45	0.000	0.000	0.744	
	STD (±)	**1.48**	**0.547**	**0.464**	**0.443**	

ASV- AMMI stability value. C – Correlation co efficiency between environment variety performance and overall genotype performance. **, *** Significant F-test at probability levels 0.05, 0.01 and 0.001, respectively.

Appendix 12 Means (t/ha), IPCA 1, IPCA 2 and ASV for 13 genotypes included in the study

Genotype	MEAN	IPCA1	IPCA2	ASV
ZM 305	4.42	0.25275	0.23748	0.410219
ZM 423	4.604	0.37399	0.17157	0.523831
ZM 501	4.669	0.24665	0.45617	0.560926
ZM 525	4.873	0.26579	0.8907	0.957639
ZM 621	4.321	-0.6905	0.36975	0.985789
ZM 627	4.583	-0.4156	0.32509	0.63885
BR993	4.074	1.27982	-0.5695	1.786899
COMP-4	4.23	0.40538	-0.4192	0.680812
OBATANPA	4.075	0.54231	-0.3341	0.791655
AFRIC 1	4.236	-0.7406	-1.0299	1.421721
NELSON'S CHOICE	4.2	-0.2823	0.69385	0.788036
OKAVANGO	4.283	0.00139	-0.4443	0.444254
Pan 6479	5.293	-1.2392	-0.3476	1.676336
Mean	4.45	0.000	0.000	0.410219
STD (±)	**0.340**	**0.6701**	**0.568**	**0.536**

Appendix 13 Maize descriptors and method of observation

	Variables	Time observed	Method	Unit
1	Pubescence	Flowering	Observing the distribution of leaf hair on top surface of leaf blade on a plot basic	
3	Venation	Flowering	Counting the visible vines parallel to the midrib on ten randomly selected plants	
4	Leaf angle	Flowering	By measuring the angle between the flag leaf and the stem on ten randomly selected plants	degree's
5	Leaf attitude	Post flowering	By observing the degree of curvature of leaf in 5 on a plot basic	
6	Stem coloration	Flowering	By observing the presence or absence of coloration of stem on ten randomly selected plants	
7	Stem thickness	Flowering	Stem width on ten randomly selected plants	cm
8	Brace root coloration	Flowering	By observing the presence or absence of coloration of brace root on ten randomly selected plants	
9	Kernel type	Before shelling	Observing whether kernels on the cob are 1 Floury,2 Semi-floury (morocho), with an external layer of hard endosperm,3 Dent,4 Semi-dent, intermediate between dent and flint but closer to dent, 5 Semi-flint, flint with a soft cap, 6 Flint	
10	Husk cover	Harvest	By observing whether the plant have a good husk cover with the following ratings 3 Poor ,5 Intermediate,7 Good	
11	Days to 50% pollen		Measured as number of days after planting when 50% of the plant shed pollen	days
12	Days to 50% silk emergence		Measured as number of days after planting when 50% of the silk have emerged	days
13	Anthesis silking interval (ASI)	Post flowering	Days to 50% silk emergence - days to 50% pollen shed	
14	Number of leaves per plant		By counting the number of leaves below the internodes	

Appendix 16 continued…….

15	Leaf area	Flowering	After flowering by measure ring the leaf which subtends the uppermost ear from ligule to apec, and mid-way along its length. The product of these values are then multiplied with a constant (0.7)	cm
16	Chlorophyll	Flowering	By recording chlorophyll data using a SPAD chlorophyll machine	
18	Average ear height	Milk-dough stage	From ground level to the node bearing the uppermost ear.	cm
19	Plant height	Milk dough stage	From ground level to the node bearing the uppermost ear.	Cm
20	Anthesis silking interval		A ratio of ear height and plant height	
21	Number of rows per cob	Before shelling	After harvest by counting the number of rows on 5 randomly selected cobs	
22	Number of ears per plant	During harvest	By counting the number of ears in 5 random selected plants	
24	Rachis diameter	Before shelling	By measuring from the tip of the cob up to it end	cm
25	Cob diameter	Before shelling	By measuring from the tip of the cob up to the start of a penducle using a ruler	cm
26	1000 kernel weight	After shelling	Adjusted to 10% moisture content	g
27	Grain yield	After shelling	Shelled grain weight per plot adjusted to 12% grain moisture and converted to tons per hector.	t/ha
28	Stem lodging	Harvest	Measured as percentage of plants that show stem lodging , that is, those stems that are broken below the ear	
29	Root lodging	Harvest	Measured as percentage of plants that show root lodging, that is, those stems that are inclining by more than 45%.	
30	Ears per plant	Harvest	Number of harvested ears with more than 10 kernels per plant harvested	
31	Ear position		Ratio of ear height and plant height	
32	Husk cover	Before harvest	Scoring ears for proportion of ear exposed by husk observed on a plot basis	

Appendix 14 Results for quantitative traits measured on 13 varieties

Variety	Days to 50% P.S.	Days to 50% S.E.	ASI	Average PH	Average EH	EPO	Chlorophyll	Leaf area	Number of leaves	Venation	Tassel length	Husk cover
ZM 305	74.33_{a}	82.00^{a}	7.67^{c}	282.40^{b}	146.13^{a}	0.51^{ab}	$58.40b^{c}$	484.78	12.89	14.00	4.21	0.48
ZM 423	78.33_{b}	83.67^{ab}	5.33^{c}	301.07^{b}	154.07^{ab}	0.51^{ab}	$58.93b^{c}$	478.02	15.11	12.44	4.71	0.3
ZM 501	79.33^{bc}	84.00^{abc}	4.67^{bc}	279.73^{ab}	127.27^{bcd}	0.46^{a}	$58.80b^{c}$	474.24	13.56	12.11	3.97	0.5
ZM 525	80.00^{bc}	85.00^{abc}	5.00^{bc}	288.20^{b}	154.40^{bcd}	0.53	64.70^{d}	499.79	14.78	12.00	4.03	0.53
ZM 621	87.0^{d}	94.00^{g}	7.00^{c}	296.20^{b}	147.47^{cd}	0.50^{a}	62.57^{cd}	487.79	12.78	11.89	3.97	0.61
ZM 627	85.67^{d}	87.00^{cd}	1.33^{a}	296.67^{b}	168.33^{d}	0.57^{b}	63.97^{cd}	458.00	13.78	13.11	3.94	0.58
BR993	91.33^{e}	93.67^{fg}	2.33^{ab}	301.33^{b}	166.00^{d}	0.55^{b}	51.17^{a}	499.28	13.89	12.33	3.80	0.54
COMP4	93.00^{e}	95.67^{g}	2.67^{ab}	300.67^{b}	164.67^{d}	0.55^{b}	62.03^{cd}	513.72	13.33	13.11	4.38	0.18
OBATANPA	87.00^{d}	94.33^{g}	7.33^{c}	284.40^{b}	154.60^{cd}	0.54^{b}	62.93^{cd}	507.71	14.22	13.56	4.52	0.48
AFRIC 1	87.00^{d}	94.00^{g}	7.00^{c}	300.47^{b}	164.93^{d}	0.55^{b}	58.10^{bc}	489.70	14.00	11.67	4.06	0.37
NC	86.33^{d}	89.67^{de}	3.33^{ab}	227.67^{a}	110.11^{ab}	0.48^{a}	60.17^{cd}	476.77	13.78	14.78	4.24	0.4
OKAVANGO	78.67^{bc}	90.67^{ef}	12.00^{d}	242.33^{a}	126.65^{bc}	0.52^{a}	56.23^{b}	451.49	14.67	12.67	4.11	0.41
PAN 6479	80.33^{c}	83.67^{ab}	3.33^{ab}	231.11^{a}	100.17^{a}	0.43^{a}	58.57^{bc}	526.96	14.22	12.67	4.46	0.42
Means	**83.72**	**89.03**	**5.31**	**279.40**	**144.98**	**0.52**	**59.74**	**488.33**	**13.92**	**12.79**	**4.18**	**0.45**
$P_{(0.05)}$	***	***	***	***	**	**	***	**NS**	**NS**	**NS**	**NS**	**NS**
LSD	**1.74**	**3.38**	**3.51**	**34.88**	**37.18**	**0.09**	**5.04**	**66.62**	**2.37**	**3.09**	**0.67**	**0.24**

Appendix 14 continued.....

Variety	Stem thickness	Stem lodging	Root lodging	Cob diameter	Cob length	Row number	Kernel type	Rachis diameter	EPP	1000KWT	grain yield
ZM 305	2.67^{ab}	0.65^{a}	0^{a}	4.43^{abcde}	17.03^{a}	13.73^{a}	2.67	1.45	1.09^{ef}	0.351^{cd}	3.38^{ab}
ZM 423	2.93^{cd}	0^{a}	0.64^{a}	4.27^{abc}	19.13^{ab}	14.13^{a}	2.00	1.42	0.99^{cd}	0.31^{b}	3.83^{ab}
ZM 501	2.6^{a}	0.6^{a}	1.19^{a}	4.13^{a}	17.67^{ab}	13.73^{a}	1.67	1.17	1.12^{f}	0.336^{c}	4.2^{b}
ZM 525	$2.9b^{cd}$	0^{a}	0^{a}	4.36^{abcd}	18.54^{ab}	13.60^{a}	1.67	1.13	$1.0d^{ef}$	0.351^{cd}	4.46^{b}
ZM 621	3.27^{f}	0^{a}	0^{a}	4.71^{e}	19.03^{ab}	14.53^{a}	2.00	1.21	0.98^{cd}	0.348^{cd}	4.34^{b}
ZM 627	3.23^{f}	4.62^{b}	0_{a}	4.34^{abcd}	18.67^{abc}	14.67^{a}	2.00	1.25	0.94^{bc}	0.354^{cd}	3.89^{ab}
BR993	2.8^{abc}	0^{a}	1.59^{a}	4.20^{ab}	18.37^{bc}	14.27^{a}	2.33	0.95	0.93^{bc}	0.312^{b}	2.72^{a}
COMP4	3.1^{de}	1.36^{a}	0^{a}	4.34^{abcd}	19.85^{bcd}	14.93^{a}	2.00	1.17	0.84^{a}	0.269^{a}	3.87^{ab}
OBATANPA	$3.2d^{ef}$	1.26^{a}	5.84^{a}	4.61^{de}	19.53^{bcde}	16.93^{a}	3.33	1.60	0.89^{ab}	0.365^{d}	3.52^{ab}
AFRIC 1	2.93^{cd}	1.28^{a}	7.75^{a}	4.53^{de}	19.30^{cde}	14.67^{a}	2.67	0.96	1.01^{cde}	0.345^{c}	3.97^{ab}
NC	2.97^{cde}	6.68^{b}	3^{a}	4.53^{de}	21.27^{cde}	13.87^{a}	1.67	1.02	0.93^{bc}	0.362^{cd}	3.89^{ab}
OKAVANGO	3.3^{f}	6.34^{b}	4.43^{a}	4.47^{bcde}	20.67^{de}	11.60^{a}	1.00	1.17	0.97^{bcd}	0.39^{e}	4.22^{b}
PAN 6479	2.97^{cde}	0.67^{a}	0^{a}	4.50^{bcde}	21.29^{e}	13.60^{a}	3.00	1.15	10.5^{f}	0.353^{cd}	6.37^{c}
Means	**2.99**	**1.80**	**1.88**	**4.42**	**19.26**	**14.17**	**2.15**	**1.20**	**1.71**	**0.34**	**4.05**
$P_{(0.05)}$	*******	*****	**NS**	*****	******	*******	**NS**	**NS**	*******	*******	*******
LSD	**0.24**	**4.44**	**6.05**	**0.32**	**1.98**	**1.37**	**0.34**	**0.54**	**0.082**	**0.02**	**1.25**

Appendix 15 Yield advantages and disadvantages (%) of the hybrid variety (Pan 6479) versus the open pollinated varieties

	Environments [1]																
	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	OVERALL YLD ADVA.
G1	25.04	43.88	17.42	29.91	26.28	-22.91	-9.85	20.77	-31.58	-7.02	28.45	11.36	33.93	11.26	23.26	25.46	16.46
G2	24.51	40.00	39.61	21.65	10.24	-44.49	-7.21	25.44	-8.27	-38.80	17.35	3.22	20.44	32.27	38.67	5.91	12.96
G3	28.95	32.56	14.61	-25.64	20.48	-13.66	-10.96	27.54	-12.03	-28.43	26.46	11.17	28.17	10.08	24.77	5.49	11.76
G4	9.24	30.70	14.61	-31.34	21.50	-22.47	-25.52	26.14	-24.44	-22.07	8.11	17.05	31.55	10.92	16.92	15.19	7.73
G5	25.58	31.47	1.12	50.43	29.86	8.37	-1.66	22.75	4.89	-24.41	17.92	33.71	33.13	21.68	11.48	7.45	18.30
G6	22.02	40.62	23.60	47.86	21.84	-18.06	-9.99	5.25	7.14	-18.73	19.77	11.55	31.94	7.39	20.85	6.61	13.41
G7	37.48	59.84	34.27	-21.65	27.30	-42.07	18.03	30.22	-25.56	-19.73	39.40	10.42	38.69	32.94	37.46	32.35	22.98
G8	31.26	43.88	29.49	-5.13	23.55	-11.01	14.56	22.75	-4.89	-30.43	32.72	17.80	30.95	18.99	12.39	32.63	19.97
G9	45.12	47.29	27.25	39.89	41.13	-26.87	10.96	25.90	-42.48	-6.69	33.00	7.95	42.26	25.71	12.99	25.74	22.96
G10	39.08	39.69	2.25	35.90	17.24	27.31	24.41	16.80	-25.56	-10.37	14.37	8.33	15.28	23.19	49.55	15.89	19.93
G11	39.79	39.53	37.64	18.52	27.47	15.86	-15.67	20.07	-21.80	-13.38	28.88	35.80	19.84	27.90	32.63	15.89	20.62
G12	21.85	34.11	19.38	17.38	18.77	-17.62	10.54	23.22	-2.26	-3.01	16.79	11.93	27.78	26.72	48.34	30.24	19.05
OVERALL YLD ADVA.	29.16	40.30	21.77	14.81	23.81	-13.97	-0.20	22.24	-15.57	-18.59	23.60	15.03	29.50	20.76	27.44	18.24	17.18

[1] Yield advantages were calculated by obtaining the yield difference between each OPV and the hybrid and expressed as a percentage