Recurrent Selection for Gray Leaf Spot (GLS) and Phaeosphaeria Leaf Spot (PLS) Resistance in Four Maize Populations and Heterotic Classification of Maize Germplasm from Western Kenya

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Abstract

Maize (*Zea mays* L.) production is constrained by a number of stresses, amongst the most important are gray leaf spot (GLS) caused by a fungus *Cercospora zeae-maydis* Tehon and E.Y. Daniels and Phaeosphaeria leaf spot (PLS) caused by *Phaeosphaeria maydis* (Henn.). The diverse germplasm comprising farmer collections and exotic material used in the medium and highland altitudes maize breeding programmes in western Kenya has not been improved for resistance to the two diseases. Heterotic patterns of germplasm from this region have also not been studied. Therefore, the objectives of this study were to (i) assess the prevalence, importance, and farmers' perceptions of GLS and PLS, (ii) characterize maize germplasm collections into their heterotic groups and (iii) improve four maize populations for GLS and PLS resistance through recurrent selection.

The participatory rural appraisal (PRA) was conducted at three sites in western Kenya during the 2005/2006 cropping season. Data was generated using a checklist in group discussions with 109 male and 123 female farmers as well as key informants. Constraints were identified and prioritised. The five most limiting, in order of importance, were low soil fertility, poor varieties and seed, drought, *Striga*, pests and diseases (GLS and PLS). Gray leaf spot and PLS were reported in all sites but farmers did not know the causes of these diseases. Farmers preferred local varieties Tiriki, Anzika and Kipindi due to their greater resistance to diseases than commercial hybrids. Farmer criteria for variety selection were low fertilizer, *Striga* and disease resistance, drought tolerance, closed tips, and high yield potential. Due to the high cost of hybrid seed farmers selected and planted their own seed from advanced generations from previous seasons. Across all the sites, yield gap between on-farm and expected yield potential was estimated as ranging from 4.73t ha^{-1} to 5.3t ha^{-1} mainly due to the identified constraints. Therefore maize breeding should focus on addressing important maize production constraints and farmers' preferences identified in this study in developing varieties that will increase maize yields on-farm.

During 2005/2006, seventy 77 testcrosses were developed through crossing 47 germplasm collections with four population testers, Kitale synthetic II (KSII), Ecuador 573 (EC 573), Pool A and Pool B. Crosses and testers were evaluated at Kakamega during 2006/2007 in a 9 x 9 triple lattice design. Significant ($p < 0.05$) differences in grain yield, ear height, days to 50% anthesis, GLS and PLS resistance were observed. Both general and specific combining ability effects (GCA and SCA, respectively) were significant ($p < 0.01$), with SCA accounting for more than 50% of the variation for GLS, PLS and yield and less than 50% for ear height, days to 50% anthesis and silk. This indicated that both additive and non-additive gene effects were important but non-additive gene effects were more important in conditioning these traits. High SCA effects indicated high heterosis between collections and populations. Both yield heterosis and SCA were used to study heterotic patterns, but percentage yield heterosis data was used to classify these materials into heterotic groups. Based on significance ($p < 0.05$) of percentage yield heterosis as a primary factor for classification, seven collections were classified to Pool A, 17 to Pool B, 12 to KSII and 6 to EC 573 heterotic groups. The study indicated that germplasm collections belong to distinct heterotic groups therefore they can be infused into these populations (Pool A, Pool B, KSII and EC 573).

Four populations, KSII, EC 573, Pool A and Pool B were subjected to one cycle of reciprocal recurrent selection (RRS) and two cycles of simple recurrent selection (SRS) during the 2004-2006 cropping seasons at Kakamega. Response to selection was assessed by evaluating C_0, C_1 and C_2 and four commercial checks in a randomised complete block design in three replications at Kakamega and Kitale during 2007. All cycles except C_0 of Pool A were more resistant to GLS than the three checks, H623, KSTP94 and PHB3253. Response to selection for GLS was significant ($p < 0.01$) in the desired direction. Gains ranged from -32.2% to 6.4% $cycle^{-1}$ for RRS and 0.0% to -61.3% $cycle^{-1}$ for SRS. Heritability estimates of between 59% and 76.3% for GLS and 39% and 80% for PLS were observed indicating that both GLS and PLS can be improved through selection. Significant negative correlations between GLS and yield were observed in Pool A C_0 ($r = -0.947$, $p < 0.01$) and between yield and PLS in Pool A C0 ($r = -0.926$, $p < 0.01$). These indicated gain in yield as GLS and PLS were selected against. Generally, SRS out performed RRS method both in genetic gain and time, as indicated by gain of -61% for SRS and -32.2% for RRS, respectively. Two cycles of selection were achieved in two years with SRS as compared to only one with RRS. These results clearly demonstrated that it is possible to improve for GLS resistance using simple and reciprocal recurrent selection methods.

The main constraints to maize production in Western Kenya were low soil fertility, *Striga,* drought, lack of seed and diseases. Farmers preferred varieties that can do well under the constraints mentioned. Local collections belonged to distinct heterotic groups with good resistance to GLS and PLS and were highly heterotic to four maize population testers with both SCA and GCA effects being important in conditioning GLS and PLS resistance. Recurrent selection methods were found to improve maize resistance to GLS and PLS. Breeding should therefore, focus in development of hybrids and improvement of populations using these local collections by employing SRS and RRS selection methods with identified constraints and farmer preferences in mind.

Declaration by the Candidate

The work reported in this thesis is based on my original work and ideas. It has not been presented for a degree in any other university.

Signed ……………………………………. Date …………………………….

Kwena, Philip Onyimbo

Declaration by the University Supervisors

This thesis has been submitted for examination with our approval as University of Kwa Zulu Natal Supervisors

Sign ……………………………………….. Date ……………………………

Prof. Pangirayi Tongoona (Principal Supervisor)

Sign…………………………………………Date ……………………………

Dr John Derera (Co-supervisor)

Dedication

This work is dedicated to

My wife

NELLEY REBAH ONYIMBO

My parents

GEORGE ANDREW KWENA, JOSEPHINE KWENA

My brother

DANIEL WANYANGU KWENA

My children

BRENDA KWENA, DENZEL K .KWENA, ELDAD T. KWENA, PATIENCE A. KWENA

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Abbreviations

ANOVA	Analysis of variance
CBOs	Cereal Bank Organizations
C_0	Cycle zero (Original population)
C_1	Cycle one
C_2	Cycle two
CIMMYT	International Centre for Maize and Improvement
DF	Degree of freedom
DFID	Department for International Development
EC 573	Ecuador 573
FAO	Food Agriculture Organization
FTC	Farmer Training Centre
GCA	General combining ability
GOK	Government of Kenya
GLS	Gray leaf spot
ITK	Indigenous Technical Knowledge
KSTP	Kakamega synthetic population
KARI	Kenya Agricultural Research Institute
KSII	Kitale synthetic II
LR	Landraces
MASL	Metres above sea level
MC	Moisture content
MRRMP	Mbambe Rural Resource Management Programme
MOA	Ministry of Agriculture
NARC	National Agricultural Research Centre
OPVs	Open pollinated varieties
PCI	Participatory crop improvement
PHB	Pioneer hybrid
PLS	Phaeosphaeria leaf spot
PPB	Participatory plant breeding
PRA	Participatory rural development
RFLP	Restriction fragment length polymorphism
RRS	Reciprocal recurrent selection
RPK	Resource rural programme Kenya
SACRED	Sustainable Agriculture Centre for Research Extension and Development in Africa

SCA	Specific combining ability
SRS	Simple recurrent selection
SSR	Simple sequence repeat

Introduction

Background Information

Maize is the most important staple food crop in Kenya, forming a major component of the diet for both urban and rural populations. It is consumed as a thick porridge, *Ugali* in most households with an annual per capita consumption of about 125kg of grain which is among the highest in the world (Pingali and Pandey, 2001). Estimates indicate that in Nyanza and Western Kenya provinces, 200kg of grain per capita is required although the actual amount per capita could be less due to high levels of poverty in the region (Odongo *et al.,* 2004). It is grown in almost all agro-ecological zones, on both large and small-scale farms. Small-scale farmers produce over 70% of the total maize that accounts for about 80% of the total maize area under production; however large scale farmers contribute significantly to marketed maize (Karanja, 1996). The total land area under maize production in Kenya is about 1.4 million hectares with an annual average production estimated at 2.8 million metric tons, giving a national mean yield of 1.7 metric tons ha^{-1} under farmers' conditions (FAO, 2006) while there is potential for increasing yield to 6t ha^{-1} through the use of improved varieties in terms of disease and pest resistance and good husbandry practices (GOK, 2005). These poor yields in Western Kenya are attributed to a range of factors which include unreliable rains, labour constraints at critical periods, low and declining soil fertility, use of recycled hybrid seed over several seasons, weeds (*Striga*), pests and disease problems (Odendo *et al*., 2001).

Gray leaf spot (GLS) caused by *Cercospora zeae maydis* is the most serious disease of maize in Kenya (Kwena and Kalama, 1999). It was first reported in 1996 on seed farms in Kitale, Western part of the country and has since spread to all maize growing areas in Kenya (Kwena and Kalama, 1999). In South Africa, Ward and Nowell (1997) reported losses of 58.4% and 50.1% of two hybrids, RS 5206 and CRN 4526, respectively, for early planted materials and 73.8% and 88.5% for materials planted 37 days later, whereas Okori *et al*. (2003) reported yield losses of around 50% in East Africa.

Phaeosphaeria leaf spot (PLS) caused by *Phaeosphaeria maydis* (Henn.) is becoming a very important disease of maize having been reported in Central America, Asia, South

Africa (Carson, 2005) and in Kenya (Njuguna *et al*., 1992). Yield losses of up to 60% have been reported (Paccola-Meirelles *et al*., 2001). Currently PLS is showing continuous high increase in spread, severity and incidence and therefore demands immediate attention as very little research has been carried out on this disease (personal observation).

High and sometimes complete yield losses occur due to various disease pathogens individually or in complexes. Disease causing pathogens such as GLS and PLS have been reported to play major roles when interacting with other environmental conditions in limiting maize production (Bigirwa *et al.,* 2001; Bhatia and Munkvold, 2002). From the participatory rural appraisals conducted in 1997 in the Rift Valley province and parts of Western Kenya by the Department for International Development (DFID) and Soil management projects, farmers attributed high yield losses to several diseases, GLS and PLS complexes inclusive (Kalama *et al*., 1987). In environments conducive to disease development, GLS and PLS complexes can drastically reduce yields for the already highly constrained resource poor farmers.

In Kenya, maize breeding programmes have relied on four heterotic groups developed from collections from farmers and introductions. These collections might be having high genetic variations since farmers in the region exchange their germplasm across the borders of Kenya, Uganda and Tanzania. The Kitale and Kakamega programmes have two heterotic groups each, KSII, EC573 and Pool A and Pool B, respectively (KARI, 2004). The existence of these heterotic groups also indicates there is heterosis within the germplasm collections from farmers but the inheritance of most of them is unknown and heterotic patterns have not been clearly established among the farmer germplasm. Selection method used for population improvement is influenced by the heterotic patterns and in any breeding programme, the understanding of heterotic groups or patterns is essential if heterosis is to be exploited fully (Preciado-Ortiz and Johnson, 2004). To systematically exploit heterosis in hybrid maize breeding programmes, knowledge of which heterotic groups the collections belong to before infusion into the populations used in the programme is essential. This will result in combining good heterotic patterns that would be useful in breeding programmes to obtain early, high-yielding and disease resistant hybrids.

Selection and use of resistant germplasm from local collections or introductions has been seen as the most feasible approach for the resource poor farmer (Abebe and Ayodele, 2005; Pratt and Gordon, 2006). Selection of population improvement method depends on the objective and the heterotic patterns and gene action. Reciprocal recurrent selection methods for interpopulation improvement that select for both GCA and SCA are very useful, as the purpose of population improvement is to develop new lines with higher combining ability for development of superior hybrids and population improvement and identification of testers. This method has been used successfully in maize breeding programmes in breeding for downy mildew resistance (De Leon *et al*., 1993). Therefore, as a foundation of hybrid development, intrapopulation improvement alone is not adequate for SCA. Use of RRS is essential for interpopulation improvement, inbred line and hybrid development. This method that utilises both GCA and SCA variation is useful in selection for GLS, as additive and non-additive gene actions confer resistance to GLS and PLS (Clements *et al*., 2000; Lehmensiek *et al*., 2001).

Although chemical control has been proposed as an alternative method of control (Wegulo, 1994), however the income status of the majority of smallholder farmers does not permit an economic chemical control programme for GLS and PLS. Furthermore, these farmers are already faced with declining soil fertility, labour constraints and high cost of hybrid maize seeds. It is imperative therefore that any integrated control programme for GLS and PLS be based on cultural methods and host plant resistance. Although deployment of tolerant or resistant materials is the most cost effective and efficient approach (Ward, 1996), currently there are no resistant commercial hybrids in Kenya to reduce the yield losses being experienced due to GLS and PLS (KARI, 2004). Given the apparent potential for these diseases, continued search for maize germplasm through selection that will lead to higher levels of resistance with preferred farmer characteristics is desirable and justifiable.

Currently, PRAs involving farmers in the research agenda have become essential in most breeding strategies. In Kenya, despite 40 varieties having been developed by KARI, adoption is very low at farm level. One of the factors has been due to the conventional breeding that breeders have been employing that have proved to be ineffective since farmer constraints and priorities in terms of preferences were not considered adequately (Witcombe *et al*., 2006). Participatory Rural Appraisal, where farmers, together with researchers are both involved in the whole process has been found to be very effective (Morris and Bellon, 2004). In Kenya, PRAs have been successful tools in constraint identification for *Striga* and stem borer in Western Kenya (Odendo *et al*., 2001). Formulation of a feasible research agenda and for effective maize breeding demands the identification of constraints, perceptions and desired maize variety characteristics in collaboration with farmers. Therefore, there is a need to assess the prevalence, importance and farmers perceptions of GLS and PLS.

Problem statement

The major disease constraints on maize production in Kenya are GLS and PLS resulting in high yield losses due to the use of susceptible varieties which were developed from populations with low resistance levels for GLS and PLS. Few or no studies have been conducted on maize germplasm improvement in the medium and highlands altitudes of Kenya focusing on resistance to GLS and PLS. Maize germplasm collections might contain some valuable variability and useful traits that can be utilised in the four major heterotic groups to broaden their genetic base, but it is not known if landraces held by farmers belong to different heterotic groups.

General objectives

The major objective of the study is to improve maize resistance to GLS and PLS in Kenyan medium and highland maize populations through recurrent selection.

Specific Objectives

The objectives of the study were:

1) To assess the prevalence, importance and farmers' perceptions of GLS and PLS in small holder farming systems of medium and highland maize growing areas of Kenya

2) To improve GLS and PLS resistance in Kenyan medium and highland maize populations through simple (SRS) and reciprocal recurrent selection (RRS)

3) To compare SRS and RRS in breeding for GLS resistance

4) To study the heterotic orientation of collected maize germplasm in relation to the medium and highland maize heterotic groups in Kenya

5) To determine the combining ability and gene action influencing the inheritance of GLS and PLS resistance in Kenyan maize germplasm

Hypotheses

The following hypotheses were tested in the study:

1) Gray leaf spot and PLS are prevalent and important in Kenyan maize growing areas and farmers have some valuable information that could be used in breeding strategies to develop disease resistant germplasm

2) The highland and medium altitude maize populations have favourable GLS and PLS resistance alleles that could be concentrated through cycles of recurrent selection

3) Response of maize germplasm to GLS and PLS resistance due to selection is influenced by method of selection.

4) Maize collections from western Kenya belong to distinct heterotic groups and can be used in the improvement of medium and highland maize germplasm

5) Both additive and non-additive gene action conditions GLS and PLS resistance in the highland and medium populations and collections

Structure of the thesis

The foregoing objectives and hypotheses are addressed in different chapters as follows:

1) Introduction

2) Chapter 1 Literature review

3) Chapter 2 Participatory Rural Appraisal

4) Chapter 3 Reciprocal recurrent selection and Simple recurrent selection for GLS in medium and highland populations in Kenya

4) Chapter 4 Heterotic classification and combining ability of local and exotic medium and highland maize germplasm in western Kenya

6) Chapter 5 Overview

Reference

Abebe, M., and M. Ayodele. 2005. Genetic analysis of resistance to gray leaf spot of mid-altitude maize inbred lines. Crop Science 45:163-170.

Bhatia, A., and G.P. Munkvold. 2002. Relationships of environmental and cultural factors with severity of gray leaf spot in maize. Plant Disease 86:1127-1133.

Bigirwa, G., R.C. Pratt, E. Adipala, and P.E. Lipps. 2001. Assessment of gray leaf spot and stem borer incidence and severity on maize in Uganda. African Crop Science Conference 4:469-474.

Carson, M.L. 2005. Yield loss potential of Phaeosphaeria leaf spot of maize caused by Phaeosphaeria maydis in the United States. Plant Disease 89:986-988.

Clements, M.J., J.W. Dudley and D.G. White. 2000. Quantitative trait loci associated with resistance to gray leaf spot of corn. Phytopathology 90:1018-1025.

De Leon, C., G. Granados, R.N. Wedderburn, and S. Pandey. 1993. Simultaneous improvement of downy mildew resistance and agronomic traits in tropical maize. Crop Science 33:100-102.

FAO, 2006. Food and Agricultural Organization Production Year Book.

GOK, 2005. Kakamega district development plan (2001-2005). Nairobi, Government printer, Kenya.

Karanja, D.D. 1996. An economic and institutional analysis in Kenya: MSU international development working paper No. 57: 3-5.

Kalama, P., G.A Ombakho, D. Ligeyo, W. Kiiya, P.O. Kwena, F. Ndungu, J.Baratonjo, S. O. Ondore and P. Chirchir. 1987. The faming systems of Chebosta. p. 142-153. *In* Participatory rural appraisal of the farming systems of the North of rift valley province, Kenya. KARI, Kenya.

KARI. 2004. Annual report. Cereals maize breeding. KARI, Kenya.

Kwena, P.O., and P. Kalama. 1999. A survey on crop pest and farmer management practices. In: the North Rift Valley province of Kenya. Towards increased use of demand driven technology. A paper presented at a conference Nairobi. 23rd – 26th March 1999. Kenya.

Lehmensiek, A., A.M. Esterhuizen, D. van Staden, S.W. Nelson, and A.E. Retief. 2001. Genetic mapping of gray leaf spot (GLS) résistance genes in maize. Theoretical Applied Genetics 103:797-803.

Morris, L., and R. Bellon. 2004. Participatory plant breeding research: Opportunities and challenges for international crop improvement system. Euphytica 136:21-35.

Njuguna, J.G.M., J.C. Kedera, L. Muriithi, S. Songa and B. Odhiambo. 1992. Overview of maize diseases in Kenya. *In* Proceedings of a workshop, Review of the National Maize Research Programme, Kakamega. Nov, 1992. KARI/ISNAR Management training linkage project. KARI, Kenya.

Odendo, M., H. De Groote and O.M. Odongo. 2001. Assessment of farmers' reference and constraints to maize production in moist mid-altitude zone of western Kenya. A paper presented at the 5th international conference of the African crop science society, Lagos. October 21-26, 2001. Nigeria.

Odongo, O.M., H. Wakhonya and G. Ambani. 2004. Maize research. KARI, Kakamega annual report. KARI, Kenya.

Okori, P., J. Fahelson, P.R. Rubaihayo, E. Adipala and C Dixelius. 2003. Assessment of genetic variation among east African Cercospora zeae maydis- populations. African Crop Science Journal 11:75-88.

Paccola-Meirelles, L.D., A.S. Ferreira, W.F. Meirelles, I.E. Marreil and C.R. Casela. 2001. Detection of a bacterium associated with a leaf spot disease of maize in Brazil. Phytopathology 149: 275-279.

Pingali, P.L., and S. Pandey .2001. Technological opportunities and priorities of the public sector. *In* P.L. Pingali (ed.) CIMMYT 1999-2000 World maize facts and trends. Meeting world maize needs: Mexico, D.F. CIMMYT.

Pratt, R.C., and S. Gordon. 2006. Breeding for resistance to foliar pathogens of maize. Plant Breeding Review 27:119-173.

Preciado-Ortiz, R.E and B.E. Johnson. 2004. Potential use of maize heterotic patterns for grouping and adapting exotic germplasms. Maydica 49:199-208.

Ward, J.M.J. 1996. Epidemiology and management of gray leaf spot disease, a new disease of maize in South Africa. PhD. Thesis, University of Natal, Pietermaritzburg, RSA.

Ward, J.M.J and D.C. Nowell. 1997. Epidemiology and management of gray leaf spot disease, a new disease of maize in South Africa. In: Proc. 11th SA Maize Breed Symp. Cedara 1994, Grain Crop Research Institute, Department of Agriculture, Pretoria, RSA.

Wegulo, S.N. 1994. Benefits assessment of fungicide usage in seed corn production in Iowa. MSc. Thesis, Iowa State University, Ames, Iowa, USA.

Witcombe, J., S. Gyawali, S. Sunwar, S. Sthapit and K. Joshi. 2006. Participatory plant breeding is better described as highly client –oriented plant breeding II. Optional farmer collaboration in the segregating generations. Experimental Agriculture 32:445-460.

Chapter 1: Literature Review

1.1 Introduction

In Kenya, maize is the most important staple food crop being grown by both small and large scale farmers (Karanja, 1996). Despite the widespread dissemination of hybrids developed by Kenya Agricultural Research Institute (KARI), yields of maize are generally low with the majority of farmers realising 1.7t ha^{-1}. The problem of pests and diseases in KARI maize breeding programme can be attributed to the mandate of the programme, which in its inception in 1955 was to breed maize with high yields. At first, the programme focused on high potential areas and later other marginal areas. Since its inception the programme has relied on two heterotic groups, Kitale synthetic II (KSII) and Ecuador 573 (EC 573) for hybrid and open pollinated varieties (OPVs) development. The programme by 1980 had done twelve cycles of recurrent selection for yield in KSII and EC 573 with no emphasis on pests and diseases. Since then, no improvement of disease resistance has been done in these two populations through selection. Heterotic groups, Pool A and Pool B were improved only for low and high nitrogen environments. This resulted in high incidences of pests and diseases, especially stalk borer, smut, rusts, northern corn leaf blight, ear rots and stalk rots. In early 1990’s, the programme incorporated disease and insect pests as part of its breeding strategy but very little has been achieved so far on population improvement of disease resistance through recurrent selection. Maize in Kenya is still constrained by serious and widespread diseases due to little focus that has been put on breeding for resistance. Among the most serious diseases threatening maize production are GLS and PLS (KARI 2004).

1.2 Gray Leaf Spot

1.2.1 Distribution

Gray leaf spot (GLS) is the most important foliar disease limiting maize production in East African countries (Bigirwa *et al*., 2001). It was first recorded in Illinois in 1924 (Tehon and Daniels, 1925). The disease has since spread and has been reported in many countries; Central America, Brazil (Paccola-Meirelles *et al*., 2001) and China

(Coates and White, 1998). In Africa, the disease has been observed in Zambia, Malawi, Mozambique, Nigeria, Ethiopia, Cameroon, Zaire, Republic of South Africa, Swaziland, Zimbabwe, Tanzania (Nowell, 1997) and in Uganda (Bigirwa *et al.,* 2001).

In Kenya, the disease was first observed in 1996 (Kwena and Kalama, 1999). It occurred in maize seed growing areas of Western Kenya around Kitale and since then it has spread to Kakamega, Kissi, Uasin Gishu, Elgeyo, Marakwet, Busia, Siaya and most maize growing areas in the country. Varying yield losses have been reported in several countries. Okori *et al.* (2003) reported losses of up to 50% in Uganda. In South Africa, yield reductions from 30% to 60% depending on hybrid and environment have been reported (Ward *et al.,* 1999). This rapid spread of GLS, with high yield losses in Africa and in particular Kenya, where the majority of maize producers are small-scale and resource poor farmers, could have serious implications on food security, as maize is a staple food for most households in Kenya.

1.2.2 Causal Organism

The causal organism of GLS is *Cercospora zeae-maydis* (Tehon and E. Y. Daniels, 1925) a polycyclic pathogen (Chupp, 1953; Stromberg and Donahue, 1986). It was first described by Tehon and Daniels (1925). However, Kingsland (1963) and Latterell and Rossi (1983) found some variations from the original description. It was found to be a different species from the pathogen that causes gray leaf spot of sorghum, *Cercospora sorghi*. Wang *et al*. (1998) identified two siblings, type I and II. Type II has been found to be prevalent in the United States (Carson *et al*., 2002) and sub-Saharan Africa (Okori *et al*., 2003). Although isolates of the pathogen have been found to vary in aggressiveness, no races so far have been reported to occur (Carson *et al.,* 2002). Varying degrees of virulence demonstrated by GLS on hybrids in Kenya may be dependent on the two sibling types (Carson *et al*., 2002). The degree of resistance expressed in a variety depends on the type of sibling present in the test area. Many ‘hot spot’ sites should be considered for effective screening programmes to capture the various pathogen populations available. Therefore, to maximize gain from selection for GLS resistance, locations with favourable environment for pathogens and with the most highly aggressive type should be considered as test sites (Carson *et al*., 2002).

1.2.3 Factors Influencing Spread and Severity

Gray leaf spot severity and spread has been found to be influenced by debris, minimum tillage, high humidity, temperature and susceptible varieties (Bhatia and Munkvold, 2002). The pathogen survives in infected maize debris that serves as the primary source of inoculum for the next growing season (Bhatia and Munkvold, 2002). Conidia produced as inoculum are slightly curved, hyaline, multiseptate, measuring 70-180μm long, 5-6μm wide and tapering 2-3μm and air borne, making them move freely in the air to infect fresh leaves (Latterell and Rossi, 1983).

Reduced tillage practices that leave a considerable amount of undisturbed crop residue on the soil surface favour the development of GLS (de Nazareno *et al.,* 1993; Bhatia and Munkvold, 2002). In South Africa and USA, high levels of GLS severity have been associated with increased use of conservation tillage (Bhatia and Munkvold, 2002). Another factor is plant density where Beckman and Payne (1982), Payne and Waldron (1983), and Ayers *et al*. (1984) found increased GLS severity with increased plant populations. Studies by Stromberg and Donahue (1986) showed that control could be achieved by even a single year of crop rotation.

It has been observed that continuous cultivation of maize in one field and prolonged periods of high relative humidity and dew increases prevalence of GLS (Stromberg and Donahue, 1986). For leaf infection to take place, leaf surface must be constantly wet for 11 to 13 hours with relative humidity in the leaf canopy of 90%, for a period of 12 to 13 hours (Rupe *et al*., 1982). Severe levels of infection have been observed in extended periods of overcast days and high relative humidity. This has further been supported by observations of high levels of disease in fields bordering trees and streams and by the fact that GLS is not seen until anthesis (Latterell and Rossi, 1983). Temperature is another factor necessary for the development of GLS disease. Temperatures of between 22ºC and 30ºC have been found to be optimum for GLS development (Ward, 1996; Nowell, 1997).

Gray leaf spot pathogen has been established to survive very harsh conditions. Thorson and Martinson (1993) found out that a single continuous period of high humidity required during germination is not necessarily a requirement for infection. In their study, they found out that germ tube development depended on relative humidity. It ceased to develop when the relative humidity was lowered to 65%, but resumed again when the humidity was increased to 95%. The germ tube does not die, provided this dry period is not prolonged. Under these harsh conditions the fungus becomes dormant and disease development and sporulation ceases, only to resume when conditions are favourable (Thorson and Martinson 1993). This explains why GLS is very severe in Western Kenya with bimodal type of rainfall where maize is grown twice in a year. This provides long conducive periods for the pathogen to multiply, whereas in the Kitale highlands maize is grown only once in a year with an off season of four months from November to March. These areas can serve very well as screening sites to avoid escapes.

1.2.4 Symptoms

The symptoms of GLS disease have been studied extensively (Freppon *et al*., 1996). They are characterised by a halo, and leaf blight. Lesions at first are small, pinpoint and surrounded by a yellow halo, but in about two weeks the lesions elongate and develop into mature sporulating lesions on susceptible germplasm (Freppon *et al*., 1996). Mature lesions are gray to tan colour, rectangular in shape and are 2cm to 6cm long and 2mm to 5mm wide. They run parallel to the veins and are restricted within. Some genotypes display chlorotic fleck lesions instead of large, tan, necrotic lessions. Lesions may coalesce under heavy infestation and result in the entire leaf being blighted. High disease pressure in fields results in the infection of leaf sheaths. Early leaf blight results in significant reduction in photosynthetic area and desiccation that results in stalk deterioration and lodging, due to increased demand for carbohydrates from stalks and root tissue by developing kernels (Lipps *et al*., 1997).

1.2.5 Methods of Controlling GLS disease

1.2.5.1 Cultural Control

One of the control strategies suggested is cultural practices (de Nazareno *et al.,* 1992). Several cultural field practices have been associated with the level of incidence of GLS and manipulation of these practices can play a role in managing the disease. It has been shown that there is a linear relationship between GLS severity and genotype resistance, planting dates and maize surface residue (Bhatia and Munkvold, 2002). Tillage practices have been found to influence the incidence of GLS. Most of the damaging epiphytotics of GLS have been observed in areas where reduced tillage is practised (de Nazareno *et al.,* 1992). This has been attributed to increased levels of inoculum when maize is planted in a field under no tillage with infested residues from previous crop, than when maize is grown under conventional tillage in fields with infested residues (de Nazareno *et al.,* 1992). This is because incorporation of plant debris infested with GLS reduces the ability of the pathogen to over winter (de Nazareno *et al.,* 1992). Management strategy where reduced tillage is minimised plays a role in reducing the incidence of GLS.

Practice of crop rotation and sanitation practices like burning of residues have been found to reduce the incidence of GLS (Ringer and Grybauskas, 1995). Though burning of residues has the effect of reducing the incidence of GLS, it reduces the organic matter of the soil and contributes to soil erosion (Ward and Nowell, 1997).

Harvesting practices have been found to reduce the level of GLS, particularly where maize is harvested for silage early before the disease develops into an epidemic (Ward and Nowell, 1997). Nowell (1997) reported an increase in the severity of GLS in irrigated maize fields, particularly where overhead irrigation and centre pivots have been used.

It has been found that planting date and duration to maturity of maize genotypes influence the severity of GLS. Short season hybrids planted early in the season are less affected. Late maturing hybrids with high yields are affected more because of longer periods of blighting during the grain filling period (Stromberg and Donahue, 1986). The shorter season hybrids reach physiological maturity before the epidemic and thus there is less yield loss (Stromberg and Donahue, 1986). Cultural control practices have their limitations, especially in small holder farms where crop rotation is not feasible. Time of planting also cannot be controlled where farmers' depend on the onset of rain to plant.

1.2.5.2 Chemical Control

Chemicals have been used to control various insect pests and crop diseases. Several fungicides have been used to control GLS. They include protectants such as manconzeb and systemic ones of the benzimidazole and triazole chemical groups. Use of fungicides as means of controlling GLS has been reported to vary in terms of their efficacy and economic feasibility (Martinson *et al*., 1994; Wegulo, 1994; Martinson and Munkvold, 1995). It has been shown that correct timing of fungicide application, number of sprays, prevailing climatic conditions, efficacy of the fungicide group and the level of host resistance are important factors that play a role in effectiveness of fungicide in control of GLS in maize (Wegulo, 1994).

In South Africa and the United States, the use of fungicides to control GLS has been found not feasible in commercial fields. However, with increases in severity and distribution it has been found to be economical to control in seed maize in United States and South Africa (Wegulo, 1994). Ward and Nowell (1997) in South Africa found out that grain yield response was not the best parameter to justify spraying but should be based on expected added income which should exceed extra cost of fungicide application.

Chemical method of control exposes farmers to health risks and can result in environmental pollution. Furthermore fungicides are expensive for poor subsistence farmers and their application demands more labour inputs and technical knowledge on time, method and rates of application. Cultural control strategies have been found to be effective when combined with tolerant or resistant materials that ensure the technology is safe and cost effective (Ward and Nowell 1997)

1.2.5.3 Host plant resistance

The use of resistant maize hybrids for control of GLS has been shown to be most effective (Gevers *et al*., 1994; Nowell, 1997; Menkir and Ayodele, 2005). Work that has been done in other countries indicates the presence of good level of resistance in high yielding commercial hybrids (Gordon *et al*., 2004; Menkir and Ayodele, 2005).

Host plant resistance has been defined as a reduction in the rate of disease increase compared to susceptible genotypes (Ayers *et al.,* 1984; Huff *et al*., 1988; Elwinger *et al*., 1990). Resistance to GLS is expressed as fleck like reactions (Latterell and Rossi, 1983; Ayers *et al*., 1984) and moderate resistance as chlorotic like reactions (Roane *et al.,* 1974). Susceptible genotypes display necrotic lesions (Ayers *et al*., 1984; Latterell and Rossi., 1983; Huff *et al*., 1988).

A number of genotypes with reactions ranging from fleck type lesions to necrotic lesions have been observed in various studies and in maize fields. In Illinois and Virginia evaluations have indicated that, out of 1,237 accessions, 2% are resistant and 2% are partially resistant (USDA-ARS-NGRP, 2004). North Carolina State University have reported several resistant inbreds (NC262A, NC290) while CIMMYT (2000) reported CML440 and CML443 as resistant.

Similarly, Roane and Genter (1976), based on evaluation of 193 commercial hybrids and 541 inbreds, reported several inbreds but only 4% of the hybrids showed resistance. Diallel analysis of crosses among the most resistant inbreds indicated that inbreds Va43, Va14 and T234 contributed the most resistance. Evaluation of 35 genotypes by Hilty *et al*. (1979) found only inbred T222 had high level of GLS resistance. Ayers *et al*. (1984) reported that a few commercially available hybrids adapted to South-eastern Pennsylvania had adequate levels of GLS resistance. Based on single cross evaluations, they reported lines Va59 and Pa887P contributed resistance to hybrids. Pennsylvania Agricultural Research Station released an experimental line Pa75-15 found to contribute resistance to hybrids as inbred line Pa875. Stromberg and Donahue (1986), after evaluation of 64 hybrids in Virginia, reported two hybrids, Pioneer Brand (PB) 3233 and Dekalb-Pfizer DK 789, as most resistant to blighting of the six hybrids, but PB 3192, although more prone to blighting, yielded consistently higher than any other hybrid tested. The hybrid also had a lower degree of stalk lodging and higher grain moisture content. They suggested that this hybrid possess greater tolerance to GLS than the Pioneer Brand (PB) 3233 and Dekalb-Pfizer DK 789.

Ulrich *et al*. (1990) classified inbreds NC250 and Va59 into an intermediate class based on three year data of six inbreds. Donahue *et al*. (1991) classified H93 as susceptible based on positive general combining ability effects without an inbred evaluation. Thompson *et al*. (1987) and Goodman and Bubeck (1991) rated B73 as susceptible and Donahue *et al*. (1991) reported Pa91 and A632 as being susceptible. Although various ranges of disease reaction have been reported, in Kenya, the common commercial hybrids being used, H625, H614, H627, H511 and H512, and the Katumani composites generally express necrotic type of lesions ascribed to susceptibility (KARI, 2002). These hybrids have been developed from two populations (KSII and EC 573) widely used in Kenya. These materials are tall, late maturing, and susceptible to insect pests and diseases prevalent in the region. The two populations have undergone twelve cycles of reciprocal half-sib recurrent selection with emphasis on yield with a genetic gain estimated at 7.0% cycle^{-1}. The low yields are still observed in farmers' fields despite the high heterosis found between these two populations. This has been attributed to high susceptibility to pests and diseases, particularly GLS and PLS (KARI, 2002).

1.2.6 Gene action conditioning GLS resistance

Several studies have been conducted to determine the genetic basis of *Cercospora zeae maydis* resistance (Elwinger *et al*., 1990; Ulrich *et al*., 1990; Bubeck *et al.,* 1993; Coates and White, 1994; Anderson, 1995; Saghai Maroof *et al*., 1996; Derera, 2005; Menkir and Ayodele, 2005;). Menkir and Ayodele (2005) found both GCA and SCA were significant (p <0.01), with GCA accounting for > 70% of the GLS variation. Similarly, Derera (2005) found GCA of 86% and SCA of 14% in the crosses. Significant mean squares for both GCA and SCA indicated that both additive and non-additive gene action conditioned resistance to GLS.

Other studies have also indicated that host resistance to GLS is regulated by a few genes inherited additively (Elwinger *et al*., 1990; Ulrich *et al*., 1990; Bubeck *et al.,* 1993; Coates and White, 1994; Anderson, 1995; Saghai Maroof *et al*., 1996). However, studies by Elwinger *et al*. (1990) and Gevers and Lake (1994) identified sources of resistance that may have dominant genes for resistance. Gevers *et al*. (1994), in a 12 line diallel cross analysis, found that although the GCA component of variance in relatively unselected material was more important than SCA, the SCA component was numerically greater in some inbreds, RO465W, RO452W, SO181W and RO558W, indicating greater deviations from additivity in some crosses. However, Ward and Nowell (1997) reported high frequency of quantitative resistance to GLS in commercial hybrids grown in South Africa. This indicates varying types of resistance to GLS present in different maize germplasm. Understanding the type of gene action in the available resistant germplasm could have value in the maize-breeding programme, in designing the method of selection for rapid germplasm improvement.

For rapid improvement, sources of resistance with dominant genes for resistance with a single gene that can easily be incorporated in local germplasm in a simple backcross have been suggested (Gevers and Lake, 1994). This has one limitation since it may be less stable as the resistance can be overcome from a single gene mutation by the pathogen. More stable polygenic resistance that increases the level and stability has been suggested (Latterell and Rossi, 1983). However, this may take several years to realize, if other desirable traits with low heritability like yield are to be gained. Anderson (1995) suggested that the decision on the level of resistance depends on the other traits to be incorporated in a breeding programme. Studies by Gevers and Lake (1994), Perkins *et al*. (1995) and Ward (1996) confirmed high levels of resistance to GLS in high grain yielding hybrids. The presence of both additive and non-additive effects suggests that RRS method that selects for both GCA and SCA is suitable for improving GLS resistance in maize populations.

1.2.7 Heritability

Genetic resistance to *Cercospora zeae maydis* is highly heritable (Clements *et al.,* 2000; Derera, 2005; Gordon and Pratt, 2006). Gordon and Pratt (2006) reported heritability based on severity of GLS ranging from 46% to 81%. Similarly Derera (2005) and Clements *et al.* (2000) reported heritability of 70% to 86% and 73%, respectively. High heritability of 61% has also been reported in regional germplasm from Eastern and Southern Africa (Vivek *et al.*, 2001). In temperate germplasm heritability estimates of 73% to 78% have been reported (Cromley *et al*., 2002). The high heritability indicates that selection for GLS can be very effective by using selection methods like RRS.

1.2.8 Selection for resistance

Inheritance of GLS resistance has been found to be highly heritable and mostly additive (Clements *et al.,* 2000; Derera, 2005; Gordon and Pratt, 2006). This indicates the resistance can be readily transferred by usual breeding techniques like recurrent selection methods. Menkir and Ayodele (2005), working on mid-altitude maize inbred lines, found most crosses with one or more resistant parents produced resistant hybrids, whereas most crosses between susceptible lines generated susceptible hybrids. This was also observed by Cromley *et al*. (2002).

1.3. Phaeosphaeria leaf spot (PLS)

1.3.1 Distribution

Phaeosphaeria leaf spot caused by *Phaeosphaeria maydis* (Henn.) was reported in Brazil to be the most important among the fungal diseases in maize and it might become a major threat to maize production (Silva and Moro, 2004). Yield losses of between 11% to 13% were reported to occur on the most susceptible hybrid, Pioneer hybrid 3489 (Carson, 2005). It has been reported in Central and South America and Asia (Carson, 1999). In Africa, the disease has been observed in South Africa at Cedera in 2004 cropping season (Flett, 2004). In Kenya, it was first observed in 1992 as a minor pathogen (Njuguna *et al*., 1992). In the past years the disease incidence has continued to increase, and now it is one of the most important diseases attacking maize in Kenya with high incidences occurring in the highland zones of Western Kenya (KARI, 2002). Carson (2005) reported PLS to be prevalent in areas of high rainfall and moderate temperatures, such as high elevations in the tropics, a similar climate to the Kenya highlands of Kitale where the disease is very severe.

1.3.2 Causal organism

The causal organism of PLS was identified as *Phaeosphaeria maydis* (P. Hennings) Rane, Payak and Renfro in India where it was observed in West Bengal and Uttar Pradesh (Rane *et al.,* 1966). There is still no proof of the real causal agent to PLS as shown by Amaral *et al.* (2005) that various pathogens are involved in PLS like symptoms of maize depending on prevailing environmental conditions and location which influence the predominance of a specific causal agent. In their isolation study, they found three fungi; *Phyllosticta* sp., *Phoma sorghina* and *Sporormiella* sp. to cause leaf spot symptoms similar to PLS on maize. This might be the case in Kenya but few observations have been taken to detect PLS like symptoms on maize.

1.3.3 Factors Influencing Spread and Symptoms

Several factors have been associated with prevalence of PLS. This includes presence of humid and hot conditions, minimum tillage and growing of susceptible varieties. Inoculum is produced as conidia and the primary source is diseased crop debris normally left in the field after harvesting. The symptoms appear after anthesis and are expressed as round, elongate or oblong leached spots with brownish coloured margins occurring on the leaves (Carson, 2005).

1.3.4 Host plant resistance and Inheritance

Field resistance to PLS has been observed in some germplasms. An experiment in Sao Paulo, Brazil, during 1996/97 to evaluate stability and adaptability of single cross hybrids from ten inbred lines from CIMMYT, hybrid L10XL11 was observed to have some resistance to PLS (Rane *et al*., 1966). Work done to determine the inheritance of PLS based on generation mean analysis of segregating populations derived from the cross B73 x Mo17 showed resistance in inbred line Mo17 to be incompletely dominant, highly heritable and controlled by three to four genes (Carson, 2001). Silva and Moro (2004) reported additive gene effects to be the most important source of variation. Estimates of both broad and narrow sense heritability were high, 0.85 and 0.70, respectively. The disease can effectively be selected against using recurrent selection methods, as both GCA and SCA were significant and high heritability is associated with PLS.

1.4 Recurrent selection

Recurrent selection is a general term that includes all methods of selection that are conducted recurrently where similar procedures are repeated in successive cycles of selection (Hallauer, 1992). The method has proved to be useful in several crops as it not only leads to the improvement of the mean performance, but also allows simultaneous maintenance of genetic variation in a population. At the same time it allows the frequency of the desirable genes and gene combinations to be increased by providing for recombination among lines derived from different foundation plants (Chatal and Gosal, 2002). These selection methods genetically improve traits inherited in a quantitative manner (Allard, 1960).

Six different types of recurrent selection are distinguished by the way in which plants with desirable attributes are identified. These are full sib, half sib, S_1 progeny, S_2 progeny, simple recurrent (SRS) and reciprocal recurrent selection (RRS) (Allard, 1960). The choice of the recurrent selection method depends on the trait under selection and whether one or two populations are included for selection. Among the recurrent selection methods, RRS is a procedure that is useful in selecting simultaneously for both GCA and SCA in two heterogeneous populations that are genetically unrelated (Comstock *et al.,* 1949). Hence this makes it useful in GLS breeding as both additive (GCA) and non-additive (SCA) genetic effects have been found to be important in resistance to GLS in some materials (Elwinger *et al*., 1990; Gevers *et al.,* 1994; Derera, 2005; Menkir and Ayodele, 2005).

Recurrent selection methods have been employed in improvement of various maize traits, but their use in the improvement of GLS and PLS resistance has been limited. The method was successful in simultaneous improvement of downy mildew resistance caused by *Peronosclerospora* sp. and agronomic traits in tropical maize where highly significant improvement levels of -11% cycle^{-1} for downy mildew resistance and 507kg cycle^{-1} for grain yield over the four populations were achieved (De Leon *et al*., 1993).

It has also been used in Kenya in improvement of Pool A and Pool B under low and high nitrogen environments and for yield in KSII and EC573 (KARI, 2002). Omoigui *et al*. (2006) selecting for low nitrogen tolerance using full sib recurrent selection, achieved genetic gains of 2.3% and 1.9% cycle^{-1} grain yield at low and high N, respectively. It also increased stay green ability and kernel weight with a corresponding gain of 17.7% and 4.7% cycle^{-1}, respectively. Similar studies have been made in improvement for mid-season drought tolerance in tropical maize (Pervez *et al*. 2004) and selection for nitrogen use efficiency in maize (Gallais and Cogue, 2005). As a result of RRS, Lori *et al*. (2005) sampled intermediate time points and gained a comprehensive genetic view of Corn Borer Synthetic #1 (CB) and Stiff Stalk Synthetic (SS) permitting evaluation of the molecular-level changes occurring. It was also used successfully for improving yield in two high oil maize synthetics (Made and Lambert, 2007) and selection for resistance to *Striga hermonthica* that resulted in increased grain yield by 24% cycle^{-1} and ear per plant by 9% cycle^{-1} (Menkir and Kling, 2007). At the same time, the gain per cycle was -7% for relative yield loss, -5% for host damage rating, -9% for emerged *S. hermonthica* plants, -4% for anthesis-silking interval and -5% for ear aspect (Menkir and Kling, 2007). Genetic gain averaging 5.2 quintals ha^{-1} was realised in Kenya after two cycles in corn populations KSII and EC 573 (Harrison, 1974).

Simple recurrent selection is one of the recurrent selection methods that utilizes phenotypic variance in selection for trait improvement. Utilization of this method in breeding programmes has been limited. Though it has not been used extensively, the method has an advantage because the time required for selection, testing and reincorporation of improved genetic recombinants into the breeding programme, or completion of one cycle of selection is shortened thus reducing the cost and time. Simple recurrent selection has been used successfully in barley breeding (McProud, 2004).

1.5 Heterosis and Heterotic Patterns

Information on heterosis and heterotic groups is important in the development of high performance hybrids and improvement of populations from collections. Hybrid vigour or heterosis is the phenomenon in which progeny of crosses between inbred lines or purebred populations are better than the expected average of the two populations, or lines for a particular trait. Heterosis observed in a variety cross is the average expression of heterosis of the genotype formed by crossing a sample of genotypes from each of the two parental lines (Hallauer and Miranda, 1988). The manifestation of heterosis usually depends on genetic divergence of the two parental varieties. Therefore, germplasm is able to be classified into specific heterotic groups or patterns depending on their similarity in combining ability and heterotic response when crossed with genotypes from other genetically distinct germplasm groups (Melchinger and Gumber, 1998).

Conventional methods based on testcross data have widely been used to estimate heterosis between populations or inbred lines and group them into heterotic groups or patterns. Based on yield and significance of high parent heterosis (HPH), mid parent heterosis (MPH), percentage heterosis and SCA data, maize germplasm is grouped into various heterotic groups. Genotypes showing highly significant SCA or heterosis are likely to belong to different heterotic groups or patterns. This method has been used in heterotic classification among flint maize populations in Spain (Pilar *et al.,* 2003) and in tropical maize under stress and non-stress environments (Betran *et al*., 2003; Manoel *et al.,* 2001; Welcker *et al*., 2005).

Heterosis has been predicted on the basis of genetic distance based on molecular markers (Warburton *et al*., 2002; Xia *et al.*, 2004). Prediction has been based on positive correlation between genetic distance of parental lines and superior hybrid performance (Barbosa *et al.,* 2003; Lu *et al.,* 2002). Restriction Fragment Length Polymorphism (RFLP) and Simple Sequence Repeat (SSR) markers have been used to correlate genetic distance to ancestry (Warburton *et al.,* 2005); to place temperate lines into known heterotic groups (Dubreuil *et al.*, 1996; Messmer *et al.*, 1992) and to assign tropical Asian maize inbred lines to potential heterotic groups (Yuan *et al*., 2000).

Different heterotic patterns are used in different countries to produce hybrids depending on their adaptability. In the USA and Europe, heterotic pattern Reid x Lancaster is the most common scheme used to produce hybrids for temperate areas. Also, the heterotic pattern European flint x Corn Belt Dent has been used in Europe (Orda's, 1991). In China, in the North Spring Maize Region, the major pattern of heterotic groups is domestic × LSC, while in the Huanghuaihai Summer Maize Region is domestic × PN (Li *et al*., 2004). In Japan, it is based on the use of the heterotic pattern of U.S. dent by Northern flint or European flint (Enoki *et al*., 2002).

In East Africa, the heterotic pattern used is KSII x EC 573, from the highland programme in Kenya. Recently two populations have been developed to form a heterotic pattern, Pool A x Pool B for the medium programme in Kenya. The first Kenyan maize hybrid 611 is a cross between a synthetic variety, KSII developed from local collections and an introduction, EC 573. Hybrid 611 was released in 1964 and has a 40% yield advantage over KSII (KARI, 2004). To date, the two populations (heterotic groups), KSII and EC 573 are the basic source of inbred lines for maize hybrid development for the highlands [1600m – 2900 metres above sea level (masl)] and Pool A and B for the medium (1110m - 1500masl) zones in Kenya (KARI, 2004). Knowledge of heterotic response enables breeders to group germplasm collections into heterotic groups for higher performance hybrid development (Reif *et al.,* 2005). This is essential for classification of germplasm collections from Western Kenya and elsewhere into the four major heterotic groups in Kenya.

1.6 Participatory Rural Appraisal (PRA)

Participatory Rural Appraisal (PRA) comprises a set of techniques aimed at shared learning between local people, farmers and research scientists. It is used not only for project appraisal, but throughout the project life span, as well as for research studies (Witcombe *et al*., 2003). It relies heavily on participation by local communities as the method is designed to enable local people to be involved, not only as sources of information, but as partners with the PRA team in gathering and analyzing the information (Daniela *et al*., 2000). The techniques used in any given situation depend on the study objective, PRA team, time and resources available, and the work location. Generally the team involved should represent the entire community, considering sex, age, wealth status and above all they should be sharing a common language for easy exchange of information so as to facilitate easy identification of constraints, possible solutions, formulation for a research agenda, implementation, evaluation and impact assessment (Witcombe *et al*., 2003).

In breeding research, PRA represents a basic essential step in Participatory Crop Improvement (PCI) or Participatory Plant Breeding (PPB). Participation of farmers in technology development and implementation is an important factor in increasing the probability of success for a technology (Daniela *et al*., 2000). This approach was adopted after the failure of the conventional method of technology development where research scientists developed technologies in the research stations without involvement of the end users, farmers. This resulted in poor adoption and sometimes total rejection of technologies as most of them never reflected real constraints that farmers faced at the farm level. In most cases technologies developed focused on the wrong target groups as it has been observed that involvement of women farmers in the research process in the assessment improves the quality of most field evaluations (Daniel *et al*., 2007). This is due to the fact that women's selection criteria often differ from those of men who are interested in characteristics that are of importance during growth and harvest periods unlike women who are keen on post harvest characteristics (Daniel *et al.,* 2007). Such cases have been experienced in the development of maize hybrids in Kenya where they were developed with yield as the main trait without focusing on traits like low fertility tolerance, height, maturity, and lodging (KARI, 2000). This has resulted in farmers growing their own local maize that require less fertility, matures early and seed can be recycled for three years without much reduction in yield as an alternative to high cost hybrid seeds.

Participatory Rural Appraisal has been used in various social and farming systems studies (Joshi and Witcombe, 1996; De Groote *et al.,* 2001). It provides breeders opportunities to understand farmers' constraints, pests, diseases, indigenous technical knowledge (ITK), perceptions, practices and their implications. Daniela *et al.* (2000) found that through PRA, communication barriers between farmers and researchers are minimised and needs in terms of crop characteristics are identified and incorporated early in breeding programmes. Therefore crop varieties meeting local needs are developed by drawing on some of the insights contributing to the effectiveness of modern plant breeding, as well as the knowledge and experience of farmers (Daniela *et al*., 2000). Also varieties adapted to the needs of low resource farmers in highly stress prone environments are developed resulting in enhanced *in situ* conservation of crop genetic resources (Witcombe *et al*., 1996).

In Kenya, KARI economists have developed methodologies for participatory variety selection (Siambi *et al.,* 2002). Scientists in Kenya, Uganda and Ethiopia are now adapting these methods. The purpose is to incorporate farmer perspectives into breeding programmes (De Groote *et al.*, 2002). In semi-arid regions of Kenya, farmers selected maize variety EE-EAC-31 as the best variety, but it ranked only 6^{th} in breeder evaluation. In Kenya, PRA's have been carried out to identify various constraints at the farm level. In moist mid-altitudes of the Lake Victoria basin, through PRA, farmers identified *Striga* as their first constraint (Odendo *et al.,* 2001). PRA was used in Uasin Gishu, Trans Nzoia and West Pokot regions of Kenya to determine the incidence, perceptions, control measures and yield losses of maize due to ear rots (Lawrence *et al*., 2002). Similarly PRAs have been used by soil management and Department for International Development (DFID) projects in the North rift valley maize growing areas of Kenya as a tool for identification of farmers' constraints, perceptions, practices, resistant germplasm and as a step in formation of farmer field schools and participatory plant breeding (KARI, 2002).

Involvement of farmers in the initial stages of problem identification, research formulation and participation in the breeding process or technology and dissemination has proved to be very successful as it makes farmers take ownership of the technology. This has proved to be very successful as shown in barley in the dry Mediterranean regions (Ceccarelli *et al*., 2001) and in India (Witcombe *et al*., 2003). There are now several examples indicating that PPB improves breeding efficiency, leads to more accelerated adoption and promotes genetic diversity (Ashby and Lilja, 2004; Morris and Bellon, 2004; Ceccarelli and Grando, 2005). In addition, research on evaluation for reducing pesticides, fertilizer and seed rates in rice farming in Vietnam by Huan *et al*. (2005); selection for spot blotch resistance in spring wheat by Ram (2006) and nitrogen management in irrigated rice in China by Ruifa *et al,* (2007) through farmer participation have been very successful.

Determining farmer preferences is essential for breeders as it provides farmers with a say in the research process as they are able to make decisions on the relevant research agenda. Furthermore breeders come to appreciate the constraints, indigenous technical knowledge, and needs of all members of the farming community (Bentley and Hogenboom, 2003). This approach has been to increase the probability and speed of adoption of technologies as breeders develop varieties and technologies that meet farmer preferences (Mangione *et al*., 2006).

1.7 Conclusions

The review was undertaken to identify gaps in regards to production constraints in Kenya, research done on GLS, PLS, recurrent selection methods, on heterotic patterns and on PRAs.

The review indicated GLS and PLS to be very important maize diseases widely spread in East and sub-Saharan Africa. In Kenya, GLS and PLS are new diseases having been reported in the mid nineties. The review also indicated very little well documented information was available on research work carried out in Kenya, except for reports on the occurrence and severity of constraints through field observations. From the review it was shown that a lot of work on the gene actions conditioning GLS has been conducted by several scientists mainly using inbred lines, but very little efforts have been tried with maize populations. In these studies, both additive and non-additive effects have been reported and also high heritability has been associated with GLS. As means of control, use of resistant material was advocated for by many scientists as shown in the review. As for PLS, very little published information was available regarding resistant germplasm, distribution and severity and, methods of improvement in African countries.

On maize production in Kenya, it was established through the review that there was a yield gap of 4.3t ha^{-1} between expected potential and on-farm, attributed to declining soil fertility, *Striga*, use of recycled seeds, unreliable rainfall, pest, diseases and low adoption of some varieties by farmers.

The review showed that PRAs were very important in the formulation of research through identification of farmer constraints, preferences and perceptions. It was also shown that PRAs have been used widely in constraint identification in various crops. Similarly participatory plant breeding has been effective in various countries in different crop programmes as indicated in the review.

Several heterotic patterns were shown to be in use in different countries depending on adaptability and objective of the programme. It also showed that there was exchange of materials between breeding programmes.

From the review it came out clear that no research so far has been undertaken to improve populations for GLS or PLS resistance using recurrent selection methods. Also information on GLS and PLS improvement was shown to be limited. It was also indicated through the review that SRS method has rarely been used in breeding programmes not only for GLS but for most traits of maize in general.

It is evident that PRAs and Participatory Plant Breeding (PPB) should be emphasised and more research on GLS improvement should consider RRS selection method that has been utilised effectively on other traits in maize. In line with population improvement, collections with desirable traits and showing high heterosis with existing populations in maize programmes should be exploited fully.

References

Allard, R.W. 1960. Principles of plant breeding. p. 253-302. John Wiley, New York

Amaral, A.L.do., F.K.S. dal, M.L. de Carli, and J.F.N. Barbosa. 2005. Pathogenic fungi causing symptoms similar to Phaeosphaeria leaf spot of maize in Brazil. Plant Disease 89:44-49.

Anderson, B.M. 1995. Gray leaf spot resistance- why do we need it? How do we get it? *In*: Proc. 31st. Illinois Corn Breeders School, University of Illinois at Urbana-Champaign, Illinois, USA. p. 186-194.

Ashby, J.A., and N. Lilja 2004. Participatory research: Does it work? Evidence from participatory plant breeding. Proceeding of the 4th crop science congress, new directions for a diverse planet, 26th September-1st October, 2004, Brisbane, Queenland, Australia.

Ayers, J.E., M.W. Johnson, Jr., and R.R. Hill, Jr. 1984. Identifying resistance to gray leaf spot. *In* Proc. 39th Corn. Sorgh. Research Conference America Seed Trade Association, Washington, D.C., USA. p. 157-175.

Barbosa, A.M.M., I.O. Geraldi, L.L. Benchimol, A.A. F. Garcia, and C.L. Souza. 2003. Relationship of intra- and interpopulation tropical maize single cross hybrid performance and genetic distances computed from AFLP and SSR markers. Euphytica 130:87–99.

Beckman, P.M., and G.A. Payne. 1982. External growth, penetration and development of *Cercospora zeae-maydis* in corn leaves. Phytopathology 72: 810-815.

Betran, F.J., J.M. Ribaut, D. Beck, and D. Gonzalez de Leo´ n. 2003. Genetic diversity, specific combining ability, and heterosis in tropical maize under stress and non stress environments. Crop Science 43:797–806.

Bentley, J., and N. Hogenboom. 2003. Working with native varieties and farm communities to create durable Andean food crops. Review mission of the Preduza project in Ecuador, Bolivia and Peru, p. 52.

Bhatia, A., and G.P. Munkvold. 2002. Relationships of environmental and cultural factors with severity of gray leaf spot in maize. Plant Disease 86:1127-1133.

Bigirwa, G., R.C. Pratt, E. Adipala, and P.E. Lipps. 2001. Assessment of gray leaf spot and stem borer incidence and severity on maize in Uganda. African Crop Science Conference 4:469-474.

Bubeck, D.M., M.M. Goodman, W.D. Beavis, and D. Grant. 1993. Quantitative trait loci controlling resistance to gray leaf spot in maize. Crop Science 33:838-847.

Carson, M.L. 1999. Vulnerability of US maize germplasm to *Phaeosphaeria l*eaf spot. Plant Disease 83:462-464.

Carson, M.L. 2001. Inheritance of resistance to Phaeosphaeria leaf spot of maize. Plant Disease 85:798-800.

Carson, M.L., M.M. Goodman, and S.M. Williamson. 2002. Variation in aggressiveness among isolates of *Cercospora* from maize as a potential cause of genotype-environment interaction in gray leaf spot trials. Plant Disease 86:1089-1093.

Carson, M.L. 2005. Yield loss potential of to Phaeosphaeria leaf spot of maize caused by *Phaeosphaeria maydis* in the United States. Plant Disease 89:986-988.

Ceccarelli, S., S. Grando, E. Bailey, A. Amri, M.El-Felah, F. Nassif, S. Rezgui, and A. Yahyaoui. 2001. Farmer participation in barley breeding in Syria, Morocco and Tunisia. Euphytica 122:521-536.

Ceccarelli, S., and S. Grando. 2005. Decentralized participatory plant breeding In: Tuberosa R, and R. L. Phillips (eds). Proceedings of the congress "In the wake of the double helix: From the green revolution to the gene revolution" Bologona. 26-30 May, 2003, p. 145-156.

Chatal, G.S., and S.S. Gosal. 2002. Principles and procedures of plant breeding. Biotechnological and Conventional Approaches. Pp. 247-268. (Ed.) Alpha Science International UK.

Chupp, C. 1953. A monograph of the fungus genus *Cercospora*. Ronald Press Co. NewYork, USA. p. 667.

Clements, M.J., J.W. Dudley, and D.G. White. 2000. Quantitative trait loci associated with resistance to gray leaf spot of corn. Phytopathology 90:1018-1025

CIMMYT. 2000. Eighth announcement of 30 maize inbred lines by CMMYT. [Online]. http://www.cimmyt.org/research/maize/announcement/announcement.doc. accessed on 20th November 2003.

Coates, S.T., and D.G. White. 1994. Sources of resistance to gray leaf spot of corn. Plant Disease 78:1153-1155.

Coates, S.T., and D.G. White. 1998. Inheritance of resistance to gray leaf spot in crosses involving selected inbred lines of corn. Phytopathology 88:972-982.

Cromley, J.M.D., A.R. Hallauer, and C.A. Martinson. 2002. Inheritance of gray leaf spot resistance in corn. Journal of Iowa Academy of Sciences, 109. (Abstract)

Comstock, R.E., H.F. Robinson, and P.H. Harvey. 1949. A breeding procedure designed to make use of both general and specific combining ability. Agronomy Journal 41:360-367.

Daniel, D., J. Perlevliet, C. Almekinders, and G. Thiele. 2007. Farmers' participation and breeding for durable disease resistance in the Andean region. Euphytica 153: 385-396.

Daniela, S., S.E. Smith, and A.D. Cleveland. 2000. Evaluating the potential for farmer and plant breeder collaboration: A case study of farmer maize selection in Oaxaca, Mexico. Euphytica 116:41-57.

De Groote, H., J.O. Okuro, C. Bett, L. Mose, M. Odendo, and E. Wekesa. 2001. Assessing the demand for insect resistant maize varieties in Kenya, by combining participatory rural appraisals and geographical information systems. Paper presented at the International Symposium on Participatory Plant Breeding and Participatory Plant Genetics Resource Management: An exchange of experiences, Boauke, Côte d'Ivoire, 7-10 May. Accelerating maize production: Synthesis in Africa's emerging maize revolution.

De Groote, H., M. Siambi, D. Friesen, and D. Diallo. 2002. Eliciting farmers' preferences for new maize varieties in Eastern Africa. *In* M. R. Bellon and J. Reeves, (ed.) Quantitative analysis of data from participatory methods in plant breeding. CIMMYT, Mexico, D. F.

De Leon, C., G. Granados, R.N. Wedderburn and S. Pandey. 1993. Simultaneous improvement of downy mildew resistance and agronomic traits in tropical maize. Crop Science 33:100-102.

de Nazareno, N.R.X., P.E. Lipps, and L.V. Madden. 1992. Survival of *Cercospora zeae-maydis* in corn residues in Ohio. Plant Disease 76:560-563.

de Nazareno, N.R.X., P.E. Lipps, and L.V. Madden. 1993. Effects of levels of corn residues on the epidemiology of gray leaf spot of corn in Ohio. Plant Disease 77:67-70.

Derera, J. 2005. Genetic effects and associations between grain yield potential, stress tolerance and yield stability in Southern African Maize (Zea Mays L.) base germplasm p 60-105. Unpublished PhD Thesis.

Donahue, P.J., E.L. Stromberg, and S.L. Meyers. 1991. Inheritance reaction to gray leaf spot in a diallel crosses of maize in 14 maize inbreds. Crop Sci. 41: 926-931.

Dubreuil, P., P. Dufour, E. Krejci, M. Causse, D. deVienne, A. Gallais, and A. Charcosset. 1996. Organization of RFLP diversity among inbred lines for maize representing the most significant heterotic groups. Crop Science 36:790–799.

Elwinger, G.F., M.W. Johnson, R.R.Jr. Hill, and J.E. Ayers. 1990. Inheritance of resistance to gray leaf spot of corn. Crop Science 30:350-358.

Enoki, H., H. Sato, and K. Koinuma. 2002. SSR analysis of genetic diversity among maize inbred lines adapted to cold regions of Japan. Theoretical Applied Genetics 104:1270-1277.

Flett, B.C. 2004. Pathogen epidemiology and development of integrated control method of the white spot of maize. ARC-Grain Crops Institute-Crop Protection (ARC-GCI), Project Abstracts (2003/2004) Crop Protection. Project no: M141/13

Freppon, J.T., R.C. Pratt, and P.E. Lipps. 1996. Chlorotic lesion response of maize to *Cercospora zeae-maydis* and its effect of gray leaf spot disease. Phytopathology 86:733-738.

Gallais, A., and M. Cogue. 2005. Genetic variation and selection for nitrogen use efficiency in maize. Maydica 50:531-547.

Gevers, H.O., and J.K. Lake. 1994. GLS1- a major gene for resistance to gray leaf spot in maize. South African Science Journal 90:377-380.

Gevers, H.O., J.K. Lake and T. Hohls. 1994. Diallel crosses analysis of resistance to gray leaf spot in maize. Plant Disease 78:379-383.

Goodman, M.M., and D. Bubeck. 1991. Evaluation of tropical germplasm for resistance to gray leaf spot. p. 12-16. *In* 46th Annual Corn improvement Conference Proceedings, Northeast, South.

Gordon, S.G., M. Bartsch, I. Matthies, H.O. Gevers, P.E. Lipps, and R.C. Pratt. 2004. Linkage of molecular markers to *Cercospora zeae-maydis* resistance in maize. Crop Science 44:628-636.

Gordon, S.G., R.C. Pratt. 2006. Breeding for resistance to maize foliar pathogens. Plant Breeding Review. 27:119-173.

Harrison, M.N. 1974. Maize improvement in Kenya. *In* C.L.A. Leakey's Crop Improvement in East Africa. Commonwealth Agricultural Bureau, Farnharm Royal. Burks, U.K.

Hallauer, A.R., and J.B. Miranda. 1988. Quantitative genetics in maize breeding. Iowa State University. Press, Ames.

Hallauer, A.R. 1992. Recurrent selection in maize. In J. Janick (edition), Plant breeding reviews. 9:115-179. John Willeys and Sons

Hilty, J.W., C.H. Harden, and F.T. Garden. 1979. Responses of maize hybrids and inbred lines to gray leaf spot disease and the effects on yields in Tennessee. Plant Disease Reporter 63:515-518.

Huan, N.H., L.V. Thiet, H.V. Chien, and K.L. Heong. 2005. Farmers' participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta, Vietnam. Crop protection 24:457-464.

Huff, C.A., J.E. Ayers, and R.R. Hill Jr. 1988. Inheritance of resistance in corn (*Zea mays*) to gray leaf spot. Phytopathology 78:790-794.

Joshi, A., and R. Witcombe. 1996. Farmer participatory crop improvement. II. Participatory variety selection, a case study in India. Experimental Agriculture 32:461-467.

Karanja, D.D. 1996. An economic and institutional analysis in Kenya: MSU International Development Working Paper No. 57: 3-5

KARI. 2000. Annual report. Cereals Maize breeding.

KARI. 2002. Annual report. Farming systems of North Rift provinces of Kenya.

KARI. 2004. Annual report. Cereals maize breeding

Kingsland, G.C. 1963. Cercospora leaf blight of corn. A case history of local epiphytotics in South Carolina. Plant Disease Reporter 47:724-5.

Kwena, P.O., and P. Kalama .1999. A survey on crop pest and farmer management practices in the North Rift Valley province of Kenya. *In*: towards increased use of demand driven technology. A paper presented at a conference Nairobi, Kenya 23 rd –26th March 1999.

Latterell, F.M., and A.E. Rossi. 1983. Gray leaf spot of corn: A disease on the move. Plant Disease 67:842-847.

Lawrence, O.M., J.M. Wanyama, H. De Groote, M. Mulaa, and W.K. Muge. 2002. Participatory rural appraisals on maize production in the moist transitional and high tropics zones in Western Kenya. KARI, Kenya

Lipps, P.E., P.R. Thomison, and R.C. Pratt. 1997. Reactions of corn hybrids to gray leaf spot. P. 163-180. *In* Proceedings 51st Annual Corn and Sorghum Research Conference, Chcago, IL, December 1997. Publication 51.am. Seed Trade Association., Inc., Washington, DC.

Li, Y., Y. Shi, Y. Song, J. Du, R. Tuberosa, and T. Wang. 2004. Analysis of genetic diversity in maize inbred lines based on AFLP markers. Maydica 49:89-95.

Lu H., J. Romero-Severson, R. Bernardo, 2002 Genetic basis of heterosis explored by simple sequence repeat markers in a random-mated maize population.Theoretical Applied. Genetic. 107: 494-502.

Lori, L.H., S. Kresovich, J.D. Nason, and K.R. Lamkey. 2005. Population diversity in a maize reciprocal recurrent selection programme. Crop Science 45:2435-2442.

Made, J.M., and R.S. Lambert. 2007. Selection response for increased grain yield in two high Oil maize synthetics. Indonesian Journal of Agricultural Sciences 8:1-9.

Mangione, D., S. Senni, M. Puccioni, S. Grando, and S. Ceccareli. 2006. The cost of participatory barley breeding. Euphytica 150:289-306.

Manoel, X.dos S; L. M Pollak, H.W.L. de Carvalho, C.A.P. Pacheco, E.E.G. e Gama, P.E. de Oliveira Guimarães, and R.V. de Andrade. 2001. Heterotic responses of tropical elite maize accessions from Latin America with Brazilian testers. Scientia Agricola, 58:767-775.

Martinson, C.A., S.N. Riviera-Canales, and F.W. Nutter. 1994. Fungicidal spray programme for seed corn production. *In*: Proceeding Annual Corn Sorghum Research Conference 41, American Seed Trade Association, Washington DC, USA. p. 71-79.

Martinson, C.A., and G.P. Munkvold. 1995. Fungicidal control of leaf diseases in corn. *In* 1995 Integrated Crop Management Conference Proceedings, Iowa State, Ames, Iowa, USA. p. 243-246.

McProud, W.L. 2004. Repetitive cycling and simple recurrent selection in traditional barley breeding programme. Euphytica 28:473-480.

Melchinger, A.E., R.K. Gumber. 1998. Overview of heterosis and heterotic groups in agronomic crops. pp. 29-44. *In* K.R. Lamkey, J.E. Staub (ed.), Concepts and breeding of heterosis in crop plants. CSSA, Madison, WI.

Menkir, A., and A. Ayodele. 2005 Genetic analysis of resistance to gray leaf spot of mid altitude maize inbred lines. Crop Science 45:163-170.

Menkir, A. and J.G. Kling. 2007. Response to recurrent selection for resistance to *Striga hermonthica* (Del.) Benth in a tropical maize population. Crop Science 47:674-682.

Messmer, M.M., A.E. Melchinger, J. Boppenmaier, R.G. Herrmann, and E. Brunklaus-Jung. 1992. RFLP analyses of early-maturing eight European maize germplasm I. Genetic diversity among flint and dents inbreds. Theoretical Applied Genetics 83:1003–1012.

Morris, M.L., and M.R. Bellon .2004. Participatory plant breeding research Opportunities and Challenges for the international crop improvement system. Euphytica 136:21-35.

Njuguna, J.G.M., J.C. Kedera, L. Muriithi, S. Songa, and B. Odhiambo. 1992. Overview of maize diseases in Kenya*. In*: KARI, Proceedings of a workshop, Review of the National Maize Research Programme, KARI/ISNAR Management Training Linkage Project. 1992. p. 100.

Nowell, D.C. 1997. Studies on ear rot and gray leaf spot of maize in South Africa. Ph.D. Thesis, Univ. Natal, Pietmaritzburg, RSA.

Odendo, M., H. De Groote, and O.M. Odongo. 2001. Assessment of farmers' reference and constraints to maize production in moist mid-altitude zone of Western Kenya. A paper presented at the 5th International conference of the African crop science society, Lagos, Nigeria October 21-26, 2001.

Okori, P., J. Fahelson, P.R. Rubaihayo, E. Adipala, and C Dixelius. 2003. Assessment of genetic variation among East African *Cercospora zeae maydis*- populations. African Crop Science Journal 11:75-88.

Omoigui, L.O., S.O. Alabi, S.G. Ado, S.O. Ajala, and A.Y. Kamara. 2006. Genetic gains from cycles of full-sib recurrent selection for low nitrogen tolerance in a tropical maize population. Maydica 51:497-505.

Orda´s, A. 1991. Heterosis in crosses between American and Spanish populations of corn. Crop Science 30:1182–1190.

Paccola-Meirelles, L.D., A.S. Ferreira, W.F. Meirelles, I.E. Marreil, and C.R. Casela. 2001. Detection of a bacterium associated with a leaf spot disease of maize in Brazil. Journal of Phytopathology 149:275-279.

Payne, G.A., and J.K. Waldron.1983. Over wintering and spore release of *Cercospora zeae-maydis* in corn debris in North Carolina. Plant Disease 67:87-89.

Perkins, J.M., D.R. Smith, J.G. Kinsey, and D.C. Dowden. 1995. Prevalence and control of gray leaf spot. Proc. 31st Ann. Illinois Corn breed. Sch., March 6-7, 1995. Univ. Illinois, Urbana-Champaign, Illinois, USA. p. 12-15.

Pervez, H.Z., G. Srinivasan, H.S. Cordova, and C. Sanchez. 2004. Gains from improvement for mid-season drought tolerance in tropical maize (*Zea mays* L.). Field Crops Research 89:135-152.

Pilar, S., B. Orda´s, R.A. Malvar, P. Revilla, and A. Orda´s. 2003. Heterotic patterns among flint maize populations. Crop Science 43:844–849.

Ram, C.S., and E. Duveiller. 2006. Farmer participatory evaluation confirms higher grain yields in spring wheat using a selection index for spot blotch resistance, maturity and kernel weight. Euphytica 150:307-317.

Rane, M.S., M.M. Payak, and B.L. Renfro. 1966. A *Phaeosheria* leaf spot of maize in India. Indian Phytopathology 19 (Abstract).

Reif, J.C., A.R. Hallauer, A.E. Melchinger. 2005. Heterosis and heterotic patterns in maize. Maydica 50:215-223.

Ringer, C.E., and A.P. Grybauskas. 1995. Infection cycle components and disease progress of gray leaf spot on field corn. Plant Disease 79:24-28.

Roane, C.W., and C.F. Genter. 1976. Breeding maize for resistance to gray leaf spot. Phytopathology 3:331.

Roane, C.W., R.L Harrison, and C.F. Genter. 1974. Observations on gray leaf spot of maize in Virginia. Plant Disease Reporter 58:456-459.

Ruifa, H., J. Cao, J. Huang, S. Peng. J. Huang, X. Zhong, Y. Zou, J. Yang, and R.J. Buresh. 2007. Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China. Agricultural systems. 94:331-340.

Rupe, J.C., M.R. Siega, and J.R. Hartman. 1982. Influence of environment and plant maturity on Gray leaf spot of corn caused by *Cercospora zeae- maydis*. Phytopathology 72:1587-1591.

Saghai Maroof, M.A., Y.G. Zue, Z.X. Xiang, E.L. Stromberg, and G.K. Rufener. 1996. Identification of quantitative trait loci controlling gray leaf spot disease in maize. Theoretical Applied Genetics 93:539-46.

Siambi, M., A.O. Diallo, H. De Groote, D.K. Friesen, and W. Muasya. 2002. Recent development in participatory plant breeding for maize in Eastern Africa: experiences from Eastern Kenya. In M. Nigussie, D. Tanner, and S. Twumasi-Afriyie (ed.). Enhancing the contribution of maize to food security in Ethiopia: Proceedings of the Second National Maize Workshop of Ethiopia, 12-16 November 2001, Addis Ababa, Ethiopia: Ethiopian Agricultural Research

Organization (EAFRO) and International Maize and Wheat Improvement (CIMMYT). Pp. 223-231.

Silva, H.P., and J.S. Moro. 2004. Diallel analysis of maize resistance to *Phaeosphaeria maydis*. Science Agriculture. (Piracicaba, Brazil), 61:36-42.

Stromberg, E.L., and P.J Donahue. 1986. Hybrid performance and yield losses associated with gray leaf spot disease. In: Proc. Ann. Corn. Sorgh. Res. Conf. 41, Am. Seed Trade Assoc., Washington D.C., USA. Pp. 92-105. *In:* Proceeding Annual Corn Sorghum Research Conference, 41st. American Seed Trade Association, Washington. DC.

Tehon, L.R., and E. Daniels. 1925. Notes on parasitic fungi of Illinois. Mycologia 17:240-249.

Thompson, D.L., R.R. Bergquist, G.A. Payne, D.T. Bowman and M.M. Goodman. 1987. Inheritance of resistance to gray leaf spot in maize. Crop Science 27:243-246.

Thorson, P.R., and C.A. Martinson. 1993. Development and survival of *Cercospora zeae-maydis* germlings in different relative humidity environments. Phytopathology 83:153-157.

USDA-ARS.2004. Germplasm Resources Information Network –(GRIN). [Online Database] National Germplasm Resources Laboratory, Beltsville, Maryland. http://www.ars-grin.gov/cgi-bin/npgs/html/dno_eval_acc.pl?89009+205001+1780. Accessed 24th June 2005.

Ulrich, J.F., J.A. Hawk, and R.B. Carroll. 1990. Diallel analysis of maize inbreds for resistance to gray leaf spot. Crop Science 30:1198-1200.

Vivek, B., K. Pixley, O. Odongo, J. Njuguna, J. Imanywoha, G. Bigirwa and A. Diallo. 2001. Regional disease nursery (REGNUR): a unique opportunity for developing multiple-disease resistant maize. *In*: Proceeding of Seventh Eastern and South African regional maize conference. 11 – 15th February 2001. Addis Ababa, Ethiopia. p. 66-68.

Wang, J.M., M. Levy, and L.D. Dunkle. 1998. Sibling species of *Cercospora* associated with gray leaf spot of maize. Phytopathology 88:1269-1275.

Warburton, M.L., X. Xianchun, J. Crossa, J. Franco, A.E. Melchinger, M. Frisch, M. Bohn, and D. Hoisington. 2002. Genetic characterization of CIMMYT inbred maize lines and open pollinated populations using large scale fingerprinting methods. Crop Science 42:1832–1840.

Warburton, M.L., J.M. Ribaut, J. Franco, J. Crossa, P. Dubreuil, and F.J. Betran. 2005. Genetic characterization of 218 elite CIMMYT maize inbred lines using RFLP markers. Euphytica 142:97–106.

Ward, J.M.J. 1996. Epidemiology and management of gray leaf spot disease, a new disease of maize in South Africa. Ph.D. Thesis., University of Natal, Pietermaritzburg, RSA.

Ward, J.M.J., and D.C. Nowell. 1997. Epidemiology and management of gray leaf spot disease, a new disease of maize in South Africa. Pp 158 In: Proc. S. Afr. Maize Breed. Sympos., 11th , Cedera 1994, Grain Crop Research Institute, Department Agriculture, Pretoria, RSA.

Ward, J.M.J., E.L. Stromberg, D.C. Nowell, and F.W. Nutter. 1999. Gray leaf spot: A disease of global importance in maize production. Plant Disease 88:884-895.

Wegulo, S.N. 1994. Benefits assessment of fungicide usage in seed corn production in Iowa. M.Sc. Thesis, Iowa State University, Ames, Iowa, USA.

Welcker, C.T., B. Andre´au, C. De Leon, S.N. Parentoni, J. Bernal, J.Fe´ licite, C. Zonkeng, F. Salazar, L. Narro, A. Charcosset, and W. J. Horst. 2005. Heterosis and Combining Ability for Maize Adaptation to Tropical Acid Soils: Implications for Future Breeding Strategies. Crop Science 45:2405–2413.

Witcombe, J. R., A. Joshi, K. D. Joshi, and B. R. Sthapit. 1996. Farmer participatory crop improvement. Varietal selection and breeding methods and their impact on biodiversity. Experimental Agriculture 32:445-460.

Witcombe, J., A. Josh, and S.N. Goyal. 2003. Participatory plant breeding in Maize: A case study from Gujarat, India. Euphytica 130:413-422.

Xia, X.C., J.C. Reif, D.A. Hoisington, A.E. Melchinger, M. Frisch, and M.L. Warburton. 2004. Genetic diversity among CIMMYT maize inbred lines investigated with SSR markers. I. Lowland tropical maize. Crop Science 44:2230–2237.

Yuan, L.X., J.H. Fu, M.Warburton, X.H. Li, S.H. Zhang, M. Khairallah, X. Liu, Z. Peng and L. Li, 2000. Comparison of genetic diversity among maize inbred lines based on RFLPs, SSRs, AFLPs and RAPDs. Acta Genet Sin 27:725–733.

Chapter 2: Participatory Rural Appraisal of farmers' Maize Production Constraints in Moist Mid Altitude Zone of Western Kenya

Abstract

On-farm maize yield is low due to biotic and abiotic stresses affecting production in small scale farms. The objectives of this study were to assess the prevalence, importance and farmers' perceptions of GLS and PLS in small holder farming systems of medium and highland maize growing areas of Kenya. The participatory rural appraisal (PRA) study was done at three sites in Western Kenya during 2005/2006 cropping season. It focused on farmer cereal banks sampled from two districts, Vihiga and Bungoma with a total of 109 male and 123 female farmers. Data was collected from both primary and secondary sources whereby primary data was generated through group interviews of male and female farmers as well as key informants using PRA tools. Secondary data was obtained from the Kenya Government institutions, non-governmental organizations working in respective divisions as well as the private sector. Data was collected by research scientists and extension staff, both at the district and division level, local leaders and more informed farmers in the villages. Major constraints to maize production identified were low soil fertility, poor varieties, lack of seed due to high cost, unreliable weather (drought) and poor farming technologies, *Striga,* pests and diseases. On diseases, GLS and PLS were identified as major constraints to maize production and were reported in all the sites but farmers were not aware of the real causes of the two diseases. Gray leaf spot and PLS were reported to be severe during the short season crop (August-December) and local varieties (Tiriki, Anzika and Kipindi) were resistant. Desirable attributes used in variety selection were *Striga* resistance, drought tolerance, pest and disease resistance, closed tips, medium height and low input requiring variety. Generally farmers indicated that though they would prefer hybrid maize but due to high costs of inputs involved they still preferred the local variety, which required less input and also matured early serving as food security. Due to high cost of seed of improved hybrids, farmers also selected their own seed (advanced generations from previous season). An average yield gap between on-farm and expected yield potential was established to range from 5.3t ha^{-1} to 4.73t ha^{-1} across the sites. From the PRA it is evident that farmers in these areas have diverse preferences and are faced with a number of

constraints, GLS and PLS inclusive, that result in very wide yield gap realised on-farm. There is need for breeding for GLS and PLS resistance and also for development of good varieties with respect to farmer preferences, in particular OPVs that can be recycled without much reduction in yield. Therefore farmers need training on better seed selection methods of recycled OPVs and their landraces (local varieties).

2.1 Introduction

Maize in the mid-altitude zones of Western Kenya is a very important crop grown twice in a year, during the long rainy season of March to July and the short rainy season from August to January. The area under maize is estimated to be 173,000 hectares with a production of 231,000 tons representing 9% of total maize production in Kenya (Karanja, 1996). Although research on maize varieties and agronomical packages has been going on in the region for more than 50 years, yields are still low estimated at 1.34mt ha^{-1} with some farmers getting below 0.5mt ha^{-1} (MOA, 2004). More than 40 varieties have been released in Kenya since 1961 (KARI, 2003) and made available to farmers through agriculture extension personnel. Although most of these varieties were made available to farmers, yield at the farm level is low probably because they were developed by breeders without much consideration of farmer preferences and on-farm constraints (Odendo *et al*., 2001). This seems to have led to low adoption of production technologies meant to improve maize farming (De Groote and Bellon, 2000; Odendo *et al*., 2001). It has been observed that farmers assess maize varieties with defined criteria to meet preferences, in most cases different from those of the researchers (Morris and Bellon, 2004; Daniel *et al.,* 2007; Peter *et al*., 2007)

Farmer-researcher collaboration to develop maize varieties is a better approach than the traditional researcher dominated (Ashby and Lilja, 2004; Witcombe *et al*., 2006). Through the use of PRA, research scientists can better dialogue with farmers to learn preferences, concerns, beliefs, practices and indigenous technical knowledge about maize production systems (Ashby and Lilja, 2004). Farmer participation in evaluations helps scientists to recommend crop varieties for development with reference to farmer criteria (Ashby, 1991).

Small scale farmers have participated in various crop improvement programmes in many countries through PPB. These programmes have aimed at improving plant breeding efficiency by allowing farmers to apply their criteria for selection to the whole breeding process. Farmers have participated in rice improvement in China (Ruifa *et al*., 2007) and in Ecuador on quinoa improvement (Elaine *et al*., 2007). This approach is reported to have been used at CIMMYT for evaluation of pre-selected maize (Banziger and Meyer, 2002); spring wheat in South Asia (Ram and Duveiller, 2006); rice in Vietnam (Huan *et al*., 2005) and also Namibian farmers were involved in pearl-millet selection (Monyo *et al*., 2001). In Kenya, farmer participation has been reported in bean and animal improvement programmes for increased fodder production (KARI, 1999).

Low adoption that contributes to low yields as indicated calls for client-oriented research where maize breeders should put more emphasis on farmer criteria of selection and preferences when developing maize varieties. It is hoped that participation of both farmers and scientists in problem identification and variety development will result in breeders understanding the priority needs of the farmers. This could result in farmers taking up the varieties as their own, thus increasing the adoption rate and realized on-farm yields. Therefore, the objective of the study was to assess the prevalence, importance and farmer perceptions of GLS and PLS in small holder farming systems of medium and highland maize growing areas of Kenya

2.2 Materials and Methods

2.2.1 Study Area

Moist Mid-altitude zone (MM) covers Western, Nyanza and a small part of the Rift Valley province in Kenya, with an altitude range of 1110 m to 1500 m (Table 2.1). This zone corresponds largely with the Lower Midland (LM) temperature belt (Jaetzold and Schmidt, 1982). In Western Kenya, there are five main ecological zones ranging from LM1, humid to LM5, arid, with the higher elevation zones receiving more rainfall. Annual rainfall averages between 700mm and 1800 mm and is bi-modal. The first rainy season starts in March and the second in August/September. Mean annual temperature is 22.1°C, with an average minimum temperature of 13°C and an average maximum of 30°C. Soils are mainly clay-loam and sandy-loam (Jaetzold and Schmidt, 1982). These conditions make western Kenya a suitable environment for maize production.

Table 2.1 Agro-ecological zones for maize production in Kenya

Agro-ecological zone	Elevation (meter)	Area (ha^{-1})
Lowland –Tropics	0-700	41,000
Dry Mid-altitude I	700-1400	166,000
Dry-Transitional	1100-1700	66000
Moist-Transitional	1200-2000	466,000
Highlands	1600-2900	316,000
Moist Mid-altitude	1110-1500	173,000
Total		1,244,000

Source: Survey data from 1992 (Hassan *et al*., 1998)

A district is subdivided into divisions according to population and administrative boundaries. The two districts Vihiga and Bungoma, where the PRA was conducted, have fifteen divisions, with Vihiga having six and Bungoma nine. Vihiga has an average population of 498,883 with an area of 563 km^2 giving it a population density of 886.1 people per km^2 which is the highest in Kenya (Table 2.2). Bungoma has a population of 876,491 with an area of 2,069 km^2 and a population density of 423.6 people per km^2 as indicated in Table 2.2. These figures are based on a 1999 National Census exercise (Kenya Central Bureau of Statistics, 2001).

Table 2.2: Population, area and maize production of the study area in Western Province of Kenya

District	Division	Population		Area KM^2	Population Density	Maize (District)		
		District	Division	DST	District	Area (ha)	Prodn. (tons)	Yield (t ha^{-1})
Vihiga	Tiriki East (Cheptulu)	498,883	59,943	563	886.1	n/a	n/a	n/a
Vihiga	Emuhaya (Esibuye)	498,883	69,250	563	886.1	n/a	n/a	n/a
Bungoma	Chwele (Nalondo)	876,491	41,174	2,069	423.6	11,630	31,401	2.7
Total		**1,874,257**	**170,367**	**3,195**		**11,630**		**2.7**

Sources: Demographics and area from Kenya Central Bureau of Statistics (2001)
**n/a= Information not available, DST=District

During 2005/2006 cropping season, PRA exercise was conducted at three sites in Western Kenya, Cheptulu, Esibuye and Nalondo. These sites represented two divisions in Vihiga district and one division in Bungoma district. Criteria for site selection focused on the relative importance of maize and areas with active farmer groups as cereal banks. The three cereal banks that participated in the PRA were Cheptulu, Esibuye and Nalondo farmer cereal banks. Secondary data on physical description of the study sites were obtained from Provincial Ministry of Agriculture in western Kenya.

Cheptulu village is situated in Cheptulu sub location, Tiriki East division, Vihiga district in Western province of Kenya. The rainfall pattern is bimodal and starts from March to July, for the long rains and August to November for the short rains. The soils range from sandy loam to clay. The land holdings range from 0.04 to 1.6ha, with the majority of households having less than 0.8ha. The land is sloppy and land conservation measures like grass strips, are common. The family is the main source of farm labour with more than three members of the family being full time (Appendix 2.7). The peak for labour requirements is around March when there is overlap of land preparation, planting and weeding (Appendix 2.6). Most labour is hired on a casual basis with less than 30% of farmers hiring it on permanent basis.

Esibuye farmer cereal bank is in Ebusubi of Western Province, Vihiga district, North Bunyore location. These farmers are from four villages namely, Emmukunzi, Ebusiratsi, Ebusubi and Ekasala. The soils are red clay and the rainfall in this area is bimodal which enables maize to be planted twice in a year. Land sizes are very small with 100% of farmers interviewed having less than 0.8ha. Source of labour is mainly from the family members with an average of three persons in a family being engaged more than 50% of their time in farm work. During peak periods of planting and weeding, 38.4% of the farmers hire casual labour.

For Nalondo the cereal group Mbambe Rural Resource Management Programme is situated in Western province, Bungoma district, North Bukusu division, North Nalondo location, Lwanda Village. The soils are red clay and the rainfall is bimodal. Most farms are less than 1.2ha. This area is vital in maize production since it is a transitional zone between the mid altitude (1110 - 1500masl) and the highlands (1600 – 2900mas) areas.

2.2.2 Data sources

Data was collected from both primary and secondary sources whereby primary data was generated through group interviews of male and female farmers as well as key informants, using PRA tools. This involved three cereal banks, Cheptulu and Esibuye in Vihiga district and Mbambe in Bungoma district. A total of 232 farmers comprising 109 males and 123 female farmers participated (Table 2.3). The key informants included research scientists, comprising maize researchers, socio-economists, pathologists and extension staff both at the district and division level, leaders and the more informed farmers in the villages. Secondary data were obtained from Kenyan government institutions and non-governmental organizations working in the respective divisions as well as the private sector.

Table 2.3: PRA study areas and number of farmer participants

District	**Division**	**Cereal bank**	**Participants**		
			Male	**Female**	**Total**
Vihiga	Tiriki East	Cheptulu	51	49	100
Vihiga	Emuhaya	Esibuye	33	42	75
Bungoma	North Bukusu	Mbambe	25	32	57
Total			109	123	232

2.2.3 Sampling procedures

Multi-stage sampling techniques were applied to select the study sites to represent diverse ecological and socio-economic environments and varying maize production systems in the moist mid-altitude zone. Two divisions were selected from Vihiga district and one from Bungoma. The criteria of selection were importance of maize, diseases and pests, cropping systems and agro ecological zones based on secondary data from the Ministry of Agriculture. For each division, one location, one sub-location and one village were randomly selected as study sites based on the presence of maize cereal banks. Lists of divisions, locations, sub locations and cereal banks were obtained from respective Districts Agricultural offices.

2.2.4 Data collection and analysis

The PRA interdisciplinary team involved KARI researchers, breeders, pathologists, socio-economists and two district and divisional extension staff members. In each district, a frontline agricultural staff member was used as the entry point to the communities. They participated in identification of locations and active farmer cereal banks. Before the PRA exercise, the research team visited the sites to establish a good rapport with the local people and relevant local administration and set dates for the exercise. The venues of the exercise were the cereal banks office compounds. In cases where women and men were unable to participate freely, they were separated for free discussion to avoid domination of some groups. Each group was given flip charts and felt pens and in each case a group appointed a rapporteur to write their results and discussions. The work of the research team was to guide and facilitate farmer discussions, while farmers took the leading role in problem identification and solution development. At the end there was a plenary session, whereby each group presented their results to the whole group of participants for validation and modification (Figs. 2.1, 2.2, 2.3, 2.4 and 2.5).

Figure 2.1: Part of farmers participating in a PRA exercise at Nalondo

Figure 2.2: Farmer giving constraints experienced to farming in the community

Figure 2.3: Farmer taking a leading role in problem identification through pair wise ranking with female farmers.

Figure 2.4.Farmer taking a leading role as rapporteur in one of the focus groups

Figure 2.5: Social scientist from KARI verifying absolute ranking of the constraints by use of pair wise ranking, with some of the male farmers

First a transect walk was done to directly observe village resources, farming land, pests and disease problems on the farms. After the transect walk, farmers assembled and various PRA tools were used to get general information from farmers. These tools included:

1. Social maps, indicating who lives in the community and where, including resources available to the community;
2. Venn diagrams, to illustrate the extent to which organizations and groups interact with each other, the importance of each, and their efforts in the community;
3. Matrix and pair wise ranking-on decision making, resource access and control and responsibility matrix were carried by farmers;
4. Daily activity chart, representing the daily workload of each of the genders to highlight gender differences;
5. Seasonal calendars and activity profiles;
6. Pair wise ranking of crops, constraints in terms of importance.

In each case, with the help of a developed checklist, farmers were asked to produce a list of varieties grown, relative proportion of the varieties, criteria used in variety selection, pests and diseases attacking maize, together with an estimate of the damage caused and ranking of importance. Data was collected on type of seed, tillage, pests, diseases, weeds, relative susceptibility of hybrids compared to local lines, possible causes as perceived by farmers, possible solutions as perceived by farmers and researchers and areas that farmers can participate in the research process.

2.3 Results

2.3.1 Agricultural Enterprises

From the PRA exercise it was established that farmers in Bungoma and Vihiga districts grew an assortment of crops (Table 2.4). Across the districts, maize was ranked as the most important staple food followed by beans. Source of cash differed from location to location depending on the type of cash crop grown. Cheptulu farmers ranked tea as the most important cash crop, while Esibuye farmers ranked cabbages (*Brassicas* spp) and Nalondo sugarcane. The other preferred crops in Bungoma were sorghum, finger millet and cassava because of their drought tolerant characteristic. Finger millet was mentioned to have some added value in the community during cultural festivities. The other crops mentioned were sweet potatoes, bananas, yams, ground nuts. Livestock enterprises were the same across the three sites, the main ones: being kept were cattle, goats, sheep and chicken. Cattle were kept as an income source to pay for fees and also for milk production. Goats and sheep were mainly for income to supplement revenue from cattle. The ranking of the crops was based on use as food and source of income (Table 2.4).

Table 2.4: Absolute ranking of source of income and food from crops at three sites in western Kenya**.**

Crop	Site						Average	
	Cheptulu Food	Cash	Esibuye Food	Cash	Nalondo Food	Cash	Food	Cash
Beans	2	4	2	n/c	2	n/c	2	4
Bananas	4	3	6	n/c	4	n/c	7	3
Sugar cane	n/f	5	n/f	n/c	n/f	1	n/f	3
Tea	n/f	1	n/f	2	n/g	n/g	n/f	2
Cabbages	7	6	9	1	3	n/c	6	3
Maize	1	2	1	n/c	1	n/c	1	2
Sweet potatoes	3	n/c	4	n/c	5	n/c	4	n/c
Cassava	5	n/c	5	n/c	7	n/c	6	n/c
Cow peas	8	n/c	3	n/c	3	n/c	5	n/c
Sorghum	n/g	n/g	7	n/c	8	n/c	8	n/c
Finger millet	n/g	n/g	8	4	4	n/c	6	4
Soya beans	10	n/c	n/f	3	n/f	n/c	10	3
Ground nuts	9	n/c	10	n/c	6	n/c	13	n/c
Coffee	n/g	n/g	n/g	n/g	n/f	2	n/f	2
Sunflower	n/g	n/g	n/g	n/g	n/f	3	n/f	3
Yams	6	n/c	n/g	n/g	9	n/c	7	n/c

Key: Low value score= very important as either cash or food crop; High value score= less important as cash or food crop; n/c=not used as cash; n/f=not used as food crop; n/g= not grown in the area

2.3.2 Maize production

Acreage and production

Maize acreage during the long rainy season in 2005 ranged from 0.1 ha to more than 0.8 ha, but most farmers had less than 0.8 ha (Table 2.5). Farmers perceived the second season August to December to be unreliable in terms of rains and few planted maize so acreage was mostly less than 0.4 ha. On average, one hectare of maize in these areas produced between 0.7t ha^{-1} to 1.4t ha^{-1} during the first season and less than 0.9t ha^{-1} in the second. Farmers were concerned about these low yields and attributed them mostly to poor varieties and inputs.

Table 2.5: Estimated area and production of maize across the three sites,Cheptulu, Esibuye and Nalondo in western Kenya during 2005

Area (ha)	First season 2005		Second season 2005	
	Percentage of farmers	Yield (t ha^{-1})	percentage of farmers	Yield (t ha^{-1})
0.1 or less	16.7	0.2-0.3	16.7	0.045-0.09
>0.1 to 0.2	27.8	0.3-0.5	22.2	0.045-0.09
0.2 to 0.4	27.8	0.3-0.5	11.1	0.045-0.36
> 0.4 to 0.8	11.1	0.5	-	-
> 0.8	27.8	0.6-0.8	16.7	0.045-0.54

Key: - = no maize production under that area (ha)

Maize varieties

Farmers in this region grew an assortment of maize varieties including both local and improved varieties. Local varieties included “Anzika” and “Sipindi”, while improved ones included H614, Pioneer, Pannar, Maseno hybrid, H511 and R1 Kayongo. Local varieties Anzika and Sipindi were grown in both seasons and were the most preferred since they are tolerant to poor soils, withstand drought, resist weeds and mature early (Table 2.6). Sipindi was grown in all districts except Cheptulu site of Vihiga district and in both long and short seasons. Hybrid 614 was one of the improved varieties preferred for its high yields when recommended agricultural practices are employed like when adequate fertilizer is applied. The other variety that was highly regarded by Esibuye farmers was R1 Kayongo, a new variety bred to resist *Striga* weed infestation. The variety is becoming popular among farmers in the area as *Striga* is one of the major weed affecting maize cultivation in medium and low land areas of western Kenya. Although farmers mentioned Maseno hybrid to be drought tolerant, they disliked it because of its susceptibility to weevils in storage. Over fifteen years ago, some varieties like “Opapali” were popular, but were phased out due to their poor roasting qualities and low yields. Another local variety, “Aburusi” used to be planted but due to the hard elongated husk that was very sharp, made farmers abandon it due to the injuries when handling it. Some of the hybrids phased out by Esibuye farmers included H622, H625, mainly due to susceptibility to ear rots and lodging, respectively.

Varieties were grown depending on the season and their tolerance to drought. Local varieties were preferred during the short rainy season compared to the hybrids as indicated in Table 2.6. A local variety, Tiriki, was grown during the short season by farmers in Cheptulu whereas Anzika was the local variety preferred in Esibuye. In Bungoma district, Nalondo most farmers grew short, early maturing hybrids that were able to escape drought. At both sites, hybrids were planted during the long rainy season (Table 2.6). Nalondo farmers had more varieties to choose from, creating a problem in choosing a variety. Farmers were being exposed to many varieties in a short time period making it difficult for their evaluation and make right choices.

Table 2.6: Rank of varieties grown per site and per season by farmers in three sites of western Kenya

			Cheptulu		Esibuye		Nalondo	
Variety	**Type**	**Colour**	Long rains	Short rains	Long rains	Short rains	Long rains	Short rains
H614	hybrid	White	1	-	2	-	1	-
H625	hybrid	White	2	-	-		3	-
Anzika	local	White	-	-	1	1		
Sipindi	local	Yellow	-	-	4	6	7	9
Pannar	hybrid	White	-	-	5	5	-	6
Pioneer	Hybrid	White	-	-	3	2	-	7
R1 Kayongo	OPV	White	-	-	6		-	-
MDC	OPV	White	-	-	-	7	-	-
Simba 61	hybrid	White	-	-	-	-	2	-
H505	hybrid	White	-	-	-	-	4	4
H513	hybrid	White	-	-	-	-	5	10
No.8	hybrid	White	-	-	-	-	6	8
H628	hybrid	White	-	-	-	-	8	-
H627	hybrid	White	-	-	-	-	12	-
H502	hybrid	White	-	-	-	-		1
Duma 43	hybrid	White	-	-	-	-		2
Duma 41	hybrid	White	-	-	-	-		3
Tiriki	local	White		1	-	-		-
H522	hybrid	White	-	-	-	4		-
H6210	hybrid	White	-	-	-	-	9	-
H6213	hybrid	White	-	-	-	-	10	-
H503	hybrid	White	-	-	-	-		12
H504	hybrid	White	-	-	-	-		13
H403	hybrid	White	-	-	-	-	13	5
H629		White	-	-	-	-	11	-
Pop corn		Yellow/ white	-	-	-	-		11
Katumani		White	-	-	-	-		-

*****Ranks: smallest rank means very important in the season and high rank less important,
- = Variety not grown in the area, MDC= Maseno double cobber

2.3.3 Farmers' Criteria in Selecting Varieties

Farmers used many criteria in selecting maize varieties but this differed from area to area depending on the constraints (Appendices; 2.1, 2.3 and 2.4). They used both positive and negative characteristics to select a variety. They also prioritised the criteria used in their selection of desirable characteristics and their rankings where a pair wise ranking method was employed to rank the characteristics (Tables 2.7, 2.8, 2.9).

2.3.3.1 Selection criteria for farmers in Cheptulu

In Cheptulu, the most important criteria were in order of importance: low input requiring variety (less fertilizer and labour, affordable seed), non lodging, closed tips, medium height and disease and pest resistant, early maturing and lastly high yields (Table 2.7). Low input requiring variety was considered the most important criterion because farmers perceived a variety requiring less input could reduce the cost of production from purchase of seed to harvest and storage. High yield was among the least important criteria with these farmers, as they argued that high yields could only be achieved after all other factors were fulfilled. Therefore in selecting for the other traits they are selecting for yield indirectly as it was the ultimate trait. This was unexpected as most maize breeders would have considered yield as the important criterion for farmers. Taste was the least ranked criteria, it was considered minor because it was only realized in roasted maize.

Table 2.7: Pair wise ranking of desirable maize variety characteristics (criteria) by men and women farmers in Cheptulu in western Kenya

Desirable characteristics	**EM**	**HY**	**DR**	**WR**	**SW**	**NL**	**LI**	**CT**	**MH**	**SCORE**	**Rank**
Early maturing	=	EM	DR	WR	EM	NL	EM	CT	MH	3	6
High yields		=	DR	WR	HY	NL	EM	CT	MH	1	8
Disease resistant			=	DR	DR	NL	DR	CT	MH	5	4
Weevil resistant				=	WR	NL	LIR	CT	MH	3	6
Sweet						NL	LI	CT	MH	0	9
Non lodging						=	LI	NL	NL	7	1
Low input							=	LI	LI	7	1
Closed tips								=	CT	6	3
Medium height									=	5	4

Key: EM-Early maturing; HY-High yields; DR-Drought resistant; WR-Weevil resistant; SW-Sweet; NL-Non lodging; LI-low input; CL-Closed tips; MH-Medium height; *Low score= high rank and less important; High score=low rank and very important

2.3.3.2 Selection criteria for farmers in Esibuye

The most important criteria used by farmers in Esibuye were *Striga* resistance followed by drought tolerance, heavy grains as indicated in Table 2.8. Farmers considered traits in maize countering biotic or abiotic stresses more important than secondary traits that depended on environment to be realized. High yield was considered the fourth criterion and taste the least criterion used in choice of variety (Table 2.8).

Table 2.8: Pair wise ranking of positive qualities, criteria of selection used by farmers of Esibuye cereal bank in western Kenya

Positive qualities	EM	HP	LF	HY	NL	S	STR	DR	HG	SCORE	RANK
Early maturing	-	EM	EM	HY	EM	EM	STR	DR	HG	4	5
High population		-	LF	HY	NL	HP	STR	DR	HG	1	7
Low fertilizer			-	HY	LF	LF	STR	DR	HG	3	6
High yields				-	HY	HY	STR	DR	HG	5	4
Non lodging					-	S	STR	DR	HG	1	7
Sweet						-	STR	DR	HG	1	7
Striga resistant							-	STR	STR	8	1
Drought resistant								-	DR	7	2
Heavy grains									-	6	3

KEY: EM-Early maturing, HP-High population, LF- Low fertility, HY-High yields, NL-Non lodging, S-Sweet, STR-Striga resistant, DR-Drought resistant, HG-Heavy grains *Low score= high rank and less important; High score=low rank and very important

2.3.3.3 Selection criteria for farmers in Nalondo

Nalondo farmers had seven preferences that they used to select varieties. The criteria in terms of importance were: low input requirements, *Striga* resistance, drought tolerance and high yielding (Table 2.9). Taste and high plant density were less considered as criteria of selection. High yield with these farmers was given more weight, as it ranked number three. Though early maturity could have been preferred, since maize is grown biannually, farmers preferred high yields in the first season. They argued that the second season is unreliable and an early maturing variety with low yield in the first season was unrealistic, so they were better off with a late maturing, but high yielding variety.

Table 2.9: Pair wise ranking of positive qualities (criteria) of maize by Nalondo Farmers in western Kenya

Positive qualities	**EM**	**HY**	**LF**	**DRP**	**HPD**	**RST**	**TST**	**CMT**	**LOR**	**SCORE**	**RANK**
Early maturing	-	HY	EM	EM	HPD	RST	EM	CMT	LOR	3	6
High yields		-	HY	HY	HY	RST	HY	CMT	LOR	5	3
Low fertility			-	LF	LF	RST	LF	LF	LOR	4	5
DRP				-	HPD	RST	DRP	CMT	LOR	1	8
HPD					-	RST	HPD	CMT	LOR	3	6
RST						-	RST	RST	LOR	7	2
TST							-	CMT	LOR	0	9
CMT								-	LOR	5	3
LOW									-	8	1

KEY: EM-Early maturing, HY-High yielding, LF-Low fertility, DRP-Drooping ears HPD-High plant density, RST-Striga resistant, TST-Taste, CMT-Climate, LOW-Low input requirement *Low score= high rank and less important; High score=low rank and very important

2.3.4 Criteria of Selection across Sites

As indicated in Table 2.10, farmers in different sites have different preferences in the type of variety characteristics required. Across the sites the most preferred six criteria were: *Striga* resistance, low input requiring variety, drought tolerance, disease resistance, heavy grains and closed tips. From the three sites, the study indicated that farmers appreciated abiotic and biotic factors. Yield across the sites was ranked ninth and taste last, among the preferences. Farmers preferred varieties with closed tips, because farmers attributed low incidence of ear rots to closed tips

Table 2.10: Criteria for farmer selection of varieties across three sites in western Kenya.

Site	Cheptulu		Esibuye		Nalondo		Average	
Desirable characteristic	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**	**Score**	**Rank**
Early maturing	3	6	4	5	3	6	3.3	11
High population	-	-	1	7	3	6	5.7	13
Low fertilizer	-	-	3	6	4	5	3.5	10
High yields	1	8	5	4	5	3	3.7	9
Non lodging	7	1	1	7	-	-	4.0	8
Sweet	0	9	1	7	0	9	0.3	15
Striga resistant	-	-	8	1	-	-	8.0	1
Drought resistant	-	-	7	2	5	3	6.0	3
Heavy grains	-	-	6	3	-	-	6.0	3
Disease resistant	5	4	-	-	7	2	6.0	3
Weevil resistant	3	6	-	-	-	-	3.0	12
Low input	7	1	-	-	8	1	7.5	2
Closed tips	6	3	-	-	-	-	6.0	3
Medium height	5	4	-	-	-	-	5.0	6
Dropping ears	-	-	-	-	1	8	1.0	14

*Low score= high rank and less important; High score=low rank and very important; - = not a criteria in the area

2.3.5 Constraints to Maize Production

Ranking of maize production constraints differed between sites (Table 2.11). Women in Nalondo and Cheptulu considered labour as a constraint, but men never regarded it as a constraint. Women in Cheptulu ranked low soil fertility, high cost of seed and labour as the most important constraints (Appendix 2.5). In Esibuye, low soil fertility and unreliable climate were perceived as the most important constraints. However farmers in Nalondo ranked the first important constraint differently between men and women. Men ranked poor seed (unviable), while women ranked lack of finance as the most important constraint to production. The other rankings were similar, but women in both Nalondo and Cheptulu, considered labour as an important constraint not considered by men. Across the sites, the results indicated that low soil fertility, poor seed, weeds, pests, diseases and unreliable climate, drought were the most perceived important constraints to maize production. There was no difference in gender ranking of constraints in Esibuye as observed in Nalondo and Cheptulu. This was due to the fact that women and men in Esibuye cultivated one farm together because of small land sizes. In other sites, men had different crop plots from women.

Table: 2.11 Absolute ranking of maize constraints by site by Gender in western Kenya

Site	Cheptulu		Esibuye		Nalondo	
Constraint	**Women**	**Men**	**Women**	**Men**	**Women**	**Men**
Fertility	1	1	1	1	-	2
High cost of Inputs	2	-	-	-	2	-
Labour	3	-	-	-	6	-
Poor timing	4	-	-	-	-	-
Poor varieties	5	-	-	-	-	-
Lack of technologies	6	-	-	-	7	-
Lack of transport	7	-	-	-	-	-
Unreliable climate	-	3	2	2	-	-
Pests and diseases	-	-	3	3	3	4
Poor seed	-	2	4	4	-	1
Striga	-	-	-	-	-	3
Poor market	-	-	-	-	4	5
Middle men	-	-	-	-	-	6
Poor storage	-	-	-	-	-	7
Theft	-	-	-	-	-	8
Low farm gate prices	-	-	-	-	5	9
Transport	-	-	-	-	-	10
Lack of finance	-	-	-	-	1	-
Poor management	-	-	-	-	8	-

*****Low rank = constraint very important; High rank= constraint less important;
- = not a constraint in the area

2.3.6 Perceived Strategies to Counter Constraints

Farmers were able to mention some of the strategies they employ to counter the constraints. For fertility, they used compost or farmyard manure and planted local varieties requiring low levels of fertilizer. Farmyard manure, compost and inorganic fertilizer were applied, depending on resource availability. Generally 59% of farmers used farmyard manure, 50.3% applied compost and 67% applied inorganic fertilizer but less than the recommended amounts.

In all the areas seed as a constraint was very important; without good seed there is no crop. Farmers mentioned that due to the high cost of seed, they selected their own seed from advanced generations from previous seasons. Farmers indicated that though they would prefer hybrid maize, due to high input costs they still preferred the local variety, requiring less input and also maturing early, serving as food security. For the farmers who planted their own seed, different selection criteria were used depending on the stage of selection. About 19% selected before harvest, they considered large stalks and healthy plants. About 21% of the farmers selected during harvesting and 46% after harvest, but before threshing, both based on closed tips, numbers of rows on the cob (8 rows), large sized cobs, not rotten and heavy cobs. Around 60% and 57% of farmers stored the selected seed in cob and threshed grain form, respectively. The threshed grain was mixed with ash, paraffin or some times purchased chemicals like “actellic” and stored. The cob form was hung around the cooking place and preserved through smoking. Other seed sources, though unreliable, included grain stockists, open air markets, other farmers and research organizations, especially the Rural Programme Kenya (RPK) promoting *Striga* resistant variety, Kayongo. Generally, farmers suggested more Ministry of Agriculture involvement through extension staff advising on land preparation, planting, pest and disease identification and control measures and also to assist in plant and cob selection for recycled seed.

2.3.7 Farmer Perception of GLS and PLS

Among the important diseases reported by farmers across the districts included maize streak, ear rots, smuts, GLS and PLS. Pests were stalk borer and weevils, in storage, as the predominant pest. Few farmers applied storage chemicals, but the majority did not. In the case of stalk borer, most did not apply chemicals, though they mentioned ash as a remedy. Farmers were able to identify and recognize diseases directly impacting on yield like ear rot and smuts. In the case of GLS, all farmers reported having knowledge of the disease, which they started observing in their fields five years ago. No local name had been associated with GLS and most farmers perceived the causes to be due to drought, frost, effect of fertilizer, rain and due to lack of crop rotation. On the mode of transmission, wind and insects, especially bees, were mentioned. Levels of occurrence of GLS were reported to be high during the short season, August – December 2005 and low during the long rains, March – August. Hybrid 614 was rated high, susceptible, while Katumani, local varieties Tiriki, Anzika and Sipindi were rated low, resistant in terms of susceptibility to GLS by the farmers (Table 2.12).

Phaeosphaeria leaf spot was reported in 2000 and the local name given to the disease is Anziga, due to its appearance. The perceived causes, mode of transmission, level of occurrence in different seasons and the reaction to the three varieties was the same as for GLS. For both diseases, farmers were unable to estimate crop losses. Some of the control strategies mentioned were alternating crops and use of resistant varieties from recognized institutions like KARI.

There was no defined method of control though some farmers mentioned uprooting but most of them disagreed because they argued that uprooting resulted in losing the entire crop as almost all the plants were usually infected. Though farmers were unable to point out direct possible control measures, they were able to differentiate reactions of the varieties they grew to GLS and PLS. Compared to improved varieties, local varieties were more resistant to both diseases (Table 2.12).

Table 2.12: Susceptibility of popular varieties to GLS and PLS in the study area of western Kenya

Variety	Susceptibility to GLS	Susceptibility to PLS
H614 (hybrid)	Moderately susceptible	Moderately susceptible
Pioneer (PHB3253)	High susceptible	High susceptible
Anzika (local)	Resistant	Resistant
R1 Kayongo	Moderate susceptible	Resistant
Sipindi (local)	Resistant	Moderately susceptible
Katumani (composite)	Resistant	Resistant
Tiriki (local)	Resistant	Resistant

2.3.8 Partners in Maize Production

Several stakeholders interacted with farmers but differed from site to site (Table 2.13). Farmers considered these organizations very important as they provided very essential farming packages. They appreciated more organizations with more interactions to be involved, particularly the government organizations.

Table 2.13: Partners in Maize Production (Organizations interacting with farmers) in western Kenya

Organization	Activities	% Involvement Nalondo	Cheptulu	Esibuye
SACRED AFRICA	Variety testing Marketing Training Field days Cash	100	-	-
Ministry of Agriculture-Extension	Training	100	100	5
Local authorities	Advice and Security	100	-	-
Seed companies	Seed testing	100	-	-
CBOS-MBAMBE	Seed information	100	-	-
KACE	Marketing	100	-	-
Mabanga FTC	Training, Advice Variety testing	40	-	-
KARI	Training, advice Provision of varieties	35	45	48
Cereal Boards	Marketing	1	-	-
Resource Rural Programme Kenya (RPK) (NGO)	Training	-	75	85
Local Focus (NGO)	Training	-	75	-
KICIP	Training	-	-	40
SCOPIC	Training	-	-	35
AGRIMACK	Training	-	-	45

* Low % = less interaction; high % = high interaction

2.4 Discussion

From the study it was shown that, although maize was ranked as the most important staple food crop, farmers still planted an assortment of other crops. The other planted crops were sorghum, finger millet and cassava, because of their drought tolerant characteristics. This indicated that farmers were aware of uncertainties that accompany farming and therefore took precautions by planting crops with low percentage of crop failure. This was also shown during the second short rain season where acreage of maize planted was less than the first long rain season. Farmers also planted local varieties that were tolerant to drought stress during the short rain season. It is clearly seen that the type of crop or variety that was planted was dictated by perceived weather conditions, percentage losses of a crop or variety and availability of a variety at minimal costs. Those varieties that were locally available at minimal cost were risked more than commercial varieties that were expensive in terms of cost and availability.

On-farm maize yields by farmers were very low compared to the on-station maize yields by breeders as indicated during the PRA exercise. Yields of maize ranged from 0.2t ha^{-1} to more than 0.8t ha^{-1} for the first season crop (March – August) and less than 0.6t ha^{-1} for the second season crop (August – December). Across the sites, average yield ranges of between 0.7t ha^{-1} to 1.4t ha^{-1} were observed. Karanja (1996) reported yield potential of 6.0t ha^{-1}, indicating that there was yield gap of between 5.3t ha^{-1} and 4.7t ha^{-1}. Similar yield gaps were reported by Odendo *et al.* (2001). This indicates that for the last six years there has been no improvement in yields by these small scale farmers in the region. It also implies that there has been little effort by breeders in addressing maize production constraints in the area for the last six years.

Farmers had a number of criteria for selecting maize varieties. Both negative and positive characteristics were used as criteria for selection, but the main emphasis was on the importance of the character in the region. The main preferred characters in order of importance were a variety that requires low input, drought resistant, *Striga,* pest and disease resistant and with closed tips. Farmers are more concerned with environmental, economical and biotic stresses that affect maize production directly than secondary characters. Although farmers appreciated high yield as the ultimate product they preferred in a variety, it was not ranked among the first four preferred criteria of selection in two sites. Farmers argued that yield is only a function of other characters and is only achieved once the other qualities have been selected for and the right environment is in place. They gave examples of varieties that gave high yields on station, but very low yields on-farm, because stresses such as low soil fertility, weeds and drought are common in farmers' fields. This implies that breeders should aim at striking a balance between yield and other traits as farmers preferred a variety that required low soil fertility levels with moderate yields.

It was also observed that farmers were more concerned with traits that directly affected the cob as was the case with open tip and tall varieties that were prone to lodging resulting in increased incidences of rots. Tall varieties were also not preferred as farmers argued that they take long in the fields. Short varieties were preferred as cob to plant ratio was higher than the tall varieties and also because farmers were able to achieve high plant density with medium height varieties. This suggested that farmers also correlated other maize traits to yield when selecting for a suitable variety. Breeders in Kenya have been selecting tall hybrids in terms of their yield potential, but from the study farmers look for a variety not only in terms of yield potential but in terms of maize population and maturity as they are interested more in maximising production in ever reducing land sizes.

Grain as finished product was also a major concern to farmers in terms of colour, quality and weight. It was indicated that farmers preferred white grains and heavy. Although most of the measurements in farmers field and local markets used volume as a standard, weight of the grain was still very important criteria for selecting a variety. Unlike breeders who use weight as measure of yield, farmers correlated grain weight to capacity to hold water when cooked as porridge or "Ugali" the most staple food.

Seed for planting maize is crucial in maize farming and all farmers suggested that seed is recycled due to high prices of improved varieties. Similar results were reported by Odendo *et al*. (2001). There were differences among farmers on the stage of selection as shown from the PRA. About 21% of farmers selected during harvesting and 46% after harvesting. Farmers selected large ears, free from rots, heavy cobs with eight row cobs. This suggested that farmers selected for tolerance to biotic and abiotic stresses as they considered the end product, unlike breeders who start selecting early in the field. This might also explain the increase in susceptibility to foliar disease, lodging, and other stresses. It is evident from the study that most farmers select the seed crop after physiological maturity, thus missing out on characters that are predominant early in the season.

Several stresses were mentioned by farmers, among them *Striga* weed, a major constraint for farmers in Bungoma. Odendo *et al*. (2001) also reported similar findings. The increase in the spread of the weed can be explained by the farming practices in the region. Weeding was mainly by hand and the decision when to weed was at 50% infection and only 45% of farmers weeded twice, while the remaining 55% weeded once. Farmers identified crop pests and weeds more easily than foliar disease that they normally confused as the same, especially GLS and Northern leaf blight. Pests, diseases and weeds were given names according to severity of damage and difficulty in control. The large grain borer (LGB) was named Osama, and Witch weed “Ukimwi”, meaning AIDS. It was clear that farmers found it easier to identify and recognize diseases, pests and weeds having a direct impact on yield.

Farmers had no knowledge of the real causes of GLS and PLS as they perceived drought, fertilizer, frost burn as the main causes. They attributed bees as the mode of transmission from farm to farm. This explained the wide spread observed for these diseases across the sites of the study. It is possible that farmers transmitted diseases from farm to farm through crop debris without realizing, as they had no knowledge that this was one of the modes of transmission. Debris have been reported as among the means of inoculum spread (Bhatia *et al*., 2002). This implies that when developing a variety for resistance to diseases or pests, added packages like information on pests and diseases in terms of factors influencing incidence and severity should accompany a variety when released to farmers

Farmers also had perceived strategies for constraints mentioned. For low soil fertility they advocated for compost, farmyard manure and planting of local varieties. For high cost of hybrid seed, recycling was practiced. From this, it implies that it is beneficial for breeders to seek farmers’ solutions to constraints before developing a variety. In the case of expensive seed and unavailability of hybrid seeds, breeders can develop OPVs as recycling is part of the strategy farmers employ in this respect.

Although many constraints were mentioned that affected these farmers, they argued that the major constraint above all was lack of technical knowledge on how to select recycled seed from the previous crop, know when to plough, plant, control pests and diseases, and how to utilize farm yard manure and compost. They suggested more involvement of the Ministry of Agriculture through extension staff during land preparation, planting, identification and control of pests and diseases and other constraints when the crop is in the field and finally how to select seed.

In reference to how breeders have been conducting research, farmers had the opinion that most important traits they preferred were not considered by breeders. They argued that breeders were developing varieties targeting one trait rather than incorporating more traits that reflect the true situation of farming constraints of a particular area. Local varieties, though low yielding, tolerated more stresses than hybrids that might have been bred for only stalk borer resistance or *Striga* resistance but susceptible to more diverse stresses on-farm. Farmers also appreciated the recent change in breeders, where they are now being more involved in the process.

It is beneficial to include both men and women when conducting a PRA as there were differences in the rankings and preferences by women and men. Men appeared to be interested in field characteristics while women were interested in post harvest ones. Men were also interested when production of maize was high and time of selling where they make decision on the amount to be sold, where to sell and on the prices, while women are left with the task of processing maize for selling but not in decision making.

2.5 Conclusions

The PRA study showed that maize production was affected by many constraints but differed from one farming system to another and farmer preferences were determined by the constraints encountered. From the study it came out that farmers considered constraints that directly reflected yield loss like ear rots, drought, poor seed that results in poor germination and Striga. Across the districts, low soil fertility, drought, poor seed and diseases were the most important. Therefore the preferred traits used as criteria for variety selection were *Striga* resistance, low input requiring variety, drought tolerance, disease resistance, heavy grains and closed tips. Local varieties were preferred more than the hybrids in stress environments and in uncertainty situations. GLS and PLS were widely spread and considered important constraints. The rapid spread indicated by the presence of GLS and PLS in all the sites calls for awareness to be made to farmers on the potential of the two diseases in yield reduction. Breeders should look for ways of coming up with better varieties in terms of resistance.

Farmers pointed out the need to have more collaborators in maize production, especially in training. In cases of recycling of seed, only OPVs should be advocated for and breeders should include development of OPVs in their programmes. There is need for training farmers in seed selection procedures. Given the scarcity of land where isolation is impossible, farmers should be encouraged to select for crops starting in the field to harvest that look uniform to the OPV. Selection should be based on phenotypic appearance, maturity, height, colour of grain, cob size, and health of the crop plus the cob at harvest. In general farmers should select for tolerance to abiotic and biotic stresses. The study established that farmers are faced with diverse constraints with varied perceptions that sometimes differs with the priorities of breeders. Research-farmer collaboration should be encouraged to bridge this gap.

Reference

Ashby, J. 1991. Adopters and Adapters. Participation of farmers in on-farm research, *In* Thripp (ed), Planned change in farming systems, Progress in on-farm research. New York: John Wiley and Sons.

Ashby, J.A., and N. Lilja. 2004. Participatory research: Does it work? Evidence from participatory plant breeding. Proceeding of the 4th international crop science congress , new directions for a diverse planet, 26th September- 1st October, 2004 Brisbane Queensland, Australia.

Banziger, M., and J. de Meyer. 2002. Collaborative maize cultvar development for stress-prone environments in Southern Africa. p. 269-296. *In:* Clevaland, D. A. and D. Soleri. (ed.) Farmers, scientists and plant Breeding. CAB International.

Bhatia, A., and G.P. Munkvold. 2002. Relationships of environmental and cultural factors with severity of gray leaf spot in maize. Plant Disease 86:1127-1133.

Daniel, D., J. Parlevliet, C. Almekinders, and G. Thiele. 2007. Farmers' participation and breeding for durable disease resistance in the Andean region. Euphytica 153:385-396.

De Groote, H., and M. Bellon. 2000. Farmers' participatory research: Application for breeders. Paper presented at the training course on breeding for stress tolerance in maize, seed production and GIS, Nairobi, September 14, 2000. Nairobi: CIMMYT.

Elaine, M., E. Peralta, N. Mazon, D.L. Danail, G. Thiele, and P. Lindhout. 2007. Aspect of participatory plant breeding for quinoa in marginal areas of Ecuador. Euphytica 153:373-384.

Hassan, R.M., K. Njoroge, J.D. Corbett and K. Njoroge. 1998. Combining Geo-referenced survey data with agroclimatic attributes to characterise maize production systems in Kenya. p. 43-68. *In* Hassan R.M. (ed.) Maize technology development and transfer. A GIS application for research planning in Kenya. Oxon, UK: CAB International.

Huan, N.H., L.V. Thiet, H.V. Chien, and K.L. Heong. 2005. Farmers'participatory evaluation of reducing pesticides, fertilizers and seed rates in rice farming in the Mekong Delta, Vietnam. Crop protection 24:457-464.

Jaetzold, R., and H. Schmidt. 1982. Farm management handbook: Natural and farm management information Vol.II/B. Nairobi: Ministry of agriculture, livestock development and marketing.

Karanja, D.D. 1996. An economic and institutional analysis in Kenya: MSU international development working paper No. 57:3-5.

KARI.1999. Annual report. Farming systems of North Rift provinces of Kenya. KARI, Kenya

KARI. 2003. Annual report. Farming systems of North Rift provinces of Kenya. KARI, Kenya.

Kenya Bureau of Statistcs. 2001. National census report of 1999. Nairobi, Government printer, Kenya.

MoA. 2004. Annual Reports of Busia, Butere-Mumias and Homa Bay Districts: Ministry of agriculture, livestock and marketing. Kenya

Monyo, E.S., S.A. Ipinge, G.M. Heinrich, and E. Chinhema. 2001. Participatory breeding: does it make a difference? Lesson from Namibian pearl-millet farmers. p. 198-207. *In*, N. Lilja, J. A. Ashby, and L. Sperling (ed) Assessing the impact of participatory research and gender analysis CGIAR programme for participatory research and gender analysis. (PRGA), Apartado Aereo 6713, Cali. Colombia.

Morris, M.L., and M.R. Bellon. 2004. Participatory plant breeding research opportunities and challenges for the international crop improvement system. Euphytica 136:21-35.

Odendo, M., H. De Groote, and O.M. Odongo. 2001. Assessment of farmers' reference and Constraints to Maize production in moist mid-altitude zone of Western Kenya. A paper presented at the 5th International conference of the African crop science society, Lagos, Nigeria October 21-26, 2001.

Peter, D., P. Craufurd, K. Marfo, W. Dogbe, and R. Bam. 2007. Improving participatory varietal selection process: participatory varietal selection and the role of informal seed diffusion mechanisms for upland rice in Ghana. Euphytica 155:315-327.

Ram, C.S., and E. Duveiller. 2006. Farmer participatory evaluation confirms higher grain yields in spring wheat using a selection index for spot blotch resistance, maturity and kernel weight. Euphytica 150:307-317.

Ruifa, H., J. Cao, J. Huang, S. Peng. J. Huang, X. Zhong, Y. Zou, J. Yang, and R.J. Buresh. 2007. Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China. Agricultural systems 94:331-340.

Witcombe, J., S. Gyawali, S. Sunwar, S. Sthapit, and K. Josh. 2006. Participatory plant breeding is better described as highly client-oriented plant breeding II. Optional farmer collaboration in the segregating generations. Experimental Agriculture 42:79-90.

Appendix

Appendix 2.1: Positive and negative characteristics of maize varieties by farmers by gender in Cheptulu in western Kenya

	Men		Women	
Variety	Positive	Negative	Positive	Negative
H614	-closed tips -High yielding -Weevil resistant -Sweet (roasted)	-Poor during 2nd season -Late maturing -Lodging -Rots for late harvested -High input requirement -Expensive seed	-High yields	-High input requirement
Tiriki (local)	-Early maturing -Low fertility requirement -Drought resistant -Very sweet -Non lodging -No breakages in the field -High flour production -Resistant(weeds & diseases) - Does well in both seasons	-Low weight -Susceptible to weevils -Low yields -Fewer cob rows	-Early maturing -High yield -Sweet	-Susceptible to maize Streak
Katumani	-Drought resistant -Non lodging -Non rotting			
H625			-High yields	-High input requirement

Appendix 2.2: Maize utilization in terms of cash and food in western Kenya

	Ranked uses of maize	
Women	**Men**	**Rank**
Food	Food	1
Income	Income	2
Fodder	Fodder	3
Firewood	Manure	4
Salt	Seeds	5

Appendix 2.3: Positive and negative characteristics of maize varieties grown by farmers of Esibuye by gender in western Kenya

	Women		**Men**	
Variety	**Positive**	**Negative**	**Positive**	**Negative**
Anzika (local)	-Low fertility -Drought resistant -Early maturing -High population	-Low yields -Susceptible to ants -Small size	-Early maturing -Low fertility	-Low yield -Small cobs
Sipindi (local) yellow	-Early maturing -Low fertility -Sweet (roasted) -Drought resistant	-Susceptible to rots -Very small in size -Poor colour (food)	_Sweet (roasted) -Drought resistant	-Small cobs -Susceptible to rots
Pioneer	-High yields -Medium maturity -Low stem lodging	-Not sweet (roasted) -Low weight -Susceptible to rots -Remains green even longer	-Early maturing -High yields	-Low weight -Short shelve life
H614	-High yields -Sweet (roasted)	-Susceptible to lodging -Late maturing -Susceptible to drought	-High yields -Heavy grains	-Susceptible to smut -Susceptible to lodging
K1 Kayongo	-High yields -Striga resistant	-Low weight -Bad for roasting	-Striga resistant -High yields	-Small in size
Maseno double cobber	-Drought resistant	-Low yields -Susceptible to weevils	-Drought resistant	-Susceptible to weevils
Pana	-High yields	-Small grains -Tall	-High yields -Resistant to weevils	-Small grains -Breaks a lot

Appendix 2.4: Positive and Negative qualities of maize varieties of Nalondo farmers in western Kenya

Varieties	**Positive**	**Negative**
H614	Non rotting Sweet (Ugali, roasting) Resistant to large grain borer (Osama), Stalk borer Heavy grains Heavy flour High germination %	Susceptible to Lusese Weak Stems Not prolific (one cob)
Simba 61	Early maturing Two cobs Not attacked by birds (closed tips) Many rows per cob (20) Not attacked by Lusese Big grains and heavy Easy to shell Good flour	Poor taste (roast) Low germination % (50%) Susceptible to rotting
H513	High germination % Early maturing Sweet Easy to shell High yields	Susceptible to insects, birds and diseases Rots Susceptible to Lusese Light flour Small grains
W403	Good germination Early maturing	Light flour Easily affected by large grain borer (Osama) Rots easily Easily attacked by animals
W505	High germination % Early maturing Two cobs High yields	Small cobs Light cobs Susceptible to Stalk borer, Large grain borer (Osama)
H625	Strong stem Heavy flour Resistant to stalk borer Tasty	Moderate yields Rots
Sipende/No. 8	Early maturing Strong stems Good taste (Sipende) Heavy grains Resistant to pests Use own seed	Poor taste (No. 8) Kasuna
502	High yields Low fertility Droops High plant density Does well in all weather	Low weight Tasteless Susceptible to Osama
513	Low rainfall Heavy grains Tasty	Susceptible to streak

Appendix 2.5: Constraints to maize production and cropping strategies by Cheptulu, Nalondo and Esibuye farmers in western Kenya

Problems	Causes	Solutions
Lack of finance	Poverty No sources of income	Avail credit facilities
Lack of labour	Laziness Sickness	
Inadequate knowledge	Lack of extension services Ignorance of farmers	Advice Education
Pests and diseases	Late planting Poor weather Poor farming practices Lack of technological knowledge Continuous cultivation	Advice Use of the right chemicals Uproot diseased plants Apply ash (stalk borer) Apply cow dung (insects)
Poor market (low farm gate prices)	Lack of information	Advice from KACE CBO Form groups, cereal banks
High costs of inputs	High demand Few stockists High transport costs	Use of organic manure (FYM) Use low rates of fertilizer and forego top dressing with CAN Use of recycled seed Buy in puts in a groups (for discount) Use OX cart (transport)
Poor management	Lack of advice Poor planning Laziness	Advice Education Early planning
Theft		
High cost of seeds		Reduce acreage, lease land
Fake, Poor seeds	Lack of education	Buy in certified seed stores Plant local varieties
Fertilizer	Lack of capital (poverty) Sale of expired fertilizer	Use of compost Planting local varieties
Unreliable weather	Deforestation	Plant local varieties

Appendix 2.6: Activity Schedule of farmers in Esibuye in western Kenya.

Activity	Month	Men	Women	Children
Field selection	January/February/August	√	√	
Bush clearing	January	√		√
Ploughing	January	√		√
Planting	February-March/August-September	√	√	√
Weeding	March	√	√	√
Guarding				√
Seed selection	August	√	√	
Harvesting	August/December	√	√	√
Transporting from field				√
Drying	August/December		√	√
Threshing	September/December		√ √	√
Storage		√	√ √	
Processing			√	
Marketing	September/January	√√ (large quantities)	√ (small quantities)	√

* √ = activity undertaken

Appendix 2.7: Pair wise ranking of income profile of main crop enterprises by Cheptulu farmers in western Kenya

Crop enterprises	Maize	Beans	Bananas	Sugar cane	Tea	Brassicas sp	Score	Rank
Maize	-	M	M	M	T	M	4	2
Beans		-	BA	B	T	B	2	4
Bananas			-	BA	T	BA	3	3
Sugar cane				-	T	BR	0	6
Tea					-	T	5	1
Brassicas						-	1	5

Score Low score = less important (high rank), high score = more important (lower rank)

Chapter 3: Improvement of GLS and PLS resistance in medium and highland maize populations of Western Kenya by Reciprocal Recurrent Selection and Simple Recurrent Selection methods

Abstract

Gray leaf spot of maize caused by *Cercospora zeae maydis* (Tehon & E.Y Daniels, 1925) and Phaeosphaeria leaf spot (PLS) caused by *Phaeosphaeria maydis* (Henn.) are a threat to food security in most countries where the diseases are endemic. Use of resistant maize germplasm is a priority. This study was undertaken to improve four maize populations, Kitale synthetic II (KSII), Ecuador 573 (EC 573), Pool A and Pool B, for GLS and PLS resistance through reciprocal recurrent selection (RRS) and Simple recurrent selection (SRS) methods. Four populations were subjected to one cycle of reciprocal recurrent selection and two cycles of SRS during 2004-2006 cropping seasons at Kakamega Research Centre. Selection gains were assessed in two trials at Kakamega and Kitale in the long rains (March – September) 2007. Gains from selection were significant ($p < 0.05$) in both methods of selection. For GLS, gains of 6.4% to -32% cycle^{-1} were realized in RRS while gains ranging from 0.0% to -61.3% were realized from C_0 to C_1 in SRS method. For PLS gains of -33%, -11.7% and -8.7% were realised by RRS in Pool A C_1, KSII C_1 and Pool B C_1, respectively. In SRS method gains were less in advanced cycles of selection suggesting effects of inbreeding in advanced cycles as selfed plants are used for recombination. Significant negative correlations between GLS and yield were observed in Pool A selection cycle; C_0 ($r = -0.947$; $p< 0.01$) and C_1 of SRS ($r =-0.944$; $p < 0.01$) and PLS C_0 ($r = -0.926$; $p < 0.01$). In EC 573 population, significant correlations between GLS and yield were observed in C_1 of SRS ($r= -0.837$; $p < 0.05$). Negative significant correlations between yield and these diseases implied yield was improved as GLS and PLS were selected against. Percentage heritability estimates for GLS and PLS in these populations ranged from 59% to 76% and 39% to 80%, respectively. This moderately high heritability in some populations indicates that GLS and PLS resistance can be selected for in these populations using recurrent selection methods. Population effects were significant ($p<0.01$) for percentage GLS gain, where the highest gain of -61.3% was observed in KSII and the lowest of 0.0% in Pool B. This suggests that there is more variability in KSII than in Pool B and high selection intensity might be required to realise gain in Pool B. From the response to

selection realised, the results from the study suggest that GLS and PLS resistance can be improved in these populations using recurrent selection methods.

3.1 Introduction

Gray leaf spot (GLS) caused by *Cercospora zeae maydis* and Phaeosphaeria leaf spot (PLS) caused by *Phaeosphaeria maydis* (Henn) are amongst the most serious diseases of maize in Kenya (Kwena and Kalama, 1999). Gray leaf spot was first reported in 1996, while PLS was reported in 1992 (Njuguna *et al*., 1992). Both diseases were reported on seed farms in Kitale, Western Kenya and have since spread to all maize growing areas. These diseases pose a threat to maize production and are most severe in areas with high relative humidity in the medium and high altitude zones. High incidences and severity in East Africa have been associated with continuous cultivation of maize all year round in areas with bimodal type rainfall patterns, reduced tillage and use of susceptible varieties developed from unimproved populations (Alka and Munkvold, 2002). In East Africa yield losses in excess of 50% have been reported for GLS by Okori *et al*. (2003), and losses of 11% for PLS (Carson, 2005). This is a threat to food security in Kenya as maize is the major staple food crop being consumed as thick porridge (Ugali) in most households with an annual per capita consumption of about 125kg, which is among the highest in the world (Pingali and Pandey, 2001).

Improvement of maize populations through recurrent selection is a common procedure in breeding programmes designed to develop hybrids from inbred lines in maize. Different selection procedures used in corn breeding have been reviewed by Sprague (1966). Progress from selection is dependent on the presence of genetic variability in the population and accurate evaluations of the breeding values of the parental plants. Progeny testing in the form of half sib (HS) and full sib (FS) selection have been successful in recurrent selection for general combining ability and qualitative genetic studies. Reciprocal recurrent selection has been successful in various programmes for population improvement. Omoigui *et al*. (2006), in selecting for low nitrogen (N) tolerance in maize using FS recurrent selection, achieved genetic gains of 2.3% and 1.9% $cycle^{-1}$ at low and high N, respectively. Byrne *et al.* (1995), also using FS selection under drought reported, 1.68% increase in grain yield. Full sib selection on Kitale populations resulted in increased grain yield from 3t ha^{-1} to more than 7t ha^{-1}. Plant height was reduced from more than 3m to less than 2m and this resulted in reduced lodging from 70% to less than 20%. Lori *et al*. (2005), in the study of genetic diversity in maize, found genetic gain averaging 2.65% $cycle^{-1}$ was realized after seven cycles of HS selection in the BSSS (HT) synthetic. Recurrent selection has also been used in selection for drought resistance by Venuprasad *et al.* (2007), *Striga* tolerance (Menkir and Kling, 2007) and SRS in Barley (MckProud , 2004)

In Kenya, two populations (KSII and EC573) for the highland programme have undergone twelve cycles of RRS for yield and Pools A and B for the medium programme have undergone one cycle of RRS for low and high nitrogen environments. The achievements of the maize breeding programme in Kenya have been its provision of a range of improved maize varieties suitable for different agro-ecological zones in Kenya (KARI, 2002). The Katumani Composite A (KC A) and Katumani Composite B (KC B) were released in 1966 and 1968, respectively and were the first improved varieties for marginal regions 700 -1400 meters above sea level (masl). The Embu programme released medium maturing hybrids, H511 and H512 in 1968 and 1970, respectively. The current research programme consists of a late maturity programme at Kitale, medium maturity at Embu, Kakamega and Muguga, early maturity programme at Katumani and coastal maize programme at Mtwapa for low lands (0 -700m masl).

Currently, the Kitale programme is concentrating on improving maize for yield, reducing maturity, and developing stalk borer resistant varieties in collaboration with the International Centre for Maize and Wheat Improvement (CIMMYT) and also looking at effective botanical pesticides for pest control (KARI, 2002). Kakamega programme is developing maize hybrids for low and high nitrogen (soil fertility) environments using RRS (KARI, 2004). Maize breeding programmes at National Agricultural Research Centre (NARC) Muguga are focused on genotypic resistance to maize streak virus (MSV) disease, head smut and common smut (KARI, 2004). Little emphasis has been put on GLS and PLS improvement through selection in Kenya.

Although several studies have used RRS for improvement of various traits in maize, no work so far has been undertaken to select for GLS and PLS resistance using recurrent selection methods either for inter or intra population improvement. Furthermore literature on this subject is generally scarce or not available.

Given that GLS and PLS resistance are conditioned by both additive and non-additive gene action and are traits of moderately high heritability (Gordon *et al*., 2004; Abebe and Ayodele, 2005; Stuart *et al*., 2006), then SRS that depends on phenotypic variance for selection can be useful. Similarly RRS method that utilizes both additive and non-additive variances can be effective in population improvement for GLS and PLS.

Development of maize inbreds and populations with resistance to *Cercospora zeae maydis* and *Phaeosphaeria maydis* is essential in many areas where ever increasing threats from GLS and PLS epidemics pose a threat to food security. Genetic resistance is the only hope to reduce yield losses, particularly in the poor farming systems of Kenya where farmers cannot afford other management practices to contain the diseases. Therefore, the objective of the study was to improve GLS and PLS resistance in Kenyan medium and highland maize populations through RRS and SRS methods.

3.2 Materials and Methods

3.2.1 Maize Populations

Maize populations used in the improvement of GLS and PLS resistance were from two maize breeding programmes, highland and medium in Western Kenya. For the highland they were EC 573, an introduction from Central America, and KSII, developed from local collections. They are tall, late maturing and are susceptible to diseases and pests prevalent in the region. They are flint in grain type and white in colour (Table 3.1). The two have undergone twelve cycles of reciprocal half sib recurrent selection with variety cross genetic gain estimated at 7.0% cycle^{-1}. The two also have high heterosis between them. From the medium programme, Pool A and Pool B populations were used. The populations are medium in height, early maturing and more than 60% flint with white grains. They have undergone one cycle of RRS under low and high nitrogen (soil fertility) environments.

Table 3.1: Maize testers for medium and highland populations used in the study

Population	Ecology	Elevation (meter)	Grain colour
KSII (tester)	Highland tropics	1600-2900	White
EC 573 (tester)	Highland tropics	1600-2900	White
Pool A (tester)	Moist mid-altitude	1110-1500	White
Pool B (tester)	Moist mid-altitude	1110-1500	White

3.2.2 Reciprocal Recurrent Selection Scheme

3.2.2.1 Crossing blocks

Cycle zero (C_0) of each population (KSII, EC 573, Pool A and Pool B) was planted at Kakamega Research Centre during the long rains of 2005 in four blocks of 20 rows of 50 hills each with a spacing of 75cm between rows and 30cm within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphorous (80kg P_2O_5 ha $^{-1}$) were applied and hand weeding was done to maintain plots clean. Thinning was done when the crop was knee high to acquire a population of 1000 plants per block per population. At flowering all ear shoots were covered before emergence of the silk with shoot bags to avoid contamination with pollen from an unknown source.

For interpopulation improvement between Pool A and Pool B, plants from Pool A were selfed to provide S_1 plants; part of the pollen was used to pollinate a plant in Pool B and vice versa for the other population. Similarly, the same procedure was done for the highland populations KSII and EC 573. The S_1 plants were coded with their corresponding cross in the other population. At harvest, the S_1 seeds were kept while their corresponding progenies were advanced to the next stage of evaluation.

3.2.2.2 Evaluation of Progenies of RRS Selection method

During the 2006 long rains, GLS and PLS evaluation trials were planted for all four populations at Kakamega Research Station in a randomized complete block design with three replications. The number of progeny families of the saved S_1 families evaluated in each population varied from population to population depending on seed availability. For EC 573, 49 families were evaluated, 50 for KSII, 50 for Pool B and 41 for Pool A. For each population families were randomly assigned to plots and planted in single row plots of 51 hills each with a spacing of 75cm between rows and 30cm within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphorous (80kg P_2O_5 ha $^{-1}$) were applied and weeding was done to maintain plots clean. For artificial inoculation, GLS and PLS inoculum was prepared from infected leaves of previous season maize crop. Dry leaves of a susceptible variety were ground. A pinch of the inoculum was placed in the whorl of the plant at knee high stage (8-10 leaves) and a second inoculation was done after another 14 days.

3.2.2.3 Data collection

Gray leaf spot and PLS were rated using a scale of 0-5, where 0=No symptoms on plants; 1=1%-20%; 2=21% - 40%; 3=41% - 60%; 4=61% - 80% and 5=81% - 100% infection of the plant based on the scale used by KARI-pathologist. Data on number of days from planting to 50% anthesis, number of days to 50% silking and ear height in centimetres from the base of the plant at ground level to the base of the ear and diseased ears were recorded. At harvest data was collected on final stand counts, the number of plants per plot that stalk lodged and root lodged, dropped ears, grain weight per plot, grain moisture and plot yield adjusted to 12.5% moisture content. Grain moisture content was determined using moisture meter at harvest.

Grain yield was calculated using the formula: Grain yield (t ha^{-1}) = [Grain weight (kg plot^{-1}) x 10 x (100-MC)/ (100-12.5)/Plot Area], where MC is the moisture content at the time of harvest.

3.2.2.4 Data analysis

General analysis of variance (ANOVA) was done based on a randomized complete block design method (Cochran and Cox, 1992) using GenStat Release 9.1 (Payne *et al*., 2006) on the data collected in each population. Linear fixed model was:

$Y_{ij}= \mu + gi + r_j + Є_{ij}$

Y=Observed value

μ= Overall mean

g_i= effects due to crosses (progeny generated in RRS)

r= replication effects

$Є_{ij}$ = Error term

3.2.2.5 Selection

Selection was based on full sib progenies performance and a selection intensity of 10% was used in each cycle and about five of saved S_1families corresponding to full sib families that had GLS score equal to or less than 2 were selected to form the next cycle (C_1).

3.2.2.6 Recombination

Based on the performance of FS families, five S_1 families were selected from the saved S_1 seeds of each population. These were planted at Kakamega Research Station in four blocks during the short rains between September 2006 and January 2007 in 20 row blocks of 50 hills per row with spacing of 75cm between rows and 30cm between plants within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphorus (80kg P_2O_5 ha $^{-1}$) were applied and hand weeding was done thrice. At flowering all the ear shoots were covered and pollen harvested, mixed for each separate population and pollination done to avoid contamination from neighbouring populations. At harvest seeds from the intermated plants in each population block were mixed to form the next cycle of selection for each population.

3.2.3 Simple Recurrent Selection

3.2.3.1 Crossing Block

During the long rains of 2005 (March- September), four populations (Pool A, Pool B and KSII and EC 573) were planted at Kakamega each in four blocks in 20 row blocks of 50 hills each with a spacing of 75cm between rows and 30cm within rows to get a population of 1000 plants per block. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphate (80kg P_2O_5 ha $^{-1}$) were applied and weeding was done to maintain plots clean. Artificial inoculation with GLS was done at the 8 to 10 leaf stage and again 14 days later. At flowering, all ear shoots were covered before emergence of the silk with shoot bags to avoid contamination with pollen from unknown sources and each plant was selfed.

3.2.3.2 Selection

Selection was based on GLS scores where only those selfed plants with scores ≤ 2.0 were selected. About 100 individual plants were selected maintaining selection intensity of 10% per cycle.

3.2.3.3 Recombination

During the short rains of 2005 (September 2005- January 2006), the selected 100 selfed plants were then intermated. The same procedure was repeated during 2006 and two cycles of selection were achieved by the end of 2006.

3.2.3.4 Evaluation of population cycles and commercial checks

To determine response to selection, cycles of all four populations (Pool A, Pool B, KSII and EC 573) of both RRS and SRS were evaluated. During the long rains of March to September 2007, cycles C_0, C_1 and C_2 and four commercial checks (H614, H623, PHB 3253 and KSTP94) were planted in a randomized complete block design in three replications in two sites at Kakamega and Kitale. They were planted in three row plots of 51 hills per row with spacing of 75cm between rows and 30cm between plants within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphate (80kg P_2O_5 ha^{-1}) were applied and hand weeding was done thrice. Data was collected on diseases, GLS, PLS, number of days from planting to 50% anthesis (50% of plants in the plot having anthers), number of days to 50% silking, ear height in centimetres from the base of the plant at ground level to the base of the ear and diseased ears. At harvest data was collected on final stand counts, the number of plants per plot that stalk lodged and root lodged, dropped ears, grain weight per plot, grain moisture and plot yield adjusted to 12.5% moisture content was calculated.

Grain yield adjusted for moisture was calculated using the formula: Grain yield (t ha^{-1}) = [Grain weight (kg $plot^{-1}$) x 10 x (100-MC)/ (100-12.5)/Plot Area], where MC is the moisture content at the time of harvest

3.2.4.5 Data analysis

Two analyses (ANOVA) of variance were done on data collected.

a) The first analysis compared population cycles (C_0, C_1, and C_2) and check (H614, H623, PHB 3253, and KSTP94) varieties in each method of selection

b) The second analysis compared the two methods of selection, SRS and RRS, gain from C_0 to C_1.

For both analyses (a and b), General analysis of variance (ANOVA) was done based on a randomized complete block design method (Cochran and Cox, 1992) using GenStat Release 9.1 (Payne *et al*., 2006).

1) For the first analysis (comparison of cycles + checks) the linear model was:

$$Y_{ijk} = \mu + r + t_i + E_k + c_{kij} + r + Є_{ijk}$$

Where Y_{ijk}= Observed value;

μ = Overall mean;

t_i= treatment effect (cycles + checks);

r = replication effect;

E_k= location effect;

t_{ik}= treatment by location effect;

$Є_{ijk}$ =error term.

2) For the second analysis, comparison of methods of selection the linear model was:

$$Y_{ijkl} = \mu + P_i + M_j + E_k + P_i M_j + P_iE_k + M_jE_k + P_i M_j E_k + R + Є_{ijk}$$

Where:-Y_{ijk}= Observed value;

μ = overall mean;

P_i= population effect;

M_j= method of selection effect;

E_k = location (site) effect;

$P_i M_j$= population x method effect;

P_iE_k =population x environment effect;

M_jE_k =method x environment effect;

$P_i M_j E_k$ = population x method x environment effect;

R = Replication;

$Є_{ijk}$ = error term.

3.2.4.6 Response to Selection

Realised response to selection, genetic gain cycle^{-1} was determined by direct comparison of cycles (C_0, C_1 and C_2) of both methods of selection and all populations. The gain realized in the selection was measured by the difference between the C_0, C_1 and C_2 populations

Calculated as gain cycle^{-1} = $(\mu C_2 - \mu C_0)/2$ where μC_2 and μC_0 = means of the traits evaluated.

3.2.4.7 Heritability estimates

Broad sense heritability was estimated by generating genetic variances (Vg) from data of FS progenies using REML in GenStat Release 9.1 (Payne *et al*., 2006) where random model was used and crosses were considered random.

Heritability was calculated using the formula:

H = Vg/Vp

where

H= Broad sense heritability

Vg= genetic variance (estimated in REML)

Vp= phenotypic variance

Vp= Vg + estimated error mean square from REML

Phenotypic correlations were computed with entry means of cycles across environments in summary statistics in GenStat Release 9.1 (Payne *et al*., 2006).

3.3 Results

3.3.1 Reciprocal recurrent selection

In the combined analysis over two locations, population cycles and checks were significant ($p < 0.05$) for GLS, PLS, plant height, ear height, days to 50% anthesis and silking but not for yield (Table 3.2). Location effects were significant ($p < 0.05$) for GLS, PLS and ear height while location by population cycles and checks interaction effects were significant (p<0.05) for grain yield and days to 50% silking as indicated in Table 3.2.

Table 3.2: Mean sum of squares for GLS and other traits of maize of population cycles in RRS and commercial checks tested in two environments in western Kenya in 2007

Source	DF	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height (cm)	Plant height (cm)
Loc.	1	95.7**	13.9*	15.2	43.6	0.2	43468.3**	1735.3
TRT	11	5.1**	0.9*	4.2	180.0**	149.2**	5313.9**	10175.3**
Loc. x TRT	11	0.5	0.2	10.2*	40.7*	49.5	261.7	497.2
Residual	46	0.3	0.3	3.9	18.8	24.1	257.3	502.1

*, ** Significant at the (p< 0.05) and (p<0.01) probability levels respectively
Key: Rep= Replication; Loc = Locations, Treatments (TRT) = Population cycles and commercial checks

There were variations in means of traits across the cycles and commercial hybrid checks. Days to silking ranged from 75 to 90 in Pool A and EC 573 populations, respectively (Table 3.3), whereas days to 50% anthesis ranged from 76 to 89. Pool A and Pool B populations had lower mean values for ear height compared to the EC 573, KSII and the four checks. Values for plant height were highest for H614, H623, KSII C_0 and EC 573 C_0, and lowest for Pool A C_0, Pool A C_1 and Pool B C_0 (Table 3.3). Commercial check variety PHB3253 and EC573 C_0 had the lowest scores for PLS of 1.4; while Pool A C_0 and KSII C_0 had the highest mean scores, but generally the PLS severity was low compared to GLS (Table 3.3). The check varieties had higher GLS values of ranging from 3.4 to 4.0 with exception of H614 that had a score of 1.5. Cycles had the lower values ranging from 1.3 to 2.6 with the exception of Pool A C_0, that had a higher score of 3.2. Population EC 573 C_1 had the lowest GLS rating of 1.3 compared to all the cycles and checks. In general, highly significant differences were observed among cycles for GLS, and C_1 outperformed C_0 in all populations except in EC 573. Variation in yield among the checks and cycles was low but cycles out yielded the checks with KSII C_1 having yielded 5.8t ha^{-1} as compared to the highest check, H614 at 4.8t ha $^{-1}$ (Table 3.3).

Table 3.3: Means for GLS and other traits of maize of population cycles in RRS and commercial checks in two environments in western Kenya in 2007

Entry	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, cm	Plant height, cm
Pool A C_0	3.2	2.6	5.1	82	81	95	186
Pool A C_1	2.6	1.8	5.4	75	76	106	213
Pool B C_0	2.3	1.9	4.7	82	82	112	209
Pool B C_1	2.1	1.8	5.8	80	81	119	226
KSII C_0	2.6	2.6	5.2	89	86	159	291
KSIIC_1	1.8	2.3	5.8	88	87	172	289
EC 573 C_0	1.4	1.4	5.0	90	89	171	291
EC 573 C_1	1.3	1.7	5.3	87	82	154	276
H614 *****	1.5	2.1	4.8	89	88	182	305
H623*****	3.4	2.1	3.5	88	88	163	299
KSTP94*****	3.6	1.9	3.0	76	76	146	284
PHB3253*****	4.0	1.4	4.6	78	79	120	255
Mean	2.5	2.1	4.9	84	83	142	260
LSD (0.05)	0.87	0.9	4	7	8	27	36.6
C.V%	21.6	26.9	41	5.1	6.0	11.4	8.5
S.E	0.2	0.2	0.8	1.7	2.0	6.6	9.1

Key ***** = Checks, commercial varieties

3.3.1.1 Response to Selection Using RRS method

Progress from selection for GLS resistance responded in the desired direction (Table 3.4). The highest improvement cycle^{-1} was in KSII (-32.2%) and Pool A (-18.4%) and the least in Pool B (-7.4%) whereas there was negative progress for GLS improvement in EC 573 (6.4%) as indicated in Table 3.4. Gains in grain yield were smaller but positive across all populations. The largest improvement was in Pool B (23.1% cycle^{-1}) and the smallest in Pool A and EC 573, 5.3% and 6.9% cycle^{-1}, respectively, with KSII having an intermediate gain of 13.2% cycle^{-1} (Table 3.4). Responses of populations to PLS severity due to selection for GLS were positively related except for population EC 573. Improvement ranged from -8.7% to -33%, in Pool B (-8.7%), KSII (-11.7%) and Pool A (-33%) cycle $^{-1}$, while population EC 573 had PLS severity increase of 23% (Table 3.4). Similarly, Pool A and Pool B gained 14.3%, and 7.8% in plant height and 11.9% and 5.6% in ear height cycle^{-1}, respectively. Reduced plant height of -5.1% and -0.7% were observed in EC 573 and KSII, respectively (Table 3.4).

Table 3.4: Percentage gain for GLS and other traits of maize of population cycles in RRS in two environments in western Kenya during 2007

Entry		GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, cm	Plant height, cm
Pool A C_0		3.2	2.6	5.1	81.5	80.8	94.7	185.9
Pool A C_1		2.6	1.8	5.4	74.8	76.0	106.0	212.5
	Gain cycle $^{-1}$	-0.6	-0.9	0.3	-6.7	-4.8	11.3	26.6
	Gain % cycle $^{-1}$	-18.4	-33.0	5.3	-8.2	-6.0	11.9	14.3
Pool B C_0		2.3	1.9	4.7	81.8	81.8	112.2	209.1
Pool B C_1		2.1	1.8	5.8	79.6	80.8	118.5	225.5
	Gain cycle $^{-1}$	-0.2	-0.2	1.1	-2.2	-1.0	6.3	16.4
	Gain % cycle $^{-1}$	-7.4	-8.7	23.1	-2.7	-1.2	5.6	7.8
KSII C_0		2.6	2.6	5.2	88.7	88.5	159.2	290.8
KSIIC_1		1.8	2.3	5.8	87.8	87.3	171.8	288.8
	Gain cycle $^{-1}$	-0.8	-0.3	0.7	-0.8	-1.2	12.6	-2.0
	Gain % cycle $^{-1}$	-32.2	-11.7	13.2	-0.9	-1.3	7.9	-0.7
EC 573 C_0		1.4	1.4	5.0	90.0	89.2	171.1	290.7
EC 573 C_1		1.3	1.8	5.3	87.4	82.3	154.2	275.8
	Gain cycle $^{-1}$	0.1	0.3	0.3	-2.6	-6.8	-16.9	-14.9
	Gain % cycle $^{-1}$	6.4	23.4	6.9	-2.9	-7.7	-9.9	-5.1
LSD (0.05)		0.9	0.9	3.6	7.0	8.2	26.5	36.6
C.V		21.6	26.9	0.4	0.1	0.1	11.4	8.5

3.3.2 Simple Recurrent Selection

In the combined ANOVA, cycle and check effects were highly significant (p<0.05) for days to 50% silk, days to 50% anthesis, ear height, plant height, diseased ears, PLS, GLS and yield (Table 3.5). Location effects were highly significant (p<0.01) only for ear height and GLS however no location effects were detected for yield, days to 50% anthesis, days to 50% silk and plant height. Cycles, checks and location interaction effects showed no significant (p<0.05) differences for days to 50% silk, days to 50% anthesis, or plant height, but were significant (p <0.05) for GLS, ear height and yield. Generally, cycles and checks effects accounted for more than 50% of the total variation of the traits (Table 3.5).

Table 3.5: Mean sum of squares for GLS and other traits of maize of population cycles in SRS and checks tested in two environments in western Kenya in 2007

Source	DF	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, cm	Plant height, cm
Loc	1	95.0**	6.4*	7.3	16.7	3.4	43931.6**	162.0
TRT	15	6.2**	1.1*	20.8**	131.1**	275.1**	5471.7**	8516.1**
Loc x TRT	15	0.8*	-	6.3*	14.3	36.4	564.9**	607.6
Residual	62	0.4	0.5	3.4	14.0	36.2	208.1	417.4

*, ** Significant (p< 0.05) and (p<0.01) probability levels, respectively
Key: Rep= Replication; Loc = Locations, Treatments (TRT) = Population cycles and commercial checks

Mean GLS scores among population cycles and checks ranged from 0.7 in EC573 C_2 to 4.0 in PHB3253 check variety (Table 3.6). Among the medium populations, of Pool A had the lowest score of 1.2 while C_0 of the same Pool A had the highest score of 3.2. The highland populations had lower GLS ratings in comparison to the medium populations and C_1 in most populations had lower GLS values than the corresponding C_0 of the same population. The checks on average had the highest GLS scores, where most of them had ratings above 3.0 with the exception of H614 that had a score rating of 1.5 (Table 3.6). Populations on average out yielded the checks in grain yield. Population EC 573 C_1 yielded 9.2t ha^{-1}; KSII $C_{1,}$ 8.5t ha^{-1}, Pool B C_1, 8.4t ha^{-1} and cycles C_1 performed better than C_0. Mean PLS ratings ranged from 1.2 to 2.6 across the populations and checks. The highest ratings were observed in Pool A C_0 and the lowest in EC573 C_0 and PHB3253 check (Table 3.6). Plant height was high in both highland populations and checks but low in cycles of medium populations Pool A and B, and they ranged from 185.9cm to 305.3cm. Similar trend was observed for ear height as indicated in Table 3.6. On average Pool A and Pool B silked and shed pollen earlier than checks and cycles of KSII and EC 573. Similarly, KSTP94 and PHB3253 had fewer days to 50% silk and 50% anthesis (Table 3.6).

Table 3.6: Means for GLS and other traits of maize of population cycles in SRS and commercial checks in two environments in western Kenya in 2007

Entry	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, (cm)	Plant height, (cm)
POOL A C_0	3.2	2.6	5.1	82	81	95	186
POOL A C_1	1.8	2.6	5.5	80	81	113	233
POOL A C_2	1.2	1.6	4.4	82	82	118	237
POOL B C_0	2.3	1.7	4.7	82	82	112	209
POOL B C_1	2.3	2.1	8.4	82	82	103	216
POOL B C_2	1.9	1.7	3.7	79	79	102	227
KSII C_0	2.6	2.4	5.2	89	89	159	291
KSII C_1	1.0	1.9	8.5	88	81	178	286
KSII C_2	1.8	1.6	7.0	88	84	165	294
EC 573 C_0	1.3	1.2	5.0	90	89	171	290
EC 573 C_1	1.0	1.7	9.2	88	82	157	282
EC 573 C_2	0.7	1.4	6.7	89	85	155	283
H614*	1.5	1.9	4.8	89	89	182	305
H623*	3.4	1.9	3.5	88	88	163	299
KSTP94*	3.6	1.7	3.0	76	76	146	284
PHB3253*	4.0	1.2	4.6	78	79	120	255
Mean	2.1	1.8	5.6	87	82	140	261
LSD (0.05)	1.0	0.3	3.0	6.1	9.7	23.5	32.9
CV	29.1	36.7	33.1	4.4	7.3	10.3	7.7
S.E	0.2	0.3	0.8	1.5	2.4	8.3	8.3

Key: * = Commercial check

3.3.2.1 Response to Selection with SRS Method

Across the populations, GLS gains from the selection were significant ($p<0.01$) cycle^{-1} except for cycles of Pool B. Selection resulted in gains of -31.6% for Pool A, -14.6% for KSII and -23% for EC 573 cycle $^{-1}$ (Table 3.7). Improvement was less in advanced cycles of selection in C_2 than in C_1, for Pool A and KSII as gains of -42.1% and -61.3% were realized from C_0 to C_1 for Pool A and KSII, respectively gains were lowest for Pool B from C_0 to C_2 (Table 3.7).

Grain yields varied from population to population with gains ranging from 6.6% to 86% from C_0 to C_1, for Pool A and EC 573, respectively. As indicated in Table 3.7, C_1 out yielded C_2 in grain yield. Percent gains per cycle for PLS were positive in some cycles as compared to GLS. Pool A had more positive gains for plant height than cycles of the other populations. Days to 50% anthesis and days to 50% silk had very low gains cycle^{-1}.

Table 3.7: Percentage gain for GLS and other traits of maize of population cycles in SRS in two environments in western Kenya during 2007

Entry	CYCLE	Gain	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, cm	Plant height, cm
POOL A									
	C_1-C_0	Gain	-1.3*	0.04	0.3	-1.8	0.2	17.8	46.9*
		% Gain	-42.1*	-1.6	6.6	-2.2	0.2	18.8	25.2
	C_2-C_1	Gain	-0.7	-1.0	-1.1	2.2	0.7	5.3	3.7
		% Gain	-36.3	-38.9	-20.1	2.7	0.8	4.7	1.6
	C_2-C_0	Gain $cycle^{-1}$	-1.0*	-0.5*	-0.4	0.2	0.4	11.6	25.3
		% Gain $cycle^{-1}$	-31.6*	-20.0*	-7.4	0.2	0.5	12.2	13.6
POOL B									
	C_1-C_0	Gain	0.0	0.3	3.7*	0.3	0.2	-9.8	6.8
		% Gain	0.0	19.3	78.4*	0.4	0.2	-8.7	3.3
	C_2-C_1	Gain	-0.3	-0.3	-4.8*	-3.2	-3.5	-1.0	11.3
		% Gain	-14.8	-16.2	-56.6	-3.9	-4.3	-0.9	5.23
	C_2-C_0	Gain $cycle^{-1}$	-0.2	0.0	-0.5	-1.4	-1.7	-5.4	9.1
		% Gain $cycle^{-1}$	-7.4	0.0	-11.3	-1.7	-2.0	-4.8	4.3
KSII									
	C_1-C_0	Gain	-1.6*	-0.5*	3.4	-0.7	-7.0	18.8	-4.8
		% Gain	-61.3*	-22.2*	65.0*	-0.8	-9.0	11.8	-1.7
	C_2-C_1	Gain	0.8	-0.2	-1.5	0.2	3.0	-12.6	8.2
		% Gain	83	-13.1	-17.9	0.19	3.5	-7.1	2.9
	C_2-C_0	Gain $cycle^{-1}$	-0.4	-0.4	0.9	-0.3	-2.0	3.1	1.7
		% Gain $cycle^{-1}$	-14.6	-16.2	17.8	-0.3	-2.3	1.9	0.6
EC 573									
	C_1-C_0	Gain	-0.3	0.5	4.3	-2.2	-6.8	-14.3	-8.8
		% Gain	-20.0	40.5	86.1*	-2.4	-7.7	-8.4	-3.0
	C_2-C_1	Gain	-0.3	-0.3	-2.5	1.2	2.5	-1.4	1.2
		% Gain	-33.3	-19.2	-27.6	1.3	3.0	-0.9	0.4
	C_2-C_0	Gain $cycle^{-1}$	-0.3	0.1	0.9	-0.5	-2.2	-7.8	-3.8
		% Gain $cycle^{-1}$	-23.3	6.8	17.4	-0.6	-2.4	-4.6	-1.3
LSD			1.0	0.4	3.0	6.1	9.7	23.5	32.9

*, ** Significant at $p < 0.05$ and $p < 0.01$ probability levels, respectively

3.3.3 Comparison of One Cycle of SRS and RRS

In a combined ANOVA over the two sites, Kakamega and Kitale, the method of selection had significant effects ($p<0.05$) for GLS, PLS, yield, days to 50% anthesis and ear height but not for days to 50% silk (Table 3.8). Significant ($p < 0.05$) location effects were observed for GLS, PLS, yield and ear height but not for yield, 50% days to silk, days to 50% anthesis. Population effects were only significant ($p<0.05$) for GLS and days to 50% silk and 50% anthesis. Location x method interaction mean squares were significant for GLS whereas method of selection x population was not significant for GLS (Table 3.8).

Table 3.8: Mean sum of squares for GLS and other traits of maize of SRS and RRS methods of selection tested in two environments in western Kenya in 2007

Source	DF	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**days to 50% silk**	**days to 50% anthesis**	**Ear height, cm**
Loc	1	58.5**	13.4**	37.4*	10.58	67.7	12175.3**
Method	1	2.1*	3.7*	64.7**	44.9	305.0*	12996.9**
Pop	3	3.5**	1.2	8.97	333.2**	162.1*	0.4
Method x. Pop	3	0.6	0.5	7.9	14.7	618.1**	340.6
Loc x Method.	1	4.1**		13.3	0.9	2.5	753.1
Loc x Pop	3	1.3*		4.3	83.6*	98.4	837.4*
Loc x Method x Pop	3	0.6		11.0	27.4	45.4	270.3
Residual	30	0.3	0.5	5.5	24.9	48.6	216.6

*, ** Significant at p< 0.05 and p< 0.01 probability levels, respectively
Key: Rep = replication; Loc = Location; Pop = Population; Method = RRS and SRS

Mean of one cycle of SRS (C_1) method for GLS rating averaged over two environments and four populations was significantly ($p < 0.05$) lower than that of RRS (C_1) method (Table 3.9). Simple recurrent selection had GLS mean rating of 1.5 and RRS a rating of 1.9. Grain yield between the two methods was significantly ($p < 0.05$) different with SRS having higher mean yields than RRS. Reciprocal recurrent selection had reduced days to 50% anthesis, compared to SRS and the two methods of selection had no significant effects on days to 50% silk, ear height and PLS severity. Overall RRS was only superior to SRS for PLS resistance (Table 3.9).

Table 3.9: Means of cycle one (C_1) of SRS and RRS methods for GLS and other traits of maize of four populations tested in two environments in western Kenya in 2007

Method	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**Day 50%s to silk**	**days to 50% anthesis**	**Ear height, cm**
SRS	1.5	2.1	7.9	84.5	83.6	137.5
RRS	1.9	2.0	5.6	82.5	81.6	137.6
Mean	1.7	2.05	6.75	83.5	79.1	137.6
LSD	0.3	0.4	1.4	2.9	4.1	8.78
CV %	32.2	31.1	34.9	6.0	8.8	10.7
S.E	0.2	0.1	0.7	1.3	1.6	4.9

* Source; means generated from Table 3.3 and Table 3.6 of RRS and SRS methods respectively

3.3.3.1 Percentage Gain in One Cycle (C_0 and C_1) of Selection for GLS Resistance between SRS and RRS Method

In one cycle of selection there were significant (p<0.05) differences between gains observed with SRS and RRS methods of selection (Table 3.10). Gain cycle^{-1} for GLS ranged from 0% to -61.3% in SRS and 6.4% to -32.2% in RRS methods of selection. The highest gain were in KSII (-61.1%) and Pool A (-42%) reduction in GLS severity, while the least gain in the undesirable direction was in EC 573, 6.4% using the RRS method. Similarly in grain yield, SRS had higher significant percentage gains than RRS (Table 3.10). Percentage yield gains per cycle was highest in EC 573, 86.1% with SRS, while the highest percentage yield gain with RRS method was 23.1% in Pool B. Method effects were not significant (p<0.05) in most of the other traits, days to 50% silk, days to 50% anthesis, ear height and PLS (Table 3.10). Generally SRS outperformed RRS in most of the traits (Table 3.10). Gains in GLS, PLS and yield differed from population to population. Pool A had GLS percentage gains of -42.1% in SRS and -18.4% in RRS. For PLS, gains of -1.6% and -33.0% were realised (Table 3.10). Kitale synthetic II had the highest gains in the right direction for GLS and PLS. For yield, the highest percentage gains were realised in Pool B and the lowest in Pool A (Table 3.10).

Table 3.10: Percentage gains realized in one cycle (C_0 to C_1) of selection by RRS and SRS methods in four maize populations tested in two environments in western Kenya in 2007

Population	Method	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	days to 50% silk	days to 50% anthesis	Ear height, cm
Pool A							
	SRS	-42.1	-1.6	6.6	-2.2	0.2	18.8
	RRS	-18.4	-33.0	5.3	-8.2	-6.0	11.9
Pool B							
	SRS	0.0	19.3*	78.4	0.4	0.2	-8.7
	RRS	-7.4	-8.7*	23.1	-2.7	-1.2	5.6
KSII							
	SRS	-61.3	-22.2	65	-0.8	-31.1*	11.8
	RRS	-32.2	-11.7	13.2	-0.9	-1.3*	7.9
EC 573							
	SRS	-20.0	40.5	86.1	-2.4	-7.7	-8.4
	RRS	6.4	23.4	6.9	-2.9	-7.7	-9.9

* Source; percentage gains generated from Table 3.4 and Table 3.7 for RRS and SRS, respectively

3.3.4 Heritability Estimates

Heritability estimates for GLS resistance were less variable in the three populations, except for Pool A (Table 3.11). Pool A had the lowest heritability of 59% as compared to KSII, 77 %, EC 573, 73% and Pool B, 73 %. Phaeosphaeria leaf spot had heritability estimates ranging from 30% to 80%. Grain yield heritability was varied with ranges of 7.0% to 42.3% depending on the population. (Table 3.11).

Table 3.11: Heritability estimates for GLS, resistance, grain yield, 50% days to anthesis and to silk, ear height

	Percentage heritability estimates			
Population	GLS	PLS	Grain yield	Ear height
POOL A	59	39	26	67
POOL B	73	76	8	52
KSII	77	80	42	79
EC 573	73	64	7	60

3.3.5 Correlations between GLS and Yield in Pool A and EC 573

The results presented are for the populations that showed some significance between GLS and yield. The correlation between GLS and yield in Pool A was negative and significant for C_0 and C_1 using SRS (Table 3.12). Pool A C_0 had correlation coefficient of r= -0.947 significant at both (*p* < 0.05 and p<0.01). Pool A C_1 with SRS method had a coefficient r = -0.944 significant at both (*p*<0.05 and *p*< 0.01). The results also indicated significant correlation between PLS and yield with a coefficient of r = -0.926 at p<0.01 (Table 3.12). There were no significant correlations shown in advanced cycles of SRS. There was no significant correlation between yield and GLS in Pool B and KSII (data not shown). Although some correlations were not significant, they were very strong as in the case of yield verse PLS in EC 573 in C_2. There were significant positive correlations shown by PLS and days to 50% silk and anthesis in Pool A C_1 in SRS and Pool A C_1 in RRS.

Table 3.12 Correlation coefficients between GLS and other traits of Pool A testcrosses and cycles of selection (C_0, C_1 and C_2) of RRS and SRS

Traits	ORIGINAL POPULATION POOL A C_0	RRS METHOD PROGENIES (CROSSES)	RRS METHOD POOL A C_1	SRS METHOD POOL A C_1	SRS METHOD POOL A C_2
GLS X YIELD	-0.947**	-0.213	-0.689	-0.944**	-0.318
GLS X PLS	0.780	-	0.057	0.011	-0.500
GLS X 50%SD	0.780	-0.012	0.057	0.011	-1.000
GLS X 50% TD	0.618	0.546	0.061	0.235	-0.500
GLS X EH	-0.751	-0.0038	-0.617	--0.923	0.000
YIELD X PLS	-0.926**	-	-0.012	0.091	0.980
YIELD X 50%SD	-0.926	-0.110	-0.012	0.091	0.318
YIELD X 50%TD	-0.809	0.010	-0.115	-0.124	0.980
YIELD X EH	0.887	-	0.762	0.791	-
PLS X 50%TD	0.964	-	-0.570**	0.974**	1.000
PLS X 50% SD	1.000**	-	0.969**	1.000**	0.500
PLS X EH	-0.946	-	-0.570	-0.066	-
50% SD X 50 TD	0.964**	0.734	0.969	-0.974**	0.500
50% SD X EH	-0.946**	-0.122	-0.570	-0.066	0.000
50%TD X EH	-0.783	-0.046	-	-	0.866
EH X PH	0.736	0.809	-	-	-0.866

*, ** Significant (p< 0.05) and (p< 0.01) probability levels respectively

In population EC 573, only C_1 of SRS method showed significant correlations between GLS and yield with coefficient r = -0.837 (p<0.05 and p<0.01). *Phaeosphaeria* leaf spot showed significant correlations with days to 50% silk as indicated Table 3.13. The other correlations were not significant. Days to 50% silk and to anthesis were significant and positively correlated indicating that as days to 50% silk are reduced, simultaneously days to 50% anthesis are reduced. Most of the correlations of C_1 in RRS were negative but not significant unlike those of SRS that varied in sign.

Table 3.13 Correlation coefficients between GLS and other traits of EC 573 testcrosses and cycles of selection (C_0, C_1 and C_2) of RRS and SRS

	ORIGINAL POPULATION	RRS METHOD		SRS METHOD	
Traits	EC 573 C_0	PROGENIES (CROSSES)	EC 573 C_1	EC 573 C_1	EC 573 C_2
GLS X YIELD	0.554	-0.054	0.082	-0.837*	0.313
GLS X PLS	0.000	-	-0.670	-0.798	-0.189
GLS X 50%SD	0.468	0.027	-0.670	-0.798	0.189
GLS X 50% TD	-0.718	0.086	-0.863	0.274	0.500
GLS X EH	-0.544	-0.003	-0.561	-0.404	-0.473
YIELD X PLS	-0.189	-	-0.440	0.738	0.874
YIELD X 50%SD	-0.189	0.009	-0.440	0.738	0.992
YIELD X 50%TD	0.121	-0.061	-0.404	-0.024	0.979
YIELD X EH	0.432		-0.017	0.113	
PLS X 50%TD	0.161		0.917*	-0.184	0.756
PLS X 50% SD	1.000		1.000**	1.000**	0.929*
PLS X EH	-				
PLS X PH	-				0.891
50% SD X 50 TD	-0.113	0.879	0.917*	0.285	1.000*
50% SD X EH	-0.113	-0.002	-		0.775
50% SD X PH	-		-		
50%TD X EH	-0.113	-0.039	-		0.526
50% TD X PH	-		-		
EH X PH	-	0.854	-		0.715

*, ** Significant (p< 0.05) and (p< 0.01) probability levels respectively
Key: TD=anthesis, SD=silking dates, EH=ear height, PH=plant height

3.4 Discussion

Negative and significant ($p<0.05$) differences observed between C_0 and C_1 of the populations when recurrent selection methods were used indicated improvement in GLS resistance in one cycle of selection. The analysis of variance and calculations of percentage grain yield indicated significant ($p<0.05$) gain in advanced cycles, C_1. The negative values that were observed for days to 50% silking and anthesis also indicated early maturity in C_1 populations, suggesting that selection for resistance improves yield performance and reduces days to maturity. This correlated response suggests some linkage in genes conditioning these traits with those of GLS. Similar success in disease resistance improvement was demonstrated in combined half-sib and S_1 family selection for downy mildew in maize (Christos and Longuis, 1975).

Gains in selection for GLS and PLS were also realized in SRS method where C_1 and C_2 out performed C_0. In this method the gain cycle^{-1} in advanced cycles, C_2-C_1 were less than C_1- C_0. However there was reduction in yield in advanced cycles of selection. This could be due to inbreeding depression effects as the method relies on intermating selfed individuals to advance to the next cycle of selection.

In comparison, SRS out performed RRS in improving GLS resistance in one cycle of selection in all the four populations where percentage gains ranging from 0.0% to -63% were realized in SRS, while ranges of between 6.4% and -32% were realized in RRS. Reciprocal recurrent selection out performed SRS in PLS improvement in all the populations except in KSII population. Given that SRS depends on phenotypic variance (field observations) for selection, then the progress seen from C_0 to C_1 and C_2 suggests that GLS and PLS are highly heritable. It is evident that the method is effective and useful in early cycles of selection in highly heritable traits.

For yield in all populations, SRS out performed RRS in gain cycle^{-1}. The highest gains were observed in Pool B from C_0 to C_1 and in EC 573 C_0 to C_1 with gain of 86.1% cycle^{-1}. In advanced cycles the yield gains reduced and were negative in Pool A and B but positive but very low in KSII and EC 573. This trend was also observed for PLS. As explained for GLS, the decrease in gain can be due to the possibility of inbreeding in advanced cycles of selection. For yield most populations out yielded hybrid checks where the highest yield for the populations was 9.2t ha^{-1} and for the hybrids 4.8t ha^{-1}. This could be attributed to low severity of GLS on populations as compared to hybrids.

In populations, GLS, PLS and yield percentage gains were significantly different ($p<0.05$). For GLS, the highest response to selection was in KSII population for both methods of selection. Gains of -61.3% and -32.2% were realised in SRS and RRS respectively for GLS. Second highest in response to GLS selection was Pool A , followed by EC 573 and the lowest gain was in Pool B with percentage GLS gains of 0.0% and -7.4%. Low response in Pool B suggests there was low variability and therefore higher selection intensity was required, while the high response in KSII implies more progress will be achieved in KSII than in other populations. It also suggests that there is more variability for GLS resistance in KSII than in other populations. Similarly for PLS, KSII had higher response compared to the other populations.

Heritability estimates for GLS resistance in these populations were very varied depending on the populations but were very high ranging from 59% to 77%. Similar results were demonstrated by Clements *et al*. (2000) and Derera (2005). Gordon and Pratt (2006) and Vivek *et al.* (2001) reported heritability of 46% to 81% and 61%, respectively. For PLS, heritability estimates ranged from 39% to 80% across the four populations. Similarly, Carson (2001) also reported heritability estimates of 80%. The high heritability estimates suggest that selection for GLS and PLS resistance can be done using SRS method based on phenotypic variance in the field without progeny testing. This must have been the case in this study as there was response to selection to GLS and PLS using these two methods. Yield had very low heritability estimates, ranging from 7.0% to 42.3%. Pool A had yield heritability estimates of 26%, Pool B 7.9%, KSII 42.3% and EC 573 heritability estimates of 7.0%. More progress can be achieved in Pool A and KSII in selecting for yield. Also with phenotypic selection where the selected cob is advanced to the next cycle, these two populations are likely to respond better than the EC 573 and Pool B. Heritability estimates for 50% days to silk and 50% days to anthesis were low, but this is expected since these traits were not being considered in the selection for GLS.

Phenotypic correlation of GLS, PLS and yield in Pool A and in EC 573 was negative and significant. This suggests that there was strong association between GLS, PLS and yields in the desired direction. Implying positive gain in yield as GLS is selected against. In selection for GLS resistance, some agronomic traits were observed to respond differently. In the case of ear height, there was reduction across the population in SRS method except in Pool A that had an increase in ear height. For RRS, there was an increase in ear height in Pool A, Pool B and KSII but a reduction in EC 573. For both methods there was a reduction in days to 50% anthesis and silk as GLS was selected for across all the populations. The same trend was also observed for days to 50% silk and anthesis in RRS. Although the correlations were small and not significant, there was a common trend in these traits as you select for GLS resistance. Implying reduced ear height and days to 50% anthesis and to silk as GLS is selected against. Similar trend was also observed with PLS and days to 50% anthesis and silk. Although reduction in days and height are small, they can be beneficial especially in EC 573 and KSII populations that are very tall and the objective has always been to reduce maturity and height.

3.5 Conclusions

The study indicates that GLS and PLS resistance can be selected for by using SRS and RRS methods. In comparison of the two methods, SRS outperformed RRS method both in gains cycle^{-1} and also two selection cycles were achieved by SRS method. One cycle of GLS and PLS selection can be achieved in at least one year when using SRS and two years in RRS method for cases where two cropping seasons are possible in one year.

For GLS using SRS, average gains of -42.1%, 0.0%, -61.3%, and -20.0% cycle^{-1} were achieved in Pool A, Pool B, KSII and EC 573, respectively. In RRS average gains of -18.4, -7.4, -32.2, 6.4 were achieved in Pool A , Pool B, KSII and EC 573, respectively.

For PLS average gains of: Pool A, -1.6%; Pool B; 19.3%; KSII, -22.2%; EC 573, 40.5% were achieved in one cycle of selection using SRS. In RRS gains of; Pool A, -33.0%; Pool B, -8.7%; KSII, -11.7%; EC 573, 23.4% were achieved. For PLS, RRS method was better than SRS, therefore when improving for PLS, RRS method will be a better choice. For yield, average gains ($C_0 – C_1$) were: Pool A, 6.6%; Pool B, 78.4%; KSII, 65.0%; EC 573, 86.1% in SRS. In RRS, gains were: Pool A, 5.3%; Pool B, 23.1%; KSII, 13.2% and EC 573, 6.9%. Simple recurrent selection method was better than RRS.

In comparing gains in populations, higher response to GLS and PLS were observed in KSII and for yield in Pool B. Much progress for GLS and PLS selection can be achieved in KSII while high selection intensity for GLS resistance should be used in Pool B.

Gray leaf spot reaction was found to be highly heritable with heritability estimates in these populations of; Pool A, 59%, Pool B, 73%; KSII, 77% and EC 573 of 73%. For yield Pool A had heritability estimates of 26%; Pool B, 7.9%; KSII, 42.3% and EC, 573 7%. Therefore, selection can be based on phenotypic evaluation in the field. This makes SRS more useful in GLS selection.

There was negative significant correlation between PLS, GLS and yield in Pool A in early cycles of selection but reduced in advanced cycles. Breeders when selecting for GLS should be conscious of reduction in yield in late cycles of selection and stop once observed.

These results clearly demonstrated that it is possible to improve GLS and PLS resistance with simple and reciprocal recurrent selection methods.

Reference

Abebe, M., and M. Ayodele. 2005. Genetic analysis of resistance to gray leaf spot of mid-altitude maize inbred lines. Crop Science 45:163-170.

Alka, B., and G.P. Munkvold. 2002. Relationships of Environmental and Cultural Factors with Severity of Gray Leaf Spot in Maize. Plant Disease 86:1127-1133.

Byrne, P.F., J. Bolanos, G.O. Edmeades, and D.L. Eaton. 1995. Gains from selection under drought versus muiltilocational testing in related tropical maize populations. Crop Science 35:63-69.

Carson, M.L. 2001. Inheritance of resistance to *Phaeosphaeria* leaf spot of maize. Plant Disease 85:798-800.

Carson, M.L. 2005. Yield loss potential of to Phaeosphaeria leaf spot of maize caused by *Phaeosphaeria maydis* in the United States. Plant Disease 89:986-988.

Clements, M.J., J.W. Dudley, and D.G. White. 2000. Quantitative trait loci associated with resistance to gray leaf spot of corn. Phytopathology 90:1018-1025.

Christos, K.G., and J.H. Longuist. 1975. Combined Half-sib and S^1 Family Selection in a Maize Composite Population. Crop Science 16:461-464.

Cochran, W.G., and G.M. Cox. 1992. Experimental designs. 2nd edition John Wiley and sons, Inc. USA.

Derera, J. 2005. Genetic effects and associations between grain yield potential, stress tolerance and yield stability in Southern African Maize (Zea Mays L.) base germplasm. PhD. Thesis. University of Kwa Zulu Natal, South Africa.

Gordon, S.G., M. Bartsch, I. Matthies, H.O. Gevers, P.E. Lipps, and R.C. Pratt. 2004. Linkage of molecular markers to *Cercospora zeae-maydis* resistance in maize. Crop Science 44:628-636.

Gordon, S.G., R.C. Pratt. 2006. Breeding for resistance to maize foliar pathogens. Plant Breeding Review 27:119-173.

KARI. 2002. Annual report. Cereals, maize breeding. KARI, Kenya.

KARI. 2004. Annual report. Cereals, maize breeding. KARI, Kenya.

Kwena, P.O., and P. Kalama .1999. A survey on crop pest and farmer management practices in the North Rift Valley province of Kenya. Towards increased use of demand driven technology. A paper presented at a conference Nairobi. 23rd - 26th March 1999. Nairobi, Kenya.

Lori, L.H., S. Kresovich, J.D. Nason, and K.R. Lamkey. 2005. Population diversity in a maize reciprocal recurrent selection programme. Crop Science 45:2435-2442.

McProud, W.L. 2004. Repetitive cycling and simple recurrent selection in traditional barley breeding programmes. Euphytica 28:473-480.

Menkir, A., and J.G. Kling. 2007. Response to Recurrent Selection for Resistance to *Striga hermonthica* (Del.) Benth in a Tropical Maize Population. Crop Science 47:674-682.

Njuguna, J.G.M., J.C. Kedera, L. Muriithi, S. Songa, and B. Odhiambo. 1992. Overview of maize diseases in Kenya. In KARI, Proceedings of a workshop, Review of the National Maize Research Programme, Kakamega. Nov. 1992. KARI/ISNAR Management training linkage project. Kenya.

Okori, P., J. Falhleson, P.R. Rubaihayo, E. Adipala, and C. Dixelius. 2003. Assessment of genetic variation among East African *Cercospora zeae maydis* populations. African Crop Science Journal 11:75-86.

Omoigui, L.O., S.O. Alabi, S.G. Ado, S.O. Ajala, and A.Y. Kamara. 2006. Genetic gains from cycles of full-sib recurrent selection for low nitrogen tolerance in a tropical maize population. Maydica 51:497-505.

Payne, R.W., D.A. Murray, S.A. Harding, D.B Baird, and D.M. Souter. 2006. GenStat for Windows (9th edition) Introduction. VSN International, Hemel Hempstead

Pingali, P.L., and S. Pandey .2001. Technological opportunities and priorities of the public sector. *In* P.L. Pingali (ed.) CIMMYT 1999-2000 World maize facts and trends. Meeting world maize needs: Mexico, D.F. CIMMYT.

Sprague, G.F. 1966. Quantitative genetic in plant improvement. In K. J Frey (ed.) Plant breeding. Iowa State University Press, Ames.

Stuart, G.G., P.E. Lipps, and R.C. Pratt. 2006. Heritability and components of resistance to *Cercospora zeae maydis* Derived from Maize Inbred V0613Y. Phytopathology 96:593-597.

Tehon, L.R., and E. Daniels. 1925. Notes on parasitic fungi of Illinois. Mycologia 17:240-249.

Venuprasad, R., H.R. Lafitte, and G.N. Atlin. 2007. Response to selection for yield under Drought Stress in Rice. Crop Science 47:285-293.

Vivek, B., K. Pixley, O. Odongo, J. Njuguna, J. Imanywoha, G. Bigirwa, and A. Diallo. 2001. Regional disease nursery (REGNUR): a unique opportunity for developing multiple-disease resistant maize. p. 66-68. *In* Proceedings of 7th

Eastern and South African regional maize conference. 11 – 15th February 2001. Addis Ababa, Ethiopia.

Chapter 4: Heterotic Classification and Combining Ability of Local and Exotic Medium and Highland Maize Germplasm in Western Kenya

Abstract

Maize germplasm collections contain some valuable variability that can be infused into the four major heterotic groups in Kenya to broaden their genetic base. However, it is not known if these collections belong to distinct heterotic groups. The objectives of the study were to (i) characterize maize germplasm collections into their heterotic groups based on percentage yield heterosis as the primary factor for classification and specific combining ability effects and (ii) determine combining ability and gene action influencing the inheritance of GLS and PLS. Seventy seven testcrosses were developed through crossing the germplasm collections to four single cross testers, Kitale synthetic II (KSII) and Ecuador 573 (EC 573) for the highlands and pools A and B for the medium zones of Kenya during short rains of 2005/6. Crosses and testers were evaluated at Kakamega during 2006 to 2007 in a 9 x 9 triple lattice design. Analysis indicated significant differences in grain yield, ear height, days to 50% anthesis, GLS and PLS resistance. Both general (GCA) and specific combining abilities (SCA) were significant ($p < 0.01$), with SCA accounting for > 50% of the variation for GLS, PLS and yield and < 50% for ear height, days to 50% anthesis and 50% silk. This indicated that both additive and non-additive gene effects were important but non-additive gene effects were more important in conditioning these traits. High SCA also indicated presence of high heterosis between collections and populations. Basing on significance from zero ($p<0.05$) of percentage yield heterosis, seven collections were classified to Pool A, 17 to Pool B, 12 to KSII and 6 to EC 573 heterotic groups. With classification based on SCA data, 9 collections belonged to Pool A heterotic group, 10 to Pool B, 13 to KSII and 11 to EC 573 heterotic group. Though there were slight differences in classification between the two methods, generally they were similar in most cases but final conclusion was based on percentage yield heterosis data. Wide genetic variability between the crosses was shown by high levels of percentage yield heterosis realised. Reg. Nur x Pool A and Murumba x Pool B were found to be among the most variable genetically with percentage yield heterosis of 153.3% and 72%, respectively. Generally, Pool A and EC 573 showed larger genetic variability with accessions than Pool B and KSII. The majority of accessions belonged to pool B and KSII. High negative GLS score percentage

heterosis was observed, indicating GLS could be improved in this population through RRS since both additive and non-additive gene effects were important. Based on yield, GLS and PLS reactions, Embu 12 x Pool A, Taiwan x Pool A, Chalco x Pool B, Embu pool B x KSII and Cheborosinik x EC 573 testcrosses were selected for on-farm evaluation. Respective collections in the selected crosses were recommended for future incorporation in the populations. The study indicated that germplasm collections used in this study belong to distinct heterotic groups and have favourable genes for GLS, PLS and yield, therefore, they can be useful in the maize breeding programme for improvement of these populations.

4.1 Introduction

Knowledge of heterosis enables breeders to group germplasm collections into heterotic groups for higher performance hybrid development (Reif *et al*., 2005). It is not known if germplasm collections from Western Kenya belong to different heterotic groups. The information will be essential for classification of the germplasm collections into the four major heterotic groups in Kenya. Knowledge of heterotic groups and patterns of local collections will be important as it will guide which materials to include in the maize breeding programme depending on the heterosis realized when a cross is made. The amount of yield heterosis obtained by a cross depends on the genetic variance of its parents (Hallauer and Miranda, 1988). Lines whose hybrid shows high heterosis indicates that they are more genetically diverse.

Several methods have been used to classify germplasm into heterotic patterns or groups. Commonly used is the diallel cross analysis for a fixed set of open pollinated varieties. Line by tester has also been widely used to group germplasm into heterotic groups or patterns. Crosses are made between a group of open pollinated varieties to a common tester variety that is either high yielder or most popular with local farmers (Hallauer and Miranda, 1988). Heterosis is expressed in the cross as percentage relative to the average performance of the two parents or high parent. Thus materials can be classified depending on the level of significance of heterosis realized in their cross (Reif *et al*., 2005). Those that show high heterosis means that the two parent varieties are genetically diverse. Specific combining ability has also been used to classify germplasm into heterotic groups (Pilar *et al.,* 2003). Germplasm with large and significant SCA are said to be genetically diverse.

Different heterotic patterns and groups are used in different countries depending on the objective or adaptation to specific environments (Enoki *et al*., 2002; Li *et al*., 2004; Milkelson *et al.,* 2001; Ordas, 1991).The most common one used in the USA and Europe is the heterotic pattern Reid x Lancaster (Moreno-Gonza´ lez, 1988). In Spain flint maize populations are used (Pilar *et al.,* 2003) and for tropical maize heterosis under stress and non stress environments (Manoel *et al.,* 2001; Betran *et al*., 2003; Welcker *et al*., 2005).

In Eastern and Southern Africa, nine heterotic groups are used in the maize breeding programmes. Most of the lines come from the CIMMYT programme (CIMMYT, 2001). In East Africa, particularly Kenya four heterotic groups are used for both highland and medium altitude programmes. These are KSII and EC 573 used in the highland programme and Pools A and B for the medium programme (KARI, 2004). Ecuador 573 is an introduction while the rest are local collections, but Pool A has some relationship with Tuxpeno, an introduction. These programmes focused on maize germplasm collections with respect to yield performance, but not on biotic stresses, GLS and PLS in particular that are currently very important. In western Kenya, heterotic groups are expected to exit because of the geographical position of the region. It is neighboured by Uganda and Tanzania and this makes it possible for the flow of germplasm within the region between farmers.

For an effective breeding programme for disease resistance, it is important to know the type of gene action conditioning resistance to enable effective choice of selection method. Several studies have been undertaken to identify the type of gene action conditioning GLS and PLS resistance in a number of germplasms and environments. Studies have indicated that additive gene action accounted for more than 80% of the total variation conditioning resistance (Viek *et al.,* 2001; Silva and Moro, 2004; Derera, 2005; Menkir and Ayodele, 2005).

Inclusion of local collections that have good adaptation in breeding programmes would result in populations that are good sources for extracting inbred lines for hybrid formation or OPV development. Given the importance of the diseases and the need to improve populations through exploitation of local and exotic germplasms, it is imperative to know the heterotic groups of the germplasm and their GCA effects for GLS and PLS since there is very little information currently on genetic analysis of GLS resistance and in which heterotic groups farmers' collections fall in Kenya.

Therefore the objective of the study was to: (i) characterize maize germplasm collections into their heterotic groups and (ii) determine their combining ability effects for GLS.

4.2 Materials and Methods

4.2.1 Germplasm Collection

Forty-seven germplasm accessions comprising eleven introductions and thirty six local collections were used in this study (Table 4.1). Four populations from medium and highland maize breeding programmes in Western Kenya were used as testers. These were Kitale Synthetic II (KS II), Ecuador 573 (EC 573) from highland programme and Pools A and B from the medium programme. Introductions were acquired from Kenyan maize breeding programmes already using the materials. Local collections were acquired from farmers in the maize growing areas in December 2004 in Western parts of Kenya (Bungoma, Siaya, Teso, Kakamega, Busia, Trans Nzoia, Uasin Gishu, Marakwet and Nandi) districts. This was by visiting every tenth homestead on the local road in the district and accessing germplasm from respective individual farmers visited. At least four farmers in each district were sampled and during the collections, data on site, farmer's name, date of collection, seed characteristics (colour, flint or dent) were recorded (Table 4.1, 4 2).

Table 4.1: Local collections of maize from farmers in four agro ecological zones of Kenya

Accession	Origin	Grain colour	Grain texture	Cob colour
Bunyore	MM	White		White/Purple
Cheborosinik	HT	White	Dent/Flint	White
Esipindi	MT	White/yellow	Dent/Flint	White
LR 1/99	HT	White	Flint	White/Purple
LR 306B	MM	Yellow/White	Flint/Dent	White
LR 43	MM	Purple	Flint	White/Purple
LR 585	HT	White	Flint/Dent	White
Maragoli	MM	White	Flint/Dent	White
MSR 9A	HT	White	Dent Dent	White
Murumba	MT	White	Flint/Dent	White
Mwala	DM	White	Flint	White
Randago	MT	White	Flint/Dent	White/Purple
Reg. Nur	HT	White	Dent	White
Embu 12	DT	White	Dent	White
Loc Mix	HT	White	Dent	White
LR 40	MM	White/Purple	Flint/Dent	White/Purple
LR 301	MM	Purple	Dent	Purple
LR 21	MT	White	Dent	White
LR 399	HT	White	Dent	White
R 12 S	HT	White	Flint/Dent	White
LR 29	MT	Purple/White	Dent	Purple
LR 385	HT			
LR 301A	MM	Purple	Dent	Purple
Otati	MT	White	Dent	Purple
Bunyore II	MM	White	Dent	White
Embu Pool B	DT	White	Dent	White
HASR	MT	White	Dent	White
LR 585 A	MM			
Embu	DT	White	Dent	White
LR 9A	MT	White	Flint/Dent	White
LR 999	MT		Flint/Dent	White
No.8	MM	White/Yellow	Flint	White
LR 42	MM	White/Purple	Dent/Flint	White/Purple
KSII (tester)	HT	White (100%)	Flint	White
EC 573 (tester)	HT	White (100%)	Flint	White
Pool A (tester)	MM	White (100%)	Flint	White
Pool B (teter)	MM	White (100%)	Flint	White

Key:DT-Dry mid-altitudes; HT-Highland tropics; MT-Moist transitional; MM-Moist midalitude ; LR- Land race

Table 4.2: Exotic maize germplasms from maize breeding programmes included in this study

Accession	Origin	Grain clour	Grain Texture	Cob colour
Costarica		White	Dent/Flint	White
Ilonga composite	Tanzania	White	Flint/Dent	White
Kawanda Double Ear	Uganda	White	Dent	White
Mwap II SR		White	Flint/Dent	White
Taiwan	Taiwan	White	Dent	White
Chitedze		White	Dent/Flint	White
CML 202	CIMMYT	White	Flintt	White
Chiapas		White	Dent	White
Tuxpeno		White	Dent	White
Chalco		White	Dent/Flint	Purple/White
MSR 9A		White	Dent	White
V37		White	Dent	White
HASR		White	Dent	White
KRN				

Key: DT-Dry mid-altitude; HT-Highland tropics; MT-Moist transitional; MM-Moist mid-altitude

4.2.2 Multiplication Nursery

Materials collected from farmers and other programmes were planted during the long rains from March – August of 2005 at Kakamega Research Station in single row plots of 51 hills each with a spacing of 75cm between rows and 30cm within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphorus (80kg P_2O_5 ha $^{-1}$) were applied and weeding was done to maintain plots clean. Accessions were screened for resistance to GLS and PLS. At flowering, all the ear shoots of each accession were covered and pollen harvested and mixed for each accession and pollinated to avoid contamination from neighbouring accessions. At maturity, each mated accession was harvested and at least forty-five plants per cobs were seed bulked. Data on morphology, diseases and pests were recorded.

4.2.3 Crossing Block

To form the testcrosses, bulked seeds from promising accessions, in terms of disease resistance after characterization and multiplication, were planted during short rains from August 2005 – February 2006 at Kakamega Research Station, in double row plots, of 51 hills each with a spacing of 75cm between rows and 30cm within rows. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphorus (80kg P_2O_5 ha $^{-1}$) was applied and weeding was done to maintain plots clean. At flowering, fifty plants per accession were crossed (Line by tester) to the four testers; KSII, EC 573, Pool A and Pool B where the accessions and testers were female and male parents, respectively.

4.2.4 Testcross Evaluation

A total of 77 testcrosses comprising 22 of Pool A, 21 of Pool B, 20 of KSII and 14 of EC 573 with enough seed for evaluation and 4 testers as checks were evaluated between September 2006 and March 2007 at Kakamega site in 9 x 9 triple lattice design. Two row plots of 51 hills per row with spacing of 75cm between rows and 30cm between plants within rows were used for each entry. Recommended fertilizer application of nitrogen (80kg N ha $^{-1}$) and phosphatic (80kg P_2O_5 ha $^{-1}$) were applied and hand weeding was done thrice.

4.2.5 Data Collection

Data on GLS and PLS, number of days from planting to 50% anthesis, 50% of plants in the plot having anthers, number of days to 50% silking, ear height (centimeters) from the base of the plant at ground level to the base of the ear and diseased ears were recorded. Gray leaf spot and PLS were rated using a scale of 0 - 5 where 0 = no symptoms on plants; 1 = 1%-20%; 2 = 21%-40%; 3 = 41%-60%; 4 = 61%-80% and 5 = 81%- 100% infection of the plant. At harvest data was collected on final stand counts, grain weight per plot, grain moisture, the number of plants per plot that stalk lodged, root lodged and dropped ears. Grain moisture was measured using moisture meter at the time of harvesting. Plot yield was adjusted to 12.5% moisture content using the formula:

Grain yield (t ha^{-1}) = [Grain weight (kg $plot^{-1}$) x 10 x (100-MC)/ (100-12.5)/Plot Area], where MC is the moisture content at the time of harvest.

4.2.6 Data Analysis

4.2.6.1 Classification of Germplasm into Heterotic Groups

Heterosis of the testcrosses for yield and SCA were used to classify germplasm into heterotic groups but the final classification was based on percentage yield since all accessions were not represented in SCA. Significant percent heterosis and SCA under t-test (value significantly different from 0 at $p \leq 0.05$ and $P \leq 0.01$, respectively) indicated the parents were genetically diverse and belonged to different heterotic groups and vice versa.

4.2.6.2 Heterosis Analysis

Heterosis (H) was calculated as:

$$H = (F_1 - T)/T \times 100$$ (Betran *et al*., 2003)

where F_1 = is the mean of F_1 hybrid (top cross) performance

T = mean of the tester.

The means of the testers were used for calculating heterosis estimates (Manoel *et al*., 2001).

To determine which heterosis values were significant, percent heterosis values were generated in each replication and subjected to analysis of variance (ANOVA) to generate standard error (SE) of each trait.

A t- test was used to test whether heterosis values were significantly different from zero using the formula:

$$t = (H\ \%)/SE$$ (McCouway *et al*., 1999)

Where H% = mean H of each trait, SE = Standard error of each trait; t values that were greater than two ($t > 2$) were considered to be significant at $p<0.05$, and $t > 3$ were significant at $P < 0.01$ and those t values that were less than two were not significant at all levels of, $p<0.05$ and $p<0.01$ (McCouway *et al.,* 1999).

4.2.6.3 Combining Ability Analysis

General combining ability (GCA) and specific combining ability (SCA) effects estimates for populations, collections and testcrosses were determined by line x tester analysis as per Singh and Chaudhary (1977) for all quantitative data in GenStat Release 9.1,(Payne *et al*., 2006) based on the following linear model:

$$Y_{ijk}=\mu + g_i + g_j + S_{ij} + r + Є_{ijk}$$

Where Y_{ijk}= Observed value (trait);

μ = Grand Mean;

g_i = General combining abilities (GCA) for lines (line main effects);

g_j = General combining abilities (GCA) for testers (tester main effects);

S_{ij} = Specific combining ability (SCA) of line x tester effect;

r = Replication effects;

$Є_{ijk}$ = Random term.

The GCA effects of lines and SCA for the crosses were estimated (Singh and Chaudhary, 1977) as follows:

GCA (lines) = ML – GML;

Where ML= mean of line, GML=grand mean of lines;

GCA (tester) = MT-GMT;

Where MT= mean of t tester, GMT= grand mean of testers;

SCA line x tester) =MC – ML – MT + GM;

Where MC = mean of the cross of each trait;

ML = mean of line for each trait;

Mt = mean of tester for each tester;

GM = grand mean for the trait.

4.3 Results

4.3.1 Germplasm Characteristics

All the testers KSII, EC 573, Pool A and Pool B were 100% white in colour, hard grain with varying grain type, flint 66% to 100% (Table 4.1). Most collections were white with exception of Sipindi and Landrace 43 (LR43) which were yellow and purple, respectively.

Otati had white grains with purple cobs. Ear height ranged from 45cm to 200cm with varying physiological characteristics.

4.3.2 Testcrosses

Analysis of variance indicated highly significant differences ($p<0.01$) among the testcrosses and four different testers for days to 50% anthesis and silking, ear height, grain yield, GLS and PLS resistance (Table 4.3). The variation was greater for yield, ear height traits and less in days to 50% anthesis and days to silking (Tables 4.4, 4.5, 4.6 and 4.7). Tables 4.4, 4.5, 4.6 and 4.7 were all generated from one Table to separate populations, that is why they have same percentage coefficient of variation, but means were calculated for each population.

Table 4.3: Mean sum of squares for GLS, PLS and other traits of maize of 77 testcrosses and 4 testers evaluated in Kakamega in 2006/2007

Source of variation	DF	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% silk	Days to 50% anthesis	Ear height, (cm)
Replication	2	1.0	1.6	0.0	15.1	52.7	2952.0
Crosses + Checks	80	2.6**	2.6**	6.0**	64.1**	43.4**	1907.8**
Mean effective error	160	0.3	0.3	0.7	6.6	6.2	116.6
Overall mean		2.8	2.0	5.1	80.7	76.3	117.8

*, ** Significant at the $p< 0.05$ and $p<0.01$ probability levels, respectively, Checks= testers (4 populations)

4.3.3 Means of Testcrosses of Pool A

Testcrosses made with pool A had the lowest mean days to anthesis and silking with days to 50% silking and to anthesis ranging from 70 to 79 days with a cross involving Chiapas and Reg Nur, respectively. There was more variation in ear height and yield with ranges for ear height being 71cm to 174.7cm and yield from 3.0t ha^{-1} to 7.6t ha^{-1} (Table 4.4). The highest testcross had yield of 7.6t ha^{-1} (Reg Nur x Pool A), but most testcrosses had yield above the check (Pool A) which was lowest at 3.0t ha^{-1}. Gray leaf spot reaction as compared to PLS was high in most crosses with a mean score of 2.5

and PLS, 2.1. The susceptible and resistant testcrosses were Randago x Pool A and Embu x Pool A with GLS scores of 4.3 and 0.7, respectively (Table 4.4).

Table 4.4: Means of GLS, PLS and other maize traits of 22 Pool A testcrosses and Pool A tester evaluated in Kakamega 2006/2007

Crosses	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% anthesis	Days to 50% silk	Ear height, (cm)
Reg. Nur x Pool A	2.3	2.3	7.6	79	80	87
Embu 12 x Pool A	1.5	0.7	7.4	71	75	97
Sipindi II x Pool A	3.3	2.7	4.0	73	78	122
Randago x Pool A	4.3	1.0	5.2	77	80	128
LR 21 x Pool A	1.7	3.0	7.2	79	85	175
LR 306B II x Pool A	2.0	1.2	4.7	75	76	110
Sipindi x Pool A	2.3	3.5	4.7	73	79	110
Mwala x Pool A	3.2	2.7	3.8	71	74	93
MSR 9 A x Pool A	1.0	2.5	5.8	73	74	113
LR 399 x Pool A	3.0	2.8	4.7	73	80	121
LR 306 B x Pool A	2.0	0.7	4.6	73	79	102
V 37 x Pool A	1.5	2.5	4.1	71	74	86
Cheborosinik x Pool A	2.3	1.8	7.3	74	81	99
LR 585 x Pool A	3.0	1.4	5.2	76	79	100
Embu x Pool A	0.7	2.0	4.8	72	77	94
LR 9A Base x Pool A	2.0	2.8	5.6	76	83	106
LR 999 x Pool A	3.2	2.0	4.9	71	74	102
No. 8 x Pool A	4.0	2.0	3.1	76	80	97
*Taiwan x Pool A	2.5	1.2	6.6	73	80	118
*Chiapas x Pool A	2.7	2.0	4.2	70	76	108
*Tuxipeno x Pool A	2.7	1.7	4.4	78	83	71
*Ilonga composite x Pool A	3.5	2.7	3.9	71	74	111
Pool A – Check	3.7	2.8	3.0	74	77	93
Mean	2.5	2.1	5.1	74	78	106
LSD (0.05)	0.84	0.93	1.38	4.62	4.23	19.32
S.E	0.1	0.3	0.4	1.6	1.5	6.9
CV%	18.1	29.5	16.4	3.3	3.2	9.2

* = exotic germplasm

4.3.4 Means of Testcrosses of Pool B

Severity of GLS was high with most crosses being classified as moderately susceptible to susceptible, with scores above 2 and less than 4 (Table 4.5). Moderately susceptible cross, Otati x Pool B had GLS score of 4.2, and the resistant cross Chalco x Pool B had a score of 1.3. The check had a GLS score of 3.3 above the mean score of 3.0 and above most of the testcrosses. Compared to GLS, PLS severity was low with crosses having an average score of 3.0 and 2.0, respectively. For yield, a cross Murumba x Pool

B had the highest grain yield of 7.6t ha^{-1}, while 9A Base x Pool B had the lowest, 3.5 tha^{-1} (Table 4.5). Days to 50% anthesis and silking ranged from 72 to 83 and 74 to 84, respectively. Ear height variations were very high between the crosses, as seen in cross with V37and Murumba with ear height of 79cm and Chalko with Pool B at 153cm (Table 4.5).

Table 4.5: Means of GLS, PLS and other maize traits of 21 Pool B testcrosses and Pool B tester evaluated in Kakamega 2006/2007

Crosses	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% anthesis	Days to 50% silk	Ear height, (cm)
LR 42 x Pool B	2.7	1.7	4.4	74	79	107
LR 585 A x Pool B	2.2	1	5.6	72	76	107
Mwala x Pool A	3.7	2.5	4.9	72	74	83
LR 1/99 x Pool B	3.7	1.8	5.6	80	81	114
Otati x Pool B	4.2	1.3	6.7	75	78	126
Cheborosinik x Pool B	3.7	1.8	4.2	83	83	121
Sipindi x Pool B	1.8	0.6	6.4	75	76	115
LR 385 x Pool B	3.0	2.5	4.1	83	83	109
LR 585 x Pool B	2.3	1.5	4.7	74	79	105
Randago x Pool B	2.5	2.8	4.6	73	75	120
LR 29 x Pool B	2.5	1.3	5.2	80	82	136
Bunyore x Pool B	3.2	2.7	3.8	75	82	87
Murumba x Pool B	2.0	3.0	7.6	72	75	79
9A Base x Pool B	2.5	3.2	3.5	75	79	83
LR 43 x Pool B	3.7	0.8	4.3	78	83	108
*Ilonga composite x Pool B	3.8	3.3	4.9	80	83	114
*Costorica x Pool B	2.5	1.2	4.9	78	80	107
*Chalco x Pool B	1.3	1.8	7.0	79	84	153
*HASR x Pool B	3.5	2.3	7.5	73	77	105
*MSR9A x Pool B	2.7	1.2	3.9	74	76	100
*V37 x Pool B	2.5	3.2	3.6	72	74	79
Pool B – Check	3.3	2.2	4.4	76	81	81
Mean	3.0	2.0	5.1	76	79	106
LSD (0.05)	0.8	0.9	1.4	5	4	19.3
S.E	0.1	0.3	0.4	1.6	1.5	6.9
CV%	18.1	29.5	16.4	3.3	3.2	9.2

* = exotic germplasm

4.3.5 Means of Testcrosses of KSII

Mean days to 50% anthesis and silking for the test crosses ranged from 71 to 83 and from 74 to 88, respectively, while for ear height means ranged from 85cm to 151cm (Table 4.6). The highest ear height was in Bunyore x KSII and the lowest was in cross

Mwala x KSII. There was very low variation in yield across the crosses except cross, Loc Mix x KSII that had the highest yield of 8.0t ha^{-1} and Mwap III x KSII that had lowest yield of 1.5t ha^{-1}. The reactions to GLS of the 16 crosses plus the check were above a score of 3.0 with the exception of five crosses, Embu Pool B x KSII, Chitedze x KSII, LR 306B X KSII, KRN X KSII and LR40 x KSII that had scores below 3.0, moderately resistant (Table 4.6). On average PLS ratings were below a score of 2.5. Cross, Embu Pool B x KSII had a mean score of 0.8, which was the lowest among all the test crosses as indicated in Table 4.6.

Table 4.6: Means of GLS, PLS and other maize traits of 20 KSII testcrosses and KSII tester evaluated in Kakamega 2006/2007

Crosses	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**Days to 50% anthesis**	**Days to 50% silk**	**Ear height (cm)**
Bunyore x KSII	3.5	2.2	6.1	76	81	151
Mwala x KSII	3.7	2.3	4.1	73	78	85
Embu Pool B x KSII	2.2	0.8	5.5	71	74	120
Maragoli x KSII	4.3	3.2	5.6	79	87	95
LR 306 B x KSII	2.8	3.3	4.2	74	81	117
Sipindi x KSII	3.8	2.8	4.7	74	81	115
Cheborosinik x KSII	3.5	2.7	6.5	74	84	142
Murumba x KSII	3.0	2.7	4.0	73	75	105
LR43 x KSII	3.2	2.0	3.9	79	87	115
LR 301 x KSII	3.7	2.2	4.9	82	88	146
Loc Mix x KSII	3.3	2.2	8.0	78	85	136
LR40 x KSII	2.8	3.2	3.3	76	80	122
*CML202 x KSII	3.2	1.5	5.5	81	83	148
*Mwap II x KSII	3.5	2.3	5.5	77	80	105
*Costorica x KSII	3.5	3.2	4.1	76	78	111
*Chitedze x KSII	2.5	2.2	5.8	79	82	126
*Taiwan x KSII	3.3	1.8	4.2	80	86	146
*Mwap III x KSII	3.2	2.8	1.5	74	80	128
*Kawanda double ear x KSII	3.3	2.5	4.8	73	84	140
*KRN x KSII	2.7	1.3	6.5	81	83	132
KSII- Check	3.2	2.5	4.4	83	88	136
Mean	3.3	2.4	4.9	77	82	125
$LSD_{0.05\%}$	0.8	0.9	1.4	5	4	19.3
S.E	0.1	0.3	0.4	1.6	1.5	6.9
CV%	18.1	29.5	16.4	3.3	3.2	9.2

* = exotic germplasm

4.3.6 Means of Testcrosses of EC 573

Generally, disease ratings were below 2.0 for PLS, whereas GLS had a mean score of 2.5. The testcrosses out performed the check in yield, except for only one cross, Maragoli x KSII that yielded 3.8t ha^{-1} but Taiwan x EC 573 was the highest yielder with 7.0t ha^{-1} (Table 4.7). In most testcrosses there were no significant differences in days to 50% anthesis and silking with exception of Bunyore II x EC 573, Kawanda double ear x EC 573 for days to 50% anthesis and KRN x EC 573 for 50% days to silking. Ear height showed a similar trend. For the traits ear height, days to 50% anthesis and silk the crosses had lower values than the tester, EC 573 the check (Table 4.7).

Table 4.7: Means of GLS, PLS and other maize traits of 14 EC 573 testcrosses and EC 573 tester evaluated in Kakamega 2006/2007

Crosses	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**Days to 50% anthesis**	**Days to 50% silk**	**Ear height, (cm)**
Bunyore II x EC 573	4.0	2.0	6.5	74	82	158
LR301A x EC 573	3.7	1.0	4.6	82	86	145
Cheborosinik x EC 573	1.5	0.5	5.4	84	86	134
LR 1/99 x EC 573	1.3	1.3	4.6	82	87	163
LR43 x EC 573	1.5	0.7	5.1	81	86	145
R12S15 x EC 573	2.3	1.3	5.0	79	83	148
Bunyore x EC 573	3.5	1.5	5.5	79	83	118
Murumba x EC 573	3.3	1.8	4.4	79	83	115
Maragoli x EC 573	3.5	1.3	3.8	79	85	128
*Mwap II x EC 573	3.2	1.2	5.4	77	86	139
*Kawanda double ear x EC 573	2.7	1.0	5.8	74	83	152
*KRN x EC 573	2.2	1.5	6.4	77	81	141
*Taiwan x EC 573	2.3	1.2	7.0	81	88	140
*Costorica x EC 573	1.8	0.8	5.5	77	84	147
EC 573–Check	1.3	0.8	4.1	85	90	166
Mean	2.5	1.2	5.3	79	85	143
LSD $_{0.05\%}$	0.8	0.9	1.4	5	4	19.3
S.E	0.1	0.3	0.4	1.6	1.5	6.9
CV%	18.1	29.5	16.4	3.3	3.2	9.2

* Exotic germplasm

4.3.7 Means of Testcrosses across Four Populations

Across the populations, Pool A and EC 573 had the lowest GLS mean score of 2.5; KSII had the highest mean score of 3.3. Pool A had the lowest cross with a GLS score of 0.7, Embu x Pool A. The most susceptible crosses to GLS had a score of 4.3, Randago x Pool A and Maragoli x KSII. Ecuador 573 cross, Cheborosinik X EC 573 had the lowest PLS score of 0.5. Generally PLS was less severe across the four populations, compared to GLS (Table 4.8). For yield, KSII cross Loc mix X KSII had the highest grain yield, and the lowest was in Pool A, the check with grain yield of 3.0t ha^{-1}. Highland populations KSII and EC 573 had more days to 50% silk and anthesis and generally they had higher ear placement than Medium altitude populations, Pool A and Pool B (Table 4.8).

Table 4.8: Summary means of GLS, PLS and other maize traits across four populations, Pool A, Pool B, KSII and EC 573 evaluated in Kakamega 2006/2007

Population	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to50% anthesis	Days to silk 50%	Ear height, (cm)
Pool A						
Maximum	4.3	3.5	7.6	79	85	174
Minimum	0.7	0.7	3.0	70	74	71
Mean	**2.5**	**2.1**	**5.1**	**74**	**78**	**106**
Pool B						
Maximum	4.2	3.3	7.5	83	84	153
Minimum	1.8	0.6	3.5	72	74	79
Mean	**2.9**	**2.0**	**5.1**	**76**	**79**	**106**
KSII						
Maximum	4.3	3.3	8.0	83	88	150.7
Minimum	2.2	0.8	3.3	71	74	85
Mean	**3.3**	**2.4**	**4.9**	**77**	**82**	**124.8**
EC 573						
Maximum	4.0	1.8	7.0	85	90	165.7
Minimum	1.3	0.5	3.8	74	81	115.3
Mean	**2.5**	**1.2**	**5.3**	**79**	**85**	**142.6**
Overall Mean	**2.8**	**2.0**	**5.1**	**76.3**	**80.7**	**117.8**
L.S.D (0.05)	0.9	1.0	1.4	4.7	4.4	19.9
S.E	0.3	0.4	0.5	1.7	1.6	7.1
C.V %	19.3	30.8	17.6	3.8	3.4	10.5

4.3.8 Heterosis

Tables 4.9, 4.10, 4.11 and 4.12 were generated from one Table.

4.3.8.1 Percent heterosis of Pool A testcrosses

Pool A had a grain yield percentage heterosis ranging from -10% to 124.2% of cross No.8 x Pool A and Reg Nur x Pool A, respectively (Table 4.9). Most of yield heterosis was positive with only one negative testcross No. 8 x Pool A. Fifteen testcrosses out of twenty two were significant ($p < 0.05$). For GLS most of the percentage heterosis had low values but most of them were negative with seven out of twenty two being significant ($p < 0.05$). Phaeosphaeria leaf spot had most percent heterosis with negative values but not significant at any level of p value (Table 4.9).

Table 4.9: Mean percentage heterosis for GLS, PLS and other maize traits in 22 testcrosses of Pool A evaluated in Kakamega 2006/2007

Crosses	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% anthesis	Days to 50% silk	Ear height, (cm)
Randago x Pool A	22.5	-60.0	57.3**	3.2	4.9	50.3**
LR 21x Pool A	-53.2*	19.2	116.7**	5.9*	10.9	104.3**
LR 306B II x Pool A	-43.9*	-57.5	43.2*	0.9	-0.4	28.2
LR 306B x Pool A	-43.9*	-74.2	34.4*	-2.2	3.1	14.4
Embu x Pool A	-82.3**	-18.3	37.9*	-3.5	1.1	9.3
LR 999 x Pool A	-10.3	-23.3	42.9*	-4.9	-3.4	18.4
LR 9A Base x Pool A	-42.1*	8.3	66.2**	2.8	8.0	25.5
LR 585 x Pool A	-15.1	-46.7	48.5*	2.2	2.6	10.5
No.8 x Pool A	12.2	-23.3	-10.1	2.7	5.0	10.6
LR 399 x Pool A	-15.9	15.0	41.5*	-1.3	4.1	40.8*
Reg. Nur x Pool A	-32.8	-4.2	124.2**	6.3*	3.9	-0.6
Embu 12 x Pool A	-24.6	-67.2	115.1**	-8.4*	-45.1**	11.3
Sipindi II x Pool A	-8.5	4.2	20.7	-1.3	1.7	48.5**
Sipindi x Pool A	-33.6	35.8	40.2*	-1.3	3.6	30.5*
Mwala x Pool A	-13.0	0.0	13.0	-4.5	-3.0	9.1
Cheborosinik x Pool A	-36.5	-25.8	121.4**	-0.9	5.7	14.8
*V37 x Pool A	-56.3*	71.7	24.4	-4.5	-3.4	1.9
*Chiapas x Pool A	-28.8	-15.0	19.0	-0.6	-0.9	30.2*
*Taiwan x Pool A	-29.9	-53.3	92.9**	-1.7	4.8	38.4*
*Tuxipeno x Pool A	24.3	-30.0	31.8	5.1	8.3	-17.4
*Ilonga composite x Pool A	0.0	4.2	17.2	-4.4	-3.4	30.8*
*MSR 9A x Pool A	-72.0**	-8.3	73.7**	-1.7	-3.0	33.8*
Pool A, tester (check)	0.0	0.0	0.0	0.0	0.0	0.0
S.E	20.5	42.3	15.1	3.0	8.7	14.3

*, ** Significant from zero at p< 0.05 and p <0.01 probability levels, respectively, * = exotic germplasm

4.3.8.2 Percent heterosis of Pool B testcrosses

Most testcrosses of Pool B were not significant ($p < 0.01$) for percentage GLS and yield heterosis (Table 4.10). Five and two out of 21 test crosses had percentage yield and GLS score heterosis significant ($p < 0.05$), respectively. Though most of PLS percentage heterosis values were negative, none was significant ($p < 0.05$). For ear height, fifteen testcrosses were positive and significant at ($p < 0.05$), while for days to 50% silk none was significant at any level of p value.

Table 4.10: Mean percentage heterosis for GLS, PLS and other maize traits in 21 testcrosses of Pool B evaluated in Kakamega 2006/2007

Crosses	GLS (0-5)	PLS (0-5)	Grain yield (t ha^{-1})	Days to 50% anthesis	Days to 50% silk	Ear height, (cm)
Sipindi x Pool B	-44.4*	-72.2	44.8**	-0.9	-6.4	41.8*
Otati x Pool B	25.4	-37.8	50.6**	-1.7	-4.0	55.1**
LR 43 x Pool B	11.1	-57.8	-3.1	2.0	1.7	32.9*
LR 585 x Pool B	-29.4	-31.1	6.8	-2.3	-2.8	30.5*
LR 42 x Pool B	-19.8	-11.1	-0.3	-2.7	-2.4	31.6*
Cheborosinik x Pool B	10.3	-13.3	-5.1	9.1**	2.1	50.1**
LR 385 x Pool B	-9.5	22.2	-7.3	9.1**	2.1	35.1*
Murumba x Pool B	-40.5	42.2	70.8**	-5.7	-8.1	-2.6
LR 585A x Pool B	-33.3	-51.1	20.6	-4.9	-6.9	32.6*
LR 29 X Pool B	-23.8	-33.3	17.1	4.7	1.7	68.4**
Bunyore x Pool B	-4.8	20.0	-14.6	-1.4	1.3	7.0
9A Base x Pool B	-25.4	48.9	-20.7	-0.9	-2.8	2.4
LR 1/99 x Pool B	11.1	-4.4	26.5	5.9	-0.3	41.0*
Mwala x Pool B	11.1	22.2	10.1	-4.9	-8.9	2.1
Pool B	0.0	0.0	0.3	0.0	0.0	0.0
Randago x Pool B*	-25.4	40.0	4.8	-4.0	-8.1	47.9**
HASR x Pool B	6.3	15.6	69.7**	-3.6	-5.7	29.4*
*MSR 9A x Pool B	-18.3	-40.0	-11.4	-2.4	-6.9	23.2
*V 37 x Pool B	-24.6	53.3	-18.9	-5.8	-8.9	-2.4
*Chalco x Pool B	58.7*	-22.2	56.9**	4.3	3.0	89.6**
*Costorica x Pool B	-24.6	-48.9	10.4	1.8	-1.3	32.1*
*Ilonga composite x Pool B	14.3	60.0	10.0	5.5	2.1	40.8*
Pool B	0.0	0.0	0.3	0.0	0.0	0.0
S.E	**20.5**	**42.3**	**15.1**	**3.0**	**8.7**	**14.3**

*, ** Significant from zero at p< 0.05 and p< 0.01 probability levels, respectively, * = exotic germplasm

4.3.8.3 Percent heterosis of KSII testcrosses

Percentage yield heterosis with testcrosses KSII had low values with only seven out of 21 testcrosses being significant (p <0.05) and positive and one significant and negative (Table 4.11). Both GLS and PLS had no significant percentage heterosis and most of them were positive. For days to 50% anthesis and silk, most heterosis values were negative and 12 out of 21 were significant for days to 50% anthesis.

Table 4.11: Mean percentage heterosis for GLS, PLS and other maize traits in 20 testcrosses of KSII evaluated in Kakamega 2006/2007

Crosses	**GLS (0-5)**	**PLS (0-5)**	**Grain yield (t ha^{-1})**	**Days to 50% anthesis**	**Days to 50% silk**	**Ear height, (cm)**
Maragoli x KSII	39.0	55.6	30.8*	-4.4	-1.1	-29.8*
LR 306B x KSII	-9.5	83.3	-2.7	-10.8*	-7.2	-13.9
Loc Mix x KSII	6.7	12.7	85.2**	-5.6	-3.3	0.6
LR 40 x KSII	-7.6	67.5	-24.1	-8.4*	-9.1	-9.6
LR 301 x KSII	20.0	12.7	14.8	-0.8	0.4	8.5
Cheborosinik x KSII	11.4	27.8	49.3**	-11.2**	-4.2	4.8
LR 43 x KSII	1.9	7.1	-8.5	-4.8	-1.1	-15.7
Sipindi x KSII	24.8	46.0	11.7	-10.4**	-7.9	15.8
Mwala x KSII	18.1	40.5	-3.4	-12.1**	-11.4	-37.1*
Bunyore x KSII	11.4	2.4	43.6**	-8.4*	-7.6	11.8
Embu Pool B x KSII	-26.7	-67.7	27.8	-14.5**	-15.5	-11.3
Murumba x KSII	-4.8	40.5	-6.4	-12.1**	-14.0	-22.1
*Taiwan x KSII	8.6	8.7	-1.9	-3.2	-2.2	7.2
*Chitedze x KSII	-21.0	-11.1	35.4*	-4.4	-6.9	-8.1
*KRN x KSII	-14.3	-12.7	50.6**	-2.0	-5.3	-2.8
*Kawanda double ear x *KSII	6.7	46.8	14.1	-12.1**	-4.5	4.0
*CML 202 x KSII	3.8	-19.0	28.9	-2.4	-5.3	9.1
*Costorica x KSII	9.5	67.5	-2.4	-8.4*	-10.6	-18.7
*Mwap II x KSII	11.4	54.8	31.2*	-7.2*	-8.4	-22.9
*Mwap III x KSII	1.9	45.2	-63.9**	-10.4**	-9.0	-5.8
KSII	0.0	0.0	0.0	0.0	0.0	0.0
S.E	**20.5**	**42.3**	**15.1**	**3.0**	**8.7**	**14.3**

*, ** Significant from zero at p < 0.05 and p <0.01 probability levels, respectively
* = Exotic germplasm

4.3.8.4 Percent heterosis of EC 573 testcrosses

Testcrosses of EC 573 had low values of percentage yield heterosis but positive, with eight out of fourteen being significant (p < 0.01) as indicated in Table 4.12. Gray leaf spot and PLS had percentage heterosis values that were high, positive and significant (p < 0.01). Percentage heterosis for days to 50% anthesis and silk of most crosses were negative and significant (p< 0.05) as shown in Table 4.12. Most crosses of EC 573 with exotic germplasm were significant (p<0.05) for most traits. Mwap II x EC 573 had percentage GLS heterosis of 155% which was positive and significant. Taiwan x EC 573 had 133.3% and 74% heterosis for PLS and yield, respectively (Table 4.12).

Table 4.12: Mean percentage heterosis for GLS, PLS and other maize traits in 14 testcrosses of EC 573 evaluated in Kakamega 2006/2007

Crosses	**GLS (0-5)**	**PLS (0-5)**	**Grain yield ($t\ ha^{-1}$)**	**Days to 50% anthesis**	**Days to 50% silk**	**Ear height (cm)**
Bunyore II x EC 573	211.1**	188.9**	60.8**	-13.3**	-8.5	-4.6
LR 43 x EC 573	11.1	11.1	27.2	-5.1	-30.6**	-12.7
Bunyore x EC 573	172.2**	155.6**	37.1*	-7.1*	-22.5*	-28.5
LR 1/99 x EC 573	0.0	122.2*	14.3	-3.4	12.6	-1.4
LR 301A x EC 573	188.9**	11.1	12.9	-3.9	-19.6*	-12.6
R12 S 15 x EC 573	77.8**	122.2*	23.6	-7.4*	-33.6**	-10.5
Murumba x EC 573	161.1**	222.2**	9.5	-7.1*	-22.5*	-30.4*
Maragoli x EC 573	172.8**	122.2*	-5.1	-7.0*	-8.9	-22.9
KRN x EC 573	72.2**	133.3**	58.1**	-8.9**	-39.9**	-14.8
Cheborosinik x EC 573	16.7	-22.2	32.1*	-1.7	-19.6*	-18.9
*Costorica x EC 573	50.0*	44.4	36.4*	-9.4**	21.1*	-11.1
*Taiwan x EC 573	77.8**	133.3**	74.2**	-5.1	-9.8	-15.8
*Mwap II x EC 573	155.6**	88.9*	32.2*	-9.3**	-19.2*	-15.9
*Kawanda double ear x EC 573	61.9**	-24.4	59.3**	-7.9*	-9.6	33.7*
EC 573 (ChecK	0.0	0.0	0.0	0.0	0.0	0.0
S.E (crosses)	20.5	42.3	15.1	3.0	8.7	14.3

*, ** Significant from zero at p < 0.05 and p<0.01 probability levels, respectively
* = Exotic germplasm

4.3.8.4 Classification of accessions into heterotic groups based on percentage yield heterosis data

Collections were classified into heterotic groups based on percentage yield heterosis and significance of the heterosis values from zero at p < 0.05 using a t test. Those that were significant belonged to a different group from the tester. Classification of collections using yield percentage heterosis indicated seven accessions belonged to Pool A, 17 to Pool B, 12 to KSII and 6 to EC 573 heterotic groups (Table 4.13). Some collections belonged to more than two heterotic groups. Mwala belonged to heterotic groups, Pool A, Pool B and KSII. Landrace 43 also belonged to three heterotic groups Pool B, KSII and EC 573. More local collections belonged to Pool B and KSII as compared to Pool A and EC 573 (Table 4.13).

Table 4.13: Classification of collections into four heterotic groups of medium and highland maize populations based on yield heterosis data

Heterotic groups				
Pool A	**Pool B**		**KSII**	**EC 573**
Sipindi	Bunyore	LR 385	Sipindi	LR 1/99
Mwala	Cheborosinik	LR 585	LR 306 B	LR 43
No. 8	LR 1/99	LR 9 A	LR 43	Maragoli
Illonga composite	LR 43	LR 42	Murumba	Murumba
Chiapas	LR 585	Costorica	Mwala	LR 301
Tuxpeno	MASR 9A	Illonga composite	LR 40	R12 S
V 37	Mwala	MSR 9A	LR 301A	
	Randago	V37	Embu Pool B	
	LR 29		Costorica	
			Kawanda Double Ear	
			Taiwan	
			Chitdze	

4.3.9 Combining Ability effects for GLS and other five maize traits

The analysis of variance of testcrosses between accessions and four populations showed significant differences ($p < 0.05$) among the crosses for some of the evaluated traits. General combining ability was significant for all the traits except GCA tester effects for yield. Specific combining ability was significant for all the traits ($p < 0.05$) but not for days to 50% anthesis and silk (Table 4.14).

Table 4.14 Mean sums of squares of GCA and SCA for GLS, PLS and other four traits of maize evaluated in 2006/2007 in Kakamega

Source	**DF**	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**Days to 50% silk**	**Days to 50% anthesis**	**Ear height, cm**
Rep	2	2.3	2.0	0.6	1.5	3.4	19.6
GCA (line)	18	7.6**	5.1**	3.6**	11.8**	5.2**	14.6**
GCA (tester)	3	23.4**	25.7**	2.4	11.9**	7.2**	38.1**
SCA (line x tester	50	5.8**	4.8**	4.1**	2.1	2.1	3.3**
Error	67	0.3	0.4	0.8	8.0	10.2	133.9

*, ** Significant at $p < 0.05$ and $p<0.01$ probability levels, respectively

In partitioning sum of squares, contribution of both GCA and SCA accounted for almost equal variations but SCA for GLS, PLS and yield accounted for more than 50% of the variations; SCA for GLS, 58.3%, for PLS, 58.8% and for yield, 74%. For days to 50% silk and anthesis and height, GCA accounted for more than 50% of the variation (Table 4.15). The variances for GCA female effects were higher than of the males for all the traits (Table 4.15).

Table 4.15: Percentages sum of squares attributable to GCA and SCA effects for GLS, PLS, yield and three other maize traits evaluated in 2006/2007 in Kakamega

Traits	**Line (Female) %GCA**	**Tester (Male) %GCA**	**%SCA**
GLS (0-5)	27.5	14.1	58.3
PLS (0-5)	22.5	18.9	58.8
Yield t ha^{-1}	23.4	2.6	74.0
50%SD	60.2	10.1	29.7
50% TD	42.5	9.8	47.7
EH (cms)	48.5	21.1	30.5

Key: 50% DT=50% days to anthesis, 50%SD=50% days to silking, EH=ear height, GLS=gray leaf spot, PLS=*Phaeosphaeria* leaf spot, Y t ha^{-1}= yield in tons per hectare

4.3.9.1 General combining ability effects for GLS, PLS, yield and four other maize traits

General combining abilities for GLS were significant from zero for accessions LR 306B with -0.6, -1.0 for MSR 9A, -0.9 for V 37 and -0.5 for EC 573 tester. Yield had positive GCA for accessions Cheborosinik and KRN with GCA of 0.8 and 1.6, respectively. With PLS, negative GCA was observed in accession LR 43 and EC 573 tester. Days to 50% silk had more negative and significant from zero ($p < 0.05$) GCA estimates as compared to days to 50% anthesis (Table 4.16). For the diseases, most testers had negative GCA variance effects except KSII. Most testers also had positive non significant ($p < 0.05$) GCA effects for yield except KSII. For yield most GCA effects for accessions were negative and non significant from zero (p<0.05) as indicated in Table 4.16.

Table 4.16: Estimates of general combining ability effects for GLS, PLS and four other maize traits of collections and testers evaluated in 2006/2007 at Kakamega

Collections/Testers	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% silk	Days to 50% anthesis	Ear height (cm)
Cheborosinik	-0.1	-0.2	0.8*	2.7**	2.4*	7.6
S.E	0.21	0.23	0.4	0.90	1.01	4.09
Bunyore	0.5*	0.1	0.2	0.7	-0.3	-1.5
Costorica	-0.3	-0.2	-0.1	-0.4	0.1	1.5
Sipindi	-0.4	0.2	0.2	-1.1	-1.0	3.6
LR 43	-0.1	-0.8**	-0.5	3.7**	2.2	2.3
Murumba	-0.1	0.5	0.4	-3.85**	-2.4	-20.4**
Mwala	0.5*	0.4	-0.8	-4.42**	-3.3*	-23**
Taiwan	-0.1	-0.6	0.9	3.4**	1.9	13.5*
S.E	0.2	0.3	0.5	1.0	1.2	4.7
Ilonga composite	0.8*	1.1**	-0.9	-0.4	0.8	8.5
Kawanda double ear	0.1	-0.2	0.4	1.0	-3.9*	17.3*
KRN	-0.5	-0.6	1.6**	-0.5	2.0	7.8
LR 1/99	-0.2	-0.1	0.1	2.8*	3.9*	19.3**
LR 306B	-0.6*	-0.3	-0.7	0.2	-1.7	-4.2
LR 585	-0.2	-0.6	-0.3	-0.1	0.3	-1.5
Maragoli	1.0**	0.3	-0.1	3.4*	1.8	-17.5**
MSR 9A	-1.0**	-0.1	-0.4	-3.9**	-1.2	2.5
Mwap II	0.5	-0.2	0.6	0.7		-6.7
Randago	0.6	0.0	-0.3	-1.4	-0.1	20**
V 37	-0.9**	0.9*	-1.4*	-4.9**	-3.6*	-21.3**
S.E	0.3	0.3	0.5	1.3	1.4	5.8
KSII (Tester)	0.5**	0.7**	-0.4	0.6	0.1	5.3*
Pool B (Tester)	0.1	-0.03	0.04	-1.5*	-.0.2	-13.5**
S.E	0.1	0.1	0.2	0.5	0.6	2.3
EC 573 (Tester)	-0.5**	-0.6**	0.1	2.7**	2.1**	20.4**
S.E	0.1	0.1	2.0	0.6	0.6	2.5
Pool A (Tester)	-0.2	-0.06	0.3	-2.3**	-2.6**	-10.5**
S.E	0.1	0.2	0.2	0.6	0.6	2.6

*, ** Value significant from zero at $p < 0.05$ and $P < 0.01$, respectively

4.3.9.2 Specific combining ability effects

Specific combining ability effects were significant from zero at p<0.05 and p<0.01, for a few of the crosses and traits. The total number of crosses with significant SCA effects for GLS were 15 with 8 being positive and 7 negative (Table 4.17). Among the highest negative SCA effects were in crosses of Pool B, Randago x Pool B, -1.0 and Sipindi x

Pool B with SCA value of -0.8. For yield, five SCA effects were positive and significant. A negative relationship trend between GLS and yield was observed in crosses of Pool B, though not significant for all the crosses analyzed for the following crosses, Murumba x Pool B had SCA value significant for GLS of -0.8 and for yield 3.1; Sipindi x Pool B, SCA for GLS, -0.8 and for yield 1.1, Cheborosinik x Pool B, SCA value for GLS, 0.8 and yield -1.7 (Table 4.17). Most of the crosses had non significant from zero and negative SCA for yield as indicated in Table 4.17. Crosses had low negative SCA for GLS and PLS, traits with the best SCA value for GLS being -1.0.

Table 4.17: Estimates of specific combining ability effects of traits evaluated in 2006/2007 at Kakamega

Crosses (Line x Tester)	**GLS (0-5)**	**PLS (0-5)**	**Grain yield t ha^{-1}**	**Days to 50% silk**	**Days to 50% anthesis**	**Ear height (cm)**
Bunyore x Pool B	-0.3	0.6	-1.5*	2.5	-0.7	-14.7*
Bunyore x KSII	-0.3	-0.6	1.2*	-1.0	0.1	30.5**
Bunyore x EC 573	0.7*	0.02	0.3	-1.1	1.0	-17.0*
Cheborosinik x Pool A	-0.2	0.2	1.1*	-0.1	-2.3	-14.5*
Cheborosinik x Pool B	0.8*	0.2	-1.7**	1.1	4.7*	10.8
Cheborosinik x KSII	0.3	0.3	1.0	-0.1	-4.9*	12.4
Cheborosinik x EC 573	-0.7*	-0.6	-0.3	-0.5	3.1	-10.4
Costorica x Pool B	-0.2	-0.5	-0.1	1.6	2.0	2.3
Costorica x KSII	0.5	0.8*	-0.5	-2.6	-0.3	-12.5
Costorica x EC 573	-0.2	-0.3	0.6	1.4	-1.3	9.0
Sipindi x Pool A	0.0	1.5**	-0.9	2.0	0.8	0.8
Sipindi x Pool B	-0.8*	-1.5**	1.1*	-2.1	0.4	8.2
Sipindi x KSII	0.8*	0.1	-0.2	0.4	-0.9	-10.3
LR 1/99 x Pool B	0.9*	-0.03	0.4	-0.9	0.4	-8.2
LR 1/99 x EC 573	-0.8*	0.1	-0.4	1.2	-0.2	7.2
LR 306B x Pool A	-0.1	-1.0*	-0.1	0.4	0.8	0.0
LR 306B x KSII	0.1	1.0*	0.2	-0.2	-0.6	-0.8
LR 43 x Pool B	0.8*	-0.3	-0.3	-0.2	-0.5	2.5
LR 43 x KSII	-0.03	0.2	-0.3	1.7	0.6	-9.3
LR 43 x EC 573	-0.7*	0.1	0.7	-1.1	0.3	5.6
LR 585 x Pool A	0.5	-0.01	0.1	0.3	2.2	-4.7
LR 585 x Pool B	-0.5	0.03	-0.1	-0.1	-1.9	3.9
Maragoli x KSII	-0.1	0.3	1.0	2.0	1.3	-9.2
Maragoli x EC 573	0.1	-0.3	-1.0	-1.8	-1.1	8.4
Randago x Pool A	1.1**	-0.9*	0.2	3.3*	3.2	2.4
Randago x Pool B	-1.0**	0.9*	-0.1	-3.1	-2.9	-3.2
Murumba x Pool B	-0.8*	0.5	3.1**	-0.8	-1.9	-3.8
Murumba x KSII	-0.2	-0.5	-0.1	-2.2	-0.9	3.7
Murumba x EC 573	1.1*	-0.03	0.1	3.3*	3.1	-1.1
Mwala x Pool A	0.01	0.4	-0.8	0.3	0.7	9.8

Crosses (Line x Tester)	GLS (0-5)	PLS (0-5)	Grain yield t ha^{-1}	Days to 50% silk	Days to 50% anthesis	Ear height (cm)
Mwala x Pool B	0.2	0.2	0.6	-0.8	-0.4	2.8
Mwala x KSII	-0.2	-0.6	0.2	0.8	0.1	-13.7*
Mwap II x KSII	-0.3	-0.1	0.2	-1.7	1.1	-10.0
Mwap II x EC 573	0.4	0.1	-0.2	1.9	-0.9	9.2
Ilonga composite x Pool A	0.0	-0.3	-0.6	-4.0*	-3.3	-3.1
Ilonga composite x Pool B	0.04	0.3	0.7	4.2*	3.6	2.3
Kawanda double ear x KSII	-0.1	0.1	-0.4	1.3	0.6	1.3
Kawanda double ear x EC 573	0.2	-0.1	0.4	-1.1	-0.4	-2.1
KRN x KSII	-0.2	-0.7*	0.2	2.2	3.1	2.5
KRN x EC 573	0.3	0.7*	-0.1	-1.9	-2.9	-3.3
MSR 9A x Pool A	-0.7*	0.7*	0.8	-0.2	0.7	4.9
MSR 9A x Pool B	0.7*	-0.7*	-0.8	0.4	-0.4	-5.7
Taiwan x Pool A	-0.1	-0.2	0.3	-1.5	-2.4	-1.4
Taiwan x KSII	0.1	-0.2	-1.4*	1.0	2.2	10.8
Taiwan x EC 573	0.1	0.4	1.2*	0.9	0.6	-10.6
V 37 x Pool A	-0.3	-0.3	0.1	0.5	7.0**	1.7
V 37 x Pool B	0.4	0.3	-0.1	-0.3	4.6*	-2.6
S.E	**0.3**	**0.3**	**0.5**	**1.6**	**1.8**	**6.7**

*, ** Value significant from 0 at p ≤ 0.05 and P≤ 0.01, respectively

4.3.9.3 Heterotic classification of accessions based on SCA

Basing on SCA for yield data and significance ($p < 0.05$) from zero using a t-test, accessions were classified into four heterotic groups for the medium and highland maize populations (Table 4.18). From SCA analysis, nine collections belonged to Pool A heterotic group, ten to heterotic group Pool B, 13 to KSII and 11 to EC 573 heterotic group. Some accessions belonged to more than one group as was seen with Murumba that was classified in Pool B, KSII and EC 573. In general most accessions belonged to two heterotic groups as indicated in Table 4.18.

Table 4.18: Accessions classified into respective heterotic groups based on SCA for yield

Pool A	Pool B	KSII	EC 573
Sipindi	Costorica	Cheborosinik	Bunyore
Illonga composite	Illonga composite	Costorica	Cheborosinik
LR 306 B	LR 1/99	Sipindi	Costorica
LR 585	LR 43	Kawanda double cobber	Kawanda double cobber
MSR9A	LR 585	KRN	KRN
Mwala	MSR 9A	LR 306B	LR 1/99
Randago	Murumba	LR 43	LR 43
Taiwan	Mwala	Maragoli	Maragoli
V 37	Randago	Murumba	Murumba
	V 37	Mwala	Mwap II
		Mwap II	Taiwan
		Taiwan	

4.4 Discussion

4.4.1 Mean of six traits of test crosses

The analysis of variance indicated significant differences ($p < 0.01$) among testcrosses plus the checks across the traits evaluated. Test crosses made from Pool A and B had on average low mean days to 50% anthesis and 50% silking and there were no significant differences between the two populations. Similarly there was no significance difference with crosses made between the highland populations, Kitale synthetic and Ecuador 573 in anthesis, silking and ear height traits. Crosses from medium altitude populations Pools B and A had average days to silking ranging from 78 to 79, respectively while those of highland populations ranged from 82 to 84 days. This was also the case with ear height, where medium altitude populations gave crosses on average shorter than those of highland populations. This suggests that breeders can use germplasm from the medium populations to reduce the ear height and simultaneously select for early maturity, by making crosses with germplasm that are good in other traits but are tall and late.

Testcrosses used in this study exhibited significant differences in their reactions to GLS and PLS diseases. The range in disease reaction was from high susceptibility to highly resistant. Disease scores for GLS among the crosses and checks ranged from 0.7 to 4.3 for pool A crosses, 1.3 to 4.2 for pool B, 2.2 to 4.3 for Kitale synthetic crosses and 1.3 to 4.0 for EC 573 crosses (Table 4.2, 4.3, 4.4, 4.5). For PLS the severity was lower as compared to GLS and ranged from 0.5 for Cheborosinik x EC 573 and 3.5 for cross between Sipindi and Pool A (Table 4.8). Generally Ecuador population was a good source of resistance to both GLS and PLS while crosses of Embu 12 x Pool A, Randago x Pool A, LR 306B, Taiwan x Pool A, Embu Pool B x KSII, Sipindi x Pool B, Cheborosinik x EC 573 had PLS scores of less than 1.5. The possibility of classifying these crosses into various classes of disease reaction indicates that local collections have some favourable PLS and GLS resistant genes for use in broadening the genetic base of the four populations. Breeders can now look for resistant materials from local collections within the East African region that are well adapted and have good disease resistance to PLS and GLS.

4.4.2 Heterotic grouping based on percentage yield heterosis

From analysis of variance testcrosses and four population testers were significant ($p < 0.01$) across all the traits evaluated. Percentage heterosis based on yield for Pool A was highly significant at $P<0.01$ with most of the crosses except in crosses with lines; No. 8, Ilonga composite, Tuxipeno, and Sipindi showed no significant difference ($p<0.05$). The high percentage of testcrosses of local collections with Pool A showing high significant difference with Pool A tester, indicated that most of the collections from farmers belonged to a different heterotic group from Pool A group, showing that they are genetically divergent as Pool A was developed from Tuxpeno line, an introduction. Out of 22 crosses, only 7 collections were classified as belonging to Pool A, making 31.8% while 68% did not belong to Pool A (Table 4.13). Similarly EC 573 had low percentage heterosis but most of them were positive and significant. From 15 crosses, 8 (53.3%) were significant ($p <0.05$) from zero indicating that the accessions from these crosses belonged to a different group. For Pool B, most of the testcrosses were not significant from zero at $p < 0.05$ where 5 out of 21 crosses that were significant from zero ($p<0.05$) were not classified in Pool B while 72.2% belonged to Pool B. This was the case with KSII where 66.6% of the collections were classified to belong to KSII. From these ratios, it implies that Pool A and EC 573 were genetically more divergent from the collections as compared to Pool B and KSII. This was the case because EC 573 is an introduction from Central America and Pool A was developed from Tuxpeno which is also an introduction.

Most crosses of pool A had very high positive values unlike those of Pool B, suggesting that most local collections are genetically more divergent to Pool A than Pool B, which were closely related genetically to the collections. Similarly Kitale synthetic II had more than 70% of the crosses with negative percentage heterosis unlike EC 573 with positive percentage heterosis. This indicated that Kitale synthetic II was more closely related genetically to the local collections than EC 573. This is expected since Pool B and KSII were developed from local collections and so they are genetically related. The 30% heterosis observed might be due to the gene flow between local collections and populations from across the borders between Kenya and Uganda and Tanzania. High positive percentage heterosis observed with testcrosses of Pool A might be due to the fact of having been developed recently from lines of Tuxipeno an introduction. This might be due to less gene flow that has taken place between Pool A with landraces in the farmers' fields. This was also indicated when Tuxpeno was classified as belonging to Pool A heterotic group. Although EC 573, an introduction is expected to have very high heterosis with the local collections, the low positive percentage heterosis realized can be attributed to the high number of recycled seed of varieties that might have originated from EC 573 as it is the pioneer of most hybrids and OPVs developed in Kenya since 1959. Most exotic germplasm showed to belong to KSII, Pool A and Pool B and showed moderate and significant heterosis with EC 573, which indicated that they were genetically diverse from EC 573.

The reason as to why Mwala belonged to the three heterotic groups is because of it having been developed from the local collections like Pool A, Pool B and KSII. This indicated that they are not genetically diverse from each other. It is advantageous to have such a genotype, since if it has some good traits then it can be infused in more populations in this case the three populations, Pool A, Pool B and KSII.

This study also showed that percentage heterosis was influenced by crosses between the grain types. Crosses between flint and dent grain types resulted in top crosses that gave higher and positive significant yield percentage heterosis than the crosses made between, flint to flint, flint/dent to flint/dent or flint/dent to flint. Similar observations were observed with Northern Spain Flint and U.S dent (Ordas *et al.*, 1991). Also Pilar *et al*. (2006) reported good yield performance of flint x dent hybrids in north-western Spain.

4.4.3 Combing ability

The analysis of variance of the testcrosses derived from crossing collections and populations indicated significant GCA and SCA effects for all the traits evaluated. This indicated that both additive and non-additive gene action effects were important for yield and in conditioning resistance to PLS and GLS. In partitioning the testcrosses sum of squares, SCA accounted for 58.3% for GLS score, 58.8% for PLS, 74.0% for yield, 29.7% for days to 50% silk, 47.7% for days to anthesis and 30.5% for ear height of the total variation observed. Specific combining ability accounted for than 50% of the variations for GLS, PLS and more than 70% for yield. This indicated that non-additive effects were more important than additive effects in conditioning resistance to GLS, PLS and yield. It also implied that populations and collections are highly heterotic for these traits. Similar results were found by Gevers and Lake. (1994). They reported greater SCA than GCA in inbreds RO465W, RO452W and RO558W. However these results differed with other studies that reported additive effects to be more important than non-additive for GLS and PLS (Elwinger *et al*., 1990; Ulrich *et al*., 1990; Bubeck *et al.,* 1993; Coates and White, 1994; Anderson, 1995; Saghai Maroof *et al*., 1996; Viek *et al.,* 2001; Silva and Moro, 2004; Derera, 2005; Menkir *et al*., 2005). The percentage GCA female effects were higher than GCA male for all traits. Variation in female and male GCA indicated the presence of maternal effect implying that breeders should consider highly which parent should be male or females for maximum expression of disease resistance and yield in the top cross made. Significant and negative SCA in this study suggests that top cross hybrids could be developed to capitalize on non-additive gene action, to improve the resistance of maize germplasm to GLS and PLS in breeding programmes in Kenya.

4.4.4 Heterotic grouping based on SCA

Basing on SCA data and significance from zero ($p < 0.05$), collections were also classified into four heterotic groups in the medium and highland. In this case, nine accessions were classified to belong to Pool A, ten to Pool B, 12 to KSII and 11 to EC 573

In comparison between classifications using SCA and percentage heterosis, Pool B and KSII had almost the same accessions being grouped similarly by both methods. Pool B had only one accession, Murumba, that was classified by SCA to belong to Pool B but percent heterosis classified it as not belonging to Pool B. Kitale synthetic II had three accessions only being classified differently by both methods. Pool A and EC 573 had more variations in their classification of the accessions compared to Pool B and KSII. Pool A had five while EC 573 had seven accessions being classified differently. Although SCA and percentage heterosis classification slightly varied, in overall they classified most accessions similarly. Therefore the two methods can effectively be used separately but it is better to compare the two for verification.

In this study the overall classification depended on percentage yield heterosis as this was the primary factor for classification since SCA data did not capture all the crosses that were made. In cases where all data is captured then it is better to compare the two methods.

4.5 Conclusions

In this study percentage yield heterosis was the primary basis of classification of collections into heterotic groups. Basing on significant from zero ($p<0.05$) of percentage yield heterosis, seven collections were classified to Pool A, 17 to Pool B, 13 to KSII and 6 to EC 573. (Table 4.5.1). This shows that maize collections from Western Kenya belong to distinct heterotic groups and therefore can be infused into these populations.

Table 4.5.1: Identified heterotic groups of collections

Heterotic groups				
Pool A	**Pool B**		**KSII**	**EC 573**
Sipindi	Bunyore	LR 385	Sipindi	LR 1/99
Mwala	Cheborosinik	LR 585	LR 306 B	LR 43
No. 8	LR 1/99	LR 9 A	LR 43	Maragoli
Illonga composite	LR 43	LR 42	Murumba	Murumba
Chiapas	LR 585	Costorica	Mwala	LR 301
Tuxpeno	MASR 9A	Illonga comp.	LR 40, LR 301A	R12 S
V 37	Mwala	MSR 9A	Embu Pool B	
	Randago	V37	Costorica	
	LR 29		Kawanda D. Ear	
			Taiwan, Chitdze	

These populations and collections are highly heterotic to each other in terms of yield, GLS and PLS in the right direction with significant from zero ($p<0.05$) positive and negative heterosis for yield and the two diseases, respectively. Resistant and high yielding hybrids can be developed from these populations and collections. In line with this the following testcrosses with high yields and resistant to GLS and PLS were identified; Embu 12 x Pool A, Taiwan x Pool A, Chalco x Pool B, Embu Pool B x KSII and Cheborosinik x EC 573. These crosses are recommended for further evaluation on-farm. Very high variations in GLS and PLS resistance were observed in these collections, on average with scores less than 2. Collections Embu 12, Taiwan and Cheborosinik have been recommended for infusion in these populations to improve GLS and PLS resistance.

Both GCA and SCA effects were significant indicating the importance of additive and non-additive gene actions, making recurrent selection methods useful in improvement of traits in these populations. Specific combining ability, accounted for more than 50% of the total variations in GLS, PLS, yield and less than 50% in days to 50% silk and anthesis and in ear height. This implied that there is high heterosis between collections and populations. Development of top cross hybrids for on-farm evaluation and inbred lines for hybrid development is recommended.

High heterosis among collections and populations for GLS, PLS, yield, ear height, days to 50% silk and anthesis was observed, implying there is wide scope for broadening the genetic base of these populations. The high variations also implied that more cycles of selection can be made in these populations by infusing local collections that are better adapted with identified desirable traits. High heterosis present in these populations should be exploited to develop top cross hybrids. More collections in the future should be pursued to capture more favourable traits present in this germplasm to improve individual populations as the study established that collections belonged to distinct heterotic groups.

Reference

Anderson, B.M. 1995. Gray leaf spot resistance- why do we need it? How do we get it? p. 186-94. *In* Proceedings of the 31st Illinois Corn Breeders School, University of Illinois at Urbana-Champaign, Illinois, USA..

Betran, F.J., J.M. Ribaut, D. Beck, and D. Gonzalez de Leon. 2003. Genetic diversity, specific combining ability, and heterosis in tropical maize under stress and non stress environments. Crop Science 43:797–806.

Bubeck, D.M., M.M. Goodman, W.D. Beavis, and D. Grant. 1993. Quantitative trait loci controlling resistance to gray leaf spot in maize. Crop Science 33:838-847.

CIMMYT. 2001. Maize inbred lines released by CIMMYT. A compilation of 454 CIMMYT maize lines (CMLs), CML1 – CML454. August 2001. 2nd draft. CIMMYT, Mexico. D.F.

Coates, S.T., and D.G. White. 1994. Sources of resistance to gray leaf spot of corn. Plant Disease 78:1153-5.

Derera, J. 2005. Genetic effects and associations between grain yield potential, stress tolerance and yield stability in Southern African Maize (Zea Mays L.) base germplasm p 60-105. PhD. Thesis. University of Kwa Zulu Natal, South Africa.

Elwinger, G.F., M.W. Johnson, R.R.Jr. Hill, and J.E. Ayers. 1990. Inheritance of resistance to gray leaf spot of corn. Crop Science 30:350-358.

Enoki H., H.Sato, K. Koinuma. 2002 SSR analysis of genetic diversity among maize inbred lines adapted to cold regions of Japan. Theoretical Applied Genetics 104:1270-1277.

Gevers, H.O., and J.K. Lake. 1994. GLS1- a major gene for resistance to gray leaf spot in maize. South African Journal Sciences 90:377-380.

Hallauer, A.R., and J.B. Miranda. 1988. Quantitative genetics in maize breeding. Iowa State University. Press, Ames.

KARI annual report. 2004. Cereals Maize breeding

LI, Y., Y. Shi, Y. Song, J. Du, R. Tuberosa, T. Wang. 2004. Analysis of genetic diversity in maize inbred lines based on AFLP markers. Maydica 49:89.

Manoel, X.dos.S., L.M. Pollak, H.W.L. de Carvalho, C.A.P. Pacheco, E.E.G. e Gama, P. E. de Oliveira Guimarães, and R.V. de Andrade. 2001. Heterotic responses of tropical elite maize accessions from Latin America with Brazilian testers. Scientia Agricola 58:767-775.

McCouway, K., M.C. Jones, and P.C. Taylor. 1999. Statistical modelling using using Genstat. London, U.K.

Menkir, A., and M. Ayodele. 2005. Genetic analysis of resistance to gray leaf spot of mid-altitude maize inbred lines. Crop Science 45:163-170.

Mickelson, H.R., H. Cordova, K.V. Pixley, and M.S. Bjarnson. 2001. Heterotic relationships among nine temperate and subtropical maize populations. Crop Science 41:1012-1020.

Moreno-Gonza´ lez, J. 1988. Diallel crossing system in sets of flint and germplasm. Theoretical Applied Genetics 73:445–450. Dent inbred lines of maize (*Zea mays* L.). Maydica 33:37–49.

Orda's. A. 1991. Heterosis in crosses between American and Spanish populations of corn. Crop Science 30:1182–1190.

Pilar, S., B. Orda´s, R.A. Malvar, P. Revilla, and A. Orda´s. 2003. Heterotic Patterns among Flint Maize Populations . Crop Science 43:844–849.

Pilar, S., B. Orda´s, R.A. Malvar, P. Revilla, and A. Orda´s. 2006. Combining abilities and heterosis for adaptation in flint maize populations. Crop Sci. 46:2666-2669.

Reif, J.C., A.R. Hallauer, and A.E. Melchinger. 2005. Heterosis and heterotic patterns in maize. Maydica 50:215-223.

Payne, R.W., D.A. Murray, S.A. Harding, D.B Baird, and D.M. Souter. 2006. GenStat for Windows (9th edition) introduction. VSN International, Hemel, Hempstead.

Saghai Maroof, M.A., Y.G. Zue, Z.X. Xiang, E.L. Stromberg, and G.K. Rufener. 1996. Identification of quantitative trait loci controlling gray leaf spot disease in maize. Theoretical Applied Genetics 93:539-46.

Singh, R.K., and B.D. Chandahany. 1977. Biometrical methods in quantitative genetic analysis, New Delhi. India.

Silva, H.P., and J.S. Moro. 2004. Diallel analysis of maize resistance to *Phaeosphaeria maydis*. Science Agriculture. (Piracicaba, Brazil), 61:36-42.

Ulrich, J.F., J.A. Hawk and R.B. Carroll. 1990. Diallel analysis of maize inbreds for resistance to gray leaf spot. Crop Science 30:1198-1200.

Vivek, B., K. Pixley, O. Odongo, J. Njuguna, J. Imanywoha, G. Bigirwa, and A. Diallo. 2001. Regional disease nursery (REGNUR): A unique opportunity for developing multiple-disease resistant maize. p. 66-68. *In* Proceedings of 7th Eastern and South African Regional Maize Conference, Addis Ababa. 11th – 15th February 2001.,Ethiopia.

Welcker, C.T., B. Andre´au, C. De Leon, S.N. Parentoni, J. Bernal, J. Fe´licite ,C. Zonkeng, F. Salazar, L. Narro, A. Charcosset, and W.J. Horst. 2005. Heterosis and combining ability for maize adaptation to topical acid soils: Implications for future breeding strategies. Crop Science 45:2405–2413.

Chapter 5: General Overview

5.1 Introduction

This chapter reviews the research findings of the study conducted in Moist Mid-altitude, in western Kenya during 2004/2007. The overall goal was to improve maize resistance to GLS and PLS in Kenyan medium and highland maize populations through recurrent selection. This was achieved by testing the following hypothesis:

1) Gray leaf spot and PLS are prevalent and important in the maize growing areas of Kenya and farmers have some valuable information that could be used in breeding strategies to develop disease resistant germplasm.

2) Maize collections from western Kenya belong to distinct heterotic groups and can be used in the improvement of medium and highland maize germplasm.

3) Both additive and non-additive gene action conditions GLS and PLS resistance in these populations and collections.
4) The highland and medium altitude maize populations have favourable GLS and PLS resistance alleles that could be concentrated through cycles of recurrent selection.
5) Response of GLS and PLS to selection is influenced by the method of selection.

5.2 Literature review

The study reviewed maize production and breeding in Kenya. From the literature it was established that:

- Small scale farmers produced over 70% of the total maize with an average yield of 1.7t ha^{-1} (Karanja, 1996) while there was a potential of 6.0t ha^{-1}. Therefore there is a wide yield gap of 4.3t ha^{-1} which was attributed to biotic, abiotic and social factors.

- Participatory rural appraisals have been successful in identifying farmer constraints in various countries, similarly with participatory plant breeding with farmers.

- Gray leaf spot and PLS were important in Kenya and widely spread in all maize growing areas. Yield losses of more than 50% due to GLS and PLS were reported in several countries. Studies conducted reported GLS and PLS to be highly heritable with both GCA and SCA effects being important. For both diseases, breeding for resistance was advocated for.

- There was very little information published in Kenya in regards to GLS and PLS research. Also it was indicated from the review that very little research in Kenya has been conducted in respect to GLS and PLS.

- Heterotic systems being followed in Kenya in regards to heterotic patterns and heterotic groups of landraces, local collections are not well documented.

- Information and use of recurrent selection methods in disease improvement especially for GLS and PLS is limited.

5.3 Maize Production Constraints, Farmers Perception and Preferences

Collaboration between farmers and scientists in identification of farmer constraints, preference and perception for variety development is essential. A PRA was undertaken in 2004/2005 in two districts of western Kenya. This was through focus group discussions involving farmers, scientists, opinion leaders, administrators and local agricultural extension staff. From the PRA the following were established:

- There was a yield gap in maize production ranging from 4.7t ha^{-1} to 5.3t ha^{-1} between on-farm maize and the expected yield potential across the sites in Western Kenya. Across the sites, the constraints considered more important were low soil fertility, non viable seed and lack of seed, drought, *Striga*, diseases

(GLS, PLS, ear rots, streak), stalk borer and poor farming technologies. Farmers also considered constraints that directly affected yield to be more important. Improved varieties were more susceptible to GLS and PLS and farmers had no knowledge of the causes and modes of transmission of GLS and PLS, as they perceived fertilizer or frost as the causal agents and bees as mode of spread from farm to farm.

- Farmer criteria for variety selection depended on importance of the constraints. Those considered important were low input requiring variety, *Striga* resistance, drought resistance, disease resistance, early maturing and heavy grains. Local varieties were more preferred than the improved hybrid varieties because they were more tolerant to stresses than hybrids.

- Farmers recycled seed for planting from advanced generations of previous season due to high cost of seed. Criteria for seed selection considered were closed tips, big cobs, 8 row and healthy cobs. Farmers were concerned of their non participation in variety development, especially in constraint identification and on-station and on-farm evaluations.

- Across all the sites, farmers emphasised the need for training in crop management, especially in pests, weeds, diseases, seed selection and better utilization of compost and farmyard manure. Above all they echoed the need of farmer and breeders collaboration in the research and on-farm activities.

5.3 Heterosis and Combining Ability of Germplasm Collections

From the heterosis study, it was established that:

- Based on yield percentage heterosis, it was established that local collections and introductions evaluated belonged to distinct heterotic groups. Seven collections were grouped to Pool A, 17 to Pool B, 13 to KSII and six to EC 573 heterotic group. Future research should focus on identifying favourable traits in these collections and infusing them into their respective populations. More germplasm collection and heterotic studies should be undertaken to identify useful germplasm that was not captured in this study.

- It was also possible to group collections into heterotic groups using SCA data. Although the classification was not based on SCA as it did not contain all representative crosses for evaluation and for proper classification of all the germplasm evaluated.

- Both GCA and SCA effects were important in conditioning GLS, PLS and yield, but SCA accounted for more than 50% of the variation in these populations. This indicated high heterosis in these populations and collections. Future research should focus on development of top cross hybrids and inbred lines that are resistant to GLS, PLS and high yielding.

- Testcrosses with good GLS, PLS resistance and high yielding were identified. These included, Embu 12 x Pool A, Taiwan x Pool A, Cheborosinik x EC 573. These top crosses will be recommended for on-farm evaluation. Embu 12, Chalco and Reg Nur were found to possess good GLS and PLS resistance levels will be recommended for improvement of these populations.

5.4 Selection for GLS and PLS Resistance

Improvement of medium and highland populations was done in 2004/2007at Kakamega research station, and the findings were as follows:

- It was established that improvement of GLS and PLS resistance can be achieved by using SRS and RRS selection methods as two and one cycle of selection for GLS and PLS were achieved in SRS and RRS in two years, respectively. Simple recurrent selection method resulted in higher percentage gains than RRS method. For the two methods, average GLS percentage gains ranged from -61.3 to 6.4 for KSII and EC 573, respectively. These two methods should be tried on other diseases to exploit their potential in disease improvement in maize breeding.

- Heritability estimates for GLS were high and ranged from 59% to 76.8% in Pool A and KSII, respectively. This makes SRS more useful as field phenotypic variances are used for selection. Therefore, SRS method should be recommended for populations that show high heritability and where time is the limiting factor. In populations with very low heritability and time is not limiting, RRS should be recommended.

- Negative and significant correlations were observed between GLS and yield and also PLS and yield. This should be exploited in selection for either GLS, PLS or yield particularly in Pool A where r = -0.926 for GLS and yield and r= -0.947 for PLS and yield were observed.

- In these populations, high response to GLS selection was observed in KSII and lowest in Pool B. In selecting for GLS resistance in these populations, high selection intensity in Pool B is recommended.

5.5 Conclusions and Way Forward

In light with the findings of this study,

- Participatory rural appraisals and participatory plant breeding should be emphasised so as to aid breeders in the type of varieties to develop. Also use of farmers' criteria in variety evaluation will result in varieties that address the real problems on-farm.

- Constraints and preferences identified in this study should be the basis of formulation for research agenda. This will guide in the type of varieties to develop. As it is now evident that farmers recycle seed due to high cost of improved seed, OPVs should be a priority for breeders to develop.

- Collections identified in this study as heterotic and with good levels of GLS and PLS resistance should be the source of germplasm to other breeding programs in Kenya and within the region.

- Simple recurrent selection and RRS methods should be a priority for population improvement not only for GLS and PLS but for other diseases as well.

- In future, more work on germplasm collection should be undertaken in Kenya to capture those collections that might have been missed out.

Maize production is constrained with a number of stresses, low soil fertility, *Striga,* poor varieties, lack of seed, drought, pests and diseases as established from this study. Collaborative work between breeders and farmers using germplasm identified in this study as having good traits in terms of GLS, PLS and high yielding should be utilised. Reciprocal recurrent selection and SRS methods identified as successful should be the way forward.

Reference

Karanja, D.D. 1996. An economic and Institutional Analysis in Kenya: MSU International Development Working Paper No. 57: 3-5.