CHAPTER 5

EVALUATION OF HYBRIDS FOR GLS RESISTANCE IN MULTIENVIRONMENTS

Abstract

Maize production is severely hindered by both biotic and abiotic stresses. Gray leaf spot (GLS) disease in maize is caused by the fungus *Cercospora zea maydis*. This disease reduces both yield and grain quality. GLS is currently regarded as one of the most yield limiting diseases of maize worldwide including Tanzania. Chemical and cultural control methods of GLS are either expensive or less effective or both. Also, many exotic hybrids perform poorly in terms of yield and GLS resistance due to poor adaptability. Thus, the Tanzanian Maize Research Program has put more emphasis to breed maize hybrids that are resistant to GLS. Despite this effort, there are still few GLS insensitive hybrids in the country. Therefore, the main aim of this study was to produce more GLS resistant hybrids for commercial use by using resistance breeding. This control strategy is very effective, safe to the environment and inexpensive. Also, the study aimed to increase the farmer's choice of growing different types of GLS insensitive cultivars and to ensure that GLS insensitive hybrids are available all the time in case of GLS hybrid breakdown of resistance. Finally, this research examined the effects of genotype x environment interactions for grain yield, GLS score and other important traits such as kernels/row, ear length, row/ear, etc. This study used 29 moderately/highly GLS resistant parents to produce 225 maize crosses for the farmers. These hybrids were tested across three locations for three seasons, which is a prerequisite to evaluate genotypes for GLS resistance. The locations were chosen to represent all the high GLS disease pressure areas in the Southern Highlands of Tanzania. The experimental design was a 15 x 15 triple lattice. Statistical analyses revealed that hybrids 48, 90 and hybrid 45 had higher stable yields and consistently low GLS ratings across locations. Furthermore, there were many hybrids that had low/high yields exhibiting low GLS scores. These crosses could be used to make other types of maize cultivars such as open pollinated varieties and doubled haploid hybrids. Finally, it was noted that there are potential GLS resistant lines in the SHT and in Population 62 which could be deployed effectively and or might be used in inbred backcrossing breeding programs. The diallel studies revealed that both GCA and SCA were significant for GLS rating indicating the importance of both additive and dominance gene actions although GCA was more important. In general, the GCA effects of inbreds were good indicators for GLS rating and hybrid performance but could not predict the performance of all hybrids. Final selection for best inbred combinations should also be based on good specific combining ability for yield.

Keywords: Environments; GLS, G x E interactions, Pathotype, RCBD.

Introduction

Cultivars grown across locations react differently to environmental factors such as temperature, soil characteristics, wind, rainfall, etc., (Crossa *et al*., 1999). All these variables are collectively known as environments (Allard, 1999). Every factor, which is an element of the environment, has the potential to cause differential performance of cultivars. The differential response of genotypes across environments is called genotype x environment (G x E) interaction (Shi *et al*., 2002; Calderini *et al*., 2001). Interaction effects are a reflection of competing physiological processes, interaction within and between different genetic systems, and interaction between the environment and these processes and their genetic control (Reynold *et al*., 2002; Rao *et al*., 2002). G x E interaction is a major problem when studying quantitative traits because it complicates the interpretation of genetic experiments and makes prediction difficult.

It is a universal practice to test the new varieties across locations and seasons so as to ensure that forthcoming cultivars have stable performances over a range of environments (Annicchiriarico, 1997). Testing environments should adequately represent the environments that cultivars will eventually be grown in or identify environments that are unsuitable for the new varieties (Gunasereka *et al*., 2003; Reynold *et al*., 2002). Testing locations are important to plant breeders for the following reasons: (1) the potential need for unique cultivars adapted to particular areas require an understanding of genotype x location interaction, (2) effective allocation of resources for testing genotypes across locations and years is based on the relative importance of genotype x location, genotype x year and genotype x year x location interactions, (3) the need to develop unique cultivars for optimum performance depends on the interactions of genotype with predictable environmental factors, and (4) lastly, quantification of cultivar's stability of performances involve evaluating genotypes across environments (Rao *et al*., 2002).

In Tanzania, like any other country where GLS is endemic/epidemic, maize yield is significantly reduced by this disease. GLS was reported in Tanzania for the first time during the 1994/95 season. Since then, GLS is threatening food security and nutrition in the country because maize is a staple food for over 60 % of Tanzanians (Lyimo, per. Comm.*). Currently, there are few commercial hybrids that are resistant to GLS.

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In order to address the production needs of the farmers, the Uyole Agricultural Research Institute, Mbeya region, has developed several moderately/highly GLS resistant parents for commercial hybrid production. Thus, this study attempted to use resistance breeding, which is the cheapest, most effective, easy to use and friendly to the environment method of managing GLS. Therefore, the main aim of this study was to produce 225 hybrids and then screen them for yield, GLS resistance, and other desirable morphological traits across locations and years for commercial use. Furthermore, this research aimed to ensure that there is a continuous supply of GLS insensitive hybrids which are genetically different to replace those which may suffer from GLS disease breakdown due to the appearance of new physiological races of the GLS pathotypes.

Materials and methods

Field evaluation of inbred lines and hybrids

Field experiments aimed to evaluate the 225 hybrids for resistance to *Cercospora zea maydis* (Tehon and Daniels, 1925) infection in high GLS disease pressure areas for the purpose of producing hybrids resistant to GLS. The fieldwork was conducted in the Southern highlands of Tanzania, which included different agro-ecological zones namely; Mbeya region, with an altitude between 1500 and 2500 metres above sea level (masl), Rukwa region with an altitude between 1500 and 1800 masl, and finally Iringa region, with an altitude between 1800 and 2500 masl. The experiment was conducted for three years (2002-2004) across three locations. The experimental sites were: Uyole farm in the Mbeya region (located approximately 650 km from Nkundi farm and 250 km from Matanana farm). The Uyole site has a flat topography with black clay loamy soils. Another site was Nkundi farm which is in the Rukwa region. This location is approximately 900 km from Matanana farm. The Nkundi site has a hilly land with red clay soils. The last experimental site was Matanana farm in the Iringa region is also a hilly topography but with reddish-brown clay soils.

Figure 1. Map of Tanzania showing regions ( ) where this study was conducted. Source: http://www.thewhitefathers.org.uk/350map.html (accessed 1/8/2007).

These locations were chosen to provide differences in soil type, vegetation, annual precipitation, temperature, altitude, etc, representing all the maize growing areas in the Southern highlands of Tanzania. There were 225 hybrids produced from 29 moderately and highly GLS resistant parents (using partial diallel crossing design) during the 2000/2001 growing season at Uyole farm, Mbeya region (Table 1). The crosses were produced for three consecutive years. Seeds from these crosses were used for hybrid evaluations in the following season until the study was completed. The inbred lines used to make crosses were selected based on previous screening tests for GLS resistance at the Uyole research farm (Lyimo per. comm).

Experimental design

The 225 hybrid combinations (210 single crosses, two control hybrids and 13 filler hybrids) were planted using a 15 x 15 triple lattice design. Inbreds were planted adjacent to the hybrids in a randomized complete block design. Planting was done in mid December every year at all the sites. The plot size was a single row plot, 5.1 m long with inter row spacing of 0.75 m and intra row spacing of 0.30 m. Two kernels were planted in each hill, thereafter plants were thinned to one plant per hill, and this resulted in a population size of 44,400 plants/ha. Disease spreader rows of the highly GLS susceptible genotype (Ph3253) (Lyimo, per. comm.) was planted around the experiments and was also planted every ten crosses in both the hybrid block and inbred lines. These rows were used for monitoring disease development with time and as source of inoculum for the hybrids. Two controls were included, a highly resistant hybrid (UH 615) and a highly susceptible hybrid (Ph3253). GLS infected corn residues were used as source of inoculum for the hybrids and inbreds, and were spread on the ground (Gevers and Lake, 1994).

Morphological traits

The morphological traits recorded included; yield, height to ear, ear length, kernels/ear, rows/ear and GLS score, respectively. The grain yield /plot was measured in terms of kilograms/ha at grain moisture content of 12.5 percent. Data on days to 50 % silking was obtained by counting number of days from the day of planting to the day when 50 % of the plants in each plot had silks. Height to ear was measured as the average height in centimetres from the ground level to the first ear in each plot. Ear length was measured as the average length in centimetres of all ears in each plot. Number of rows/ear was obtained by counting the number of rows/ear for all ears in a plot. The average number of rows/ear was taken as the overall number of rows/ear of that plot. Number of kernels/row was obtained by counting the number of kernels/row for all ears of a plot. The average number of kernels/row was taken as the overall number of kernels/ear of that plot. Gray leaf score was scored from a scale of 1 to 9 with an increment of 0.25. A genotype with 1 score was highly resistant, while 9 was highly susceptible (Donahue *et al*., 1991).

Table 1. Origin, pedigree and heterotic patterns of maize lines used in this study.

No	Line name	Kernel type	GLS rating	Germplasm source	Pedigree	Established heterotic group†
1	K53015213	Flint	3.25	K205 x K230	K530 $S_5$152-1-3	A
2	K5301482	Flint	3.00	K205 x K230	K530 $S_5$1482 (97)-1	A
3	K53014821	Flint	2.25	K205 x K230	K530 $S_5$14821(98)-1	A
4	P629521	Flint	2.75	Population 62	P62 $s_7$95-2-1	A
5	P621111	Flint	2.50	Population 62	P62 S_7 11-1 -1	A/B
6	P627733	Flint	2.00	Population 62	P62 $s_6$77-3Pap3	A
7	P62L50	Flint	2.25	Population 62	P62 $s_6$86-95-1-4	A
8	P62145	Flint	1.50	Population 62	P62s_7 145-95	A/B
9	CML37	Dent	2.25	Population 32	Pop32c4Hc128-1-1-B-H5	A
10	P621621	Flint	1.75	K205 5x K230	K530 $S_5$66-5 (97)-1	A
11	P628495	Flint	2.50	Population 62	P62 $s_6$84-95Blk	A/B
12	P62103	Flint	8.00	Population 62	P62 103-93	A
13	CML11	Dent	3.00	Population 21	Pop21c5hc219-3-2-2-3#7-1B-4-10b	A
14	E50932815	Dent	2.25	E250 x E393	E5093 s_6Pap28-1-5	B
15	P621321	Flint	1.75	Population 62	P62 $s_7$13-2-1	A
16	K375891	Dent	2.50	K337 x K358	K3758 $S_7$9-1-1-1	A
17	P62101	Flint	3.50	Population 62	P62 101-95	A
18	P62148	Flint	2.50	Population 62	P62 148-95	B
19	E5093642	Dent	3.50	E250 x E393	E5093 $s_7$64	B
20	K37581011	Dent	3.25	K337 x K358	K3758 $S_7$10-1-1	A
21	K3758L36	Dent	2.00	K337xK358	K3758s_6L36	B
22	K53015233	Dent		K337 x K358	K530$s_5$152-3-3	A
23	K3758911	Dent		K337 x K358	K3758$s_7$89-1-1	A
24	K37581011	Dent		K337 x K358	K3758$s_7$10-1-1	A
25	K3758111	Dent		K337 x K358	K3758$s_6$1-1-1-1pap	A
26	K37586911	Dent		K337 x K358	K3758$s_6$69-1-1	A
27	K375869111	Dent		K337 x K358	K3758$s_6$9-1-1	A
28	K37588913	Dent		K337 x K358	K3758$s_6$89-1-3	A
29	K3758L36	Dent		K337 x K358	K3758s_6 L36	A

† (Lyimo per.comm).

Statistical Analyses

Statistical analyses of the hybrids evaluated across three locations and for three years (nine environments) necessitated the use of experimental model where a value or performance of any trait measured was a function of the average performance of that trait across all the three years and three locations, which was also dependant on the interaction of different hybrids with the locations in which they were evaluated or by environmental factors present in the locations such as temperature, rainfall, duration and intensity of sunlight, altitude, relative humidity, soil characteristics (such as soil type, soil texture, soil pH, soil fertility, etc), drought, etc. Furthermore, a performance of a trait was affected by how an individual hybrid interacted with seasonal and/ or climatic variations of weather conditions like temperature, rainfall and its distribution, wind speed and direction, relative humidity, dry spell, etc. Also, the expression of any hybrid trait was dependant on the genotype of that particular hybrid, in other words, the total genetical endowment of the hybrid i.e. some hybrids were genetically short, others were tall, while some were genetically resistant to GLS disease and others did not have any GLS resistant genes. Also, some had moderate resistance/susceptibility to the GLS pathogen and thus, different hybrids responded differently to the GLS pathogen. Interaction effects such as replications within different locations and seasons could have different impact on the performance of traits among the hybrids. The other type of interaction that could affect the individual performance of a trait in a hybrid could be the three way interaction where by three factors of hybrids, locations, and seasons all together interact in a complex way to cause differential performance of traits among the hybrids. The experimental model also included the error term as a variable which could affect the expression of a hybrid trait. The accuracy/inaccuracy of data recorded by the experimenter during the execution process of the experiment could also affect the expression of a trait which is under the error term of the experimental model.

Thus, in an effort to take all these variables into account of the experimental model, this study was represented mathematically as follows:

$Y_{ijkl} = \mu + \tau_i + L_j + S_k + r(L_j \times S_k) + (\tau_i \times S_k) + (\tau_i \times L_j) + (\tau_i \times L_j \times S_k) + \varepsilon_{ijkl}$ where:
Y_{ijkl} = is a trait performance (e.g. yield).
μ = is the average performance of a trait.
τ_i = is the effect of the $_i$th hybrid.
L_j = is the effect of $_j$th location on the performance of the trait.
S_k = is the effect of $_k$th season on the performance of the trait.
$S_k \times L_j$ = is the effect of the $_k$th season in the $_i$th location.
$r(L_j \times S_k)$ = is the effect of a replication in the $_k$th season and $_j$th location.
$\tau_i \times S_k$ = is the effect of the $_i$th hybrid in the $_k$th season.
$\tau_i \times L_j$ = is the effect of the $_i$th hybrid in the $_j$th location.
$\tau_i \times L_j \times S_k$ = is the effect of the $_i$th hybrid in the $_j$th location and in the $_k$th season.
ε_{ijkl} = is the experimental error effect or noise.

Statistical analyses of SAS software, SAS 1999 version 1, 9.3 programme was used for the data analyses.

Mean yields and the correlation coefficients among the phenotypic traits and location correlations

The mean yields and GLS scores for the 225 hybrid combinations at one location with the yields and GLS scores at each of the other locations were used to determine location similarities (Campbell and Kern, 1982). Correlation coefficients for yield and GLS rating between locations were computed using the SAS procedure (SAS, 1999 version 1.9.3) respectively.

Analysis of Variance

Additional statistics of assigning hybrids into yield (Y-axis and GLS scores in X-axis) was used to group together the experimental hybrids into clusters that differed from one another in terms of GLS disease scores and yields respectively. Furthermore, data were combined over locations and analysed as combined series using the general linear model (GLM) procedure (SAS, 1999 version 9.1.3). All effects were considered as random.

Analyses for general combining ability (GCA) and specific combing ability (SCA) for a 21 maize diallel grown at Uyole, Matanana and Nkundi for 3 years at each site.

Data for grain yield and gray leaf spot rating were analysed using Method 4 Model 1 analysis (Eisenhart, 1947; Griffing, 1956). In these analyses it was assumed that all factors were fixed except environments. This is because the lines used were not a random sample. They were highly selected inbred lines. Combining abilities were calculated as defined by Sprague and Tatum (1942).

Results

The phenotypic correlation coefficients (r) of different traits measured for the 225 hybrids across three locations and three years in this study are shown in Table 2.

Table 2. Phenotypic correlation coefficients between traits studied.

	50 % silking	Ear height	Ear length	Rows/ear	Kernels/row	GLS score	Yield
50%silking	-	0.34*	-0.20*	-0.10*	-0.17*	0.11*	-0.36*
Ear height		-	0.32*	0.17*	0.15*	-0.30*	0.29*
Ear length			-	0.07*	0.60**	-0.14*	0.35*
Row/ear				-	0.02^{NS}	-0.12*	0.16*
Kernels/row					-	-0.03*	0.43*
GLS score						-	-0.34*
Grain yield							-

*, ** significant at the 5% and 1% level of probability, respectively.

Table 2 exhibited that grain yield was positively correlated to all traits studied except GLS disease (r = - 0.34) and days to 50 % silking (r = - 0.36). Furthermore, yield was statistically associated with the following traits: kernels/row (r = 0.43), ear length (r = 0.35), ear height (r = 0.29) and the number of rows/ear (r = 0.16). GLS disease score, however, was negatively correlated with traits such as ear height (r = -0.30), ear length (r = -0.14), number of rows/ear (r = -0.12) and number of kernels/row (r = -0.03), but was positively correlated to days 50 % silking (r = 0.11). Also, results showed that the number of kernels/row and ear length recorded the highest correlations (r = 0.60) between any two traits studied. But the number of kernels/row had no association with the number of rows/ear (r = 0.02). Generally, the correlation coefficients among the remaining traits were positive and were between, 0.1 and 0.3.

Phenotypic associations (yield and GLS traits) for all the hybrids across the three locations are exhibited in Table 3.

Table 3. Correlations of grain yield and GLS for 225 hybrids across 3 locations and 3 seasons.

	Uyole site	Matanana site	Nkundi site
Uyole site	-	0.60* (0.67**)	0.71** (0.85**)
Matanana site		-	0.54* (0.77**)
Nkundi site			-

( ) Correlation coefficient for yield
*, ** significant at the 5% and 1% level of probability, respectively.

Phenotypic correlations (Table 3) revealed that the highest correlation coefficient for yield was in the order of: Uyole-Nkundi sites (0.85) > Nkundi-Matanana sites (0.77) > Uyole-Matanana sites (0.67). Furthermore, Table 3 also showed that Nkundi-Uyole sites recorded the highest association for GLS (0.71). However, the lowest association for this disease was exhibited between Nkundi-Matanana (0.54) sites. The GLS correlation coefficient between Matanana-Uyole was 0.60.

Inbred line general combining ability (GCA) effects for gray leaf spot and grain yields from a 21 maize diallel grown across 3 locations (Uyole, Matanana and Nkundi) from 2001 to 2003 in this research is shown in Table 4.

Table 4. Inbred general combining ability effects from a 21 maize diallel grown across 3 locations for 3 years

		GCA effects	
Line no	Inbred name	Gray leaf spot rating	Grain yield (kg/ha)
1	P62145	-0.6	601.8
2	K53015213	0.1	-112.6
3	K375891	-0.1	-16.4
4	K37581011	0.1	605.9
5	K5301482	-0.2	-122.3
6	P627733	-0.3	340.0
7	K3758L36	-0.2	89.0
8	K53014821	-0.1	237.0
9	CML37	0.1	512.1
10	P629521	0.1	119.7
11	CML11	0.2	154.6
12	P621621	-0.5	316.6
13	P621111	0.0	154.0
14	P62L50	0.2	140.5
15	P628495	0.0	416.1
16	P62103	0.8	-405.3
17	P62101	-0.1	-726.6
18	P62148	-0.2	226.6
19	E50932815	0.1	-814.7
20	E5093642	0.0	100.0
21	P621321	-0.4	-900.5
	LSD (0.05)	1.0	1800.0

The inbred line general combining ability effects for gray leaf spot disease ratings and grain yields revealed that lines P62145 (-0.6), P621621 (-05) and P621321 (-0.4) were the three inbreds with the lowest GCA effects for GLS rating. Furthermore, inbred lines K375891 (-0.1), K53014821 (-0.1), P62101 (-0.1), K5301482 (-0.2), K3758L36 (-0.), P62148 (-0.2) and P627733 (-0.3) had GCA effects for GLS rating below zero. Inbred lines P621111, P628495 and E5093642 exhibited GCA effects for GLS rating being 0.0, while lines K53015213, K37581011 and E5093642 showed positive GCA effects (0.1) for GLS rating. Also, lines CML11 and P62L50 had positive GLS effects (0.2). The highest GCA effect for the rating was exhibited by line P62103 (0.8) which was the most susceptible line in this study. The GCA effects for grain yield (kg/ha) was highest for line P621321 (900.0) and lowest for inbred E50932815 (-814.7). The other four inbreds which recorded the highest GCA effects were the following lines: line K37581011 (605.9), line P62145 (601.8), line CML37 (512.1) and finally line P628495 (416.2). Whereas lines P627733 (-840.0), P62103 (-405.3) and line K5301482 (-122.3) had the lowest GCA effects for grain yield in this research.

The inbred line specific combining ability effects for gray leaf spot rating in this research is revealed in Table 5.

Table 5. Inbred line specific combining ability effects for gray leaf spot rating from a 21 maize line diallel grown at Uyole, Matanana and Nkundi sites for 3 years.

	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Line 7	Line 8	Line 9	Line 10	Line 11	Line 12	Line 13	Line 14	Line 15	Line 16	Line 17	Line 18	Line 19	Line 20	Line 21
Line1	-	0.1	0.2	0.1	0.5	0.1	0.4	0.1	-0.3	-0.1	-0.2	0.3	0.0	0.1	0.4	0.2	-0.2	-0.3	0.1	-0.2	0.4
Line2			-0.1	-0.2	0.1	0.3	0.4	0.2	-0.1	-0.2	0.0	0.2	-0.1	0.0	0.1	-0.4	-0.1	0.2	0.0	-0.1	0.2
Line3				0.1	-0.2	0.2	0.0	0.3	-0.3	0.1	0.1	0.1	-0.2	0.1	0.3	0.0	0.3	0.1	-0.2	0.0	-0.1
Line4					0.2	0.3	0.1	-0.3	-0.1	-0.2	0.0	0.1	0.0	0.0	0.0	-0.3	0.2	0.3	-0.1	-0.2	0.4
Line5						0.0	0.2	0.1	0.4	0.1	-0.4	0.1	0.2	0.3	-0.1	-0.2	0.2	0.1	-0.4	0.1	0.0
Line6							0.1	0.2	0.0	0.1	0.3	0.3	-0.1	0.1	0.0	-0.1	0.1	0.3	-0.3	0.3	0.7
Line7								0.2	0.3	0.1	0.0	0.2	0.0	0.0	0.0	0.2	0.1	0.3	-0.2	0.1	0.2
Line8									0.0	0.1	0.2	0.1	0.2	0.4	0.0	-0.3	0.1	0.2	-0.1	0.2	0.1
Line9										-0.2	0.1	0.2	0.3	-0.1	0.2	-0.2	0.0	0.4	0.0	0.0	0.1
Line10											-0.1	0.3	0.1	0.0	0.1	-0.1	0.0	0.2	0.0	0.1	0.2
Line11												0.2	0.1	-0.2	0.2	-0.5	-0.1	0.1	0.2	0.1	0.0
Line12													0.4	0.3	0.3	0.1	0.0	0.2	0.1	0.1	0.2
Line13														-0.1	0.3	0.0	0.2	0.1	0.3	0.2	0.1
Line14															0.0	-0.2	0.1	0.2	-0.1	0.0	0.1
Line15																0.2	0.1	0.3	0.1	0.0	0.2
Line16																	0.0	0.1	0.0	-0.1	0.1
Line17																		0.0	0.3	0.1	0.0
Line18																			0.1	0.1	0.5
Line19																				0.2	0.1
Line20																					0.2
Line21																					

LSD (0.0) = 0.36

Generally, the specific combining ability effects for GLS rating ranged from 0.0 to 0.7. Furthermore, most crosses revealed positive SCA effects for GLS rating as revealed in Table 5. This Table showed that 36 out of 210 hybrids (i.e. 17.1%) in the diallel had SCA effects of zero, and 82.9 percent had SCA effects for the remaining values. Furthermore, the specific combining ability effects for GLS rating exhibited 35.7 percent of the hybrids had a SCA effect of 0.1 and -0.1. The greatest SCA effect (0.7) for GLS rating was showed by a hybrid line 6 x line 21. This cross, however, was followed by hybrids that had a SCA effect of 0.5. These crosses were line 1 x line 5 and line 21 x line 18. Other hybrids which also exhibited greater SCA effect (0.4) were crosses of line 2 x line 7, line 1 crossed with line 7, line 15 and line 21. Others were crosses of line 5 x line 9, line 4 x line 21, line 14 x line 8, line 18 x line 9 and finally line 13 x line12 respectively. While the lowest SCA effects (-0.5) was exhibited by line 16 x line 11. Crosses which also exhibited low SCA effects (-0.4) included hybrids of line 16 x line 2, line 11 x line 5 etc.

Table 6. Mean squares (MS) for all traits studied for the 225 hybrids across three locations and three seasons.

		MS						
Source of Variation	df	A	B	C	D	E	F	G
1.Locations	2	501708.56**	38345.77**	1991.88**	1329.86**	83.67**	978.20**	2564.03**
2.Seasons	2	194901.66**	4540.08**	2083.68**	3821.39**	69.43**	5953.78**	2383.20**
3.Season x Location	4	57802.46**	10909.34**	312.80**	1053.60**	12.70**	686.56**	220.77**
4. Reps (season x location)	12	4305.81**	179.34**	85.32^{NS}	59.35**	2.15^{NS}	186.27**	121.23^{NS}
5.Hybrids	224	1267.33**	64.24**	9.27**	23.65**	10.87**	114.82**	14.04**
6.Hybrid x Season	448	690.81*	39.11**	4.26**	10.52**	5.80**	55.47**	6.33**
7.Hybrid x Location	448	359.04*	24.24	2.12**	4.89**	1.93^{NS}	26.94^{NS}	2.42**
8.Hybrid x Season x Location	896	365.13*	23.44	2.33**	5.14**	1.91*	26.56**	2.26**
9. Pooled error	3654	319.05	16.49	1.40	3.87	1.75	22.59	1.72

*, ** Significant at the 5 % and 1 % level of probability respectively.
A = Ear height.
B = Days to 50% silking.
C = GLS score.
D = Ear length.
E = Number of rows/ear.

F = Number of kernels/row.
G = Yield (T/ha).

The combined analysis of variance (ANOVA) of all the 225 hybrids revealed statistical differences among the seven traits studied (Table 6). Location effects, however, were found in all the traits studied. The highest location effects were on ear height (s^2 = 501,708.56), followed by days to 50 % silking (s^2 = 38345.77), yield (s^2 = 2564.03), GLS disease (s^2 = 1991.88), ear length (s^2 = 1329.86), number of kernels/row (s^2 = 978.20) and lastly the number of rows/ear (s^2 = 83.67). The seasonal (year) effects on the traits also revealed similar trends as the effects of locations with the highest effects on ear height (s^2 = 194,901.66) and smallest effect on the number of rows/ear (s^2 = 69.43). The number of kernels/row (s^2 = 5953.78) was the second highest trait affected by seasonal weather conditions followed by days to 50 % silking (s^2= 4540.08), ear length (s^2 = 3821.39), yield (s^2 = 2383.20), GLS disease (s^2 = 2083.68) in that order. Furthermore, this research revealed that season by location effects were smallest on the number of rows/ear (s^2 = 12.70) but greater effect on ear height (s^2 = 57802.46), days to 50 % silking (s^2 = 10909.34), ear length (s^2 = 1053.60) and number of kernels/row (s^2 = 686.56). Season by location effects caused variations on GLS disease by a variance of 312.80 and on yield by a variance of 220.77 respectively.

This study also revealed that hybrids exhibited different trait responses. Maximum trait variability among the hybrids was on ear height (s^2 = 1267.33). While moderately trait differences of the crosses were on the number of kernels/row (s^2 = 114.82) and days to 50 % silking (s^2 = 64.24). Ear length (s^2 = 23.65), yield (s^2 = 14.04), number of rows/ear (s^2 = 10.87) and GLS disease (s^2 = 9.27), however, varied lowly among the hybrids. Ear height was highly affected by hybrid x season interactions. The number of kernels /row (s^2 = 55.47) and days to 50% silking (s^2 = 39.11) were moderately affected by the hybrid x season effects. The remaining traits such as GLS disease (s^2 = 4.26) and ear length (s^2 = 10.52) were lowly affected by the hybrids x season interactions. The hybrids across locations varied highly on ear height (s^2 = 359.04) and exhibited low variation on GLS disease (s^2 = 2.12), ear length (s^2 = 4.89) and yield (s^2 = 2.42). Days to 50 % silking, however, was moderately (s^2 = 24.24) affected by the hybrid x location effects. There were no effects of hybrid by location on number of rows/ear and number of kernels/row.

The three way interaction effects (hybrid x location x season) on individual traits exhibited that ear height (s^2 = 365.13) was the mostly affected trait. GLS disease (s^2 = 2.33) and yield (s^2 = 2.26) were equally affected by the three way interaction. The three way interaction caused lowest variation on number of rows/ear ($s^2 = 1.91$), but days to 50 % silking ($s^2 = 23.44$) and the number of kernels/row ($s^2 = 26.56$) were affected in the same magnitude by the interaction. Ear height ($s^2 = 5.14$) was lowly affected by the three way interaction.

Generally, results of this study showed that ear height was highly affected by locations, seasons, location x seasons, hybrids, hybrid x season, hybrid x location, hybrid x season x location than any other traits studied. But the number of rows/ear was least affected by these sources of variation. GLS disease and yield were also significantly affected by all the sources of variation as well as their interactions.

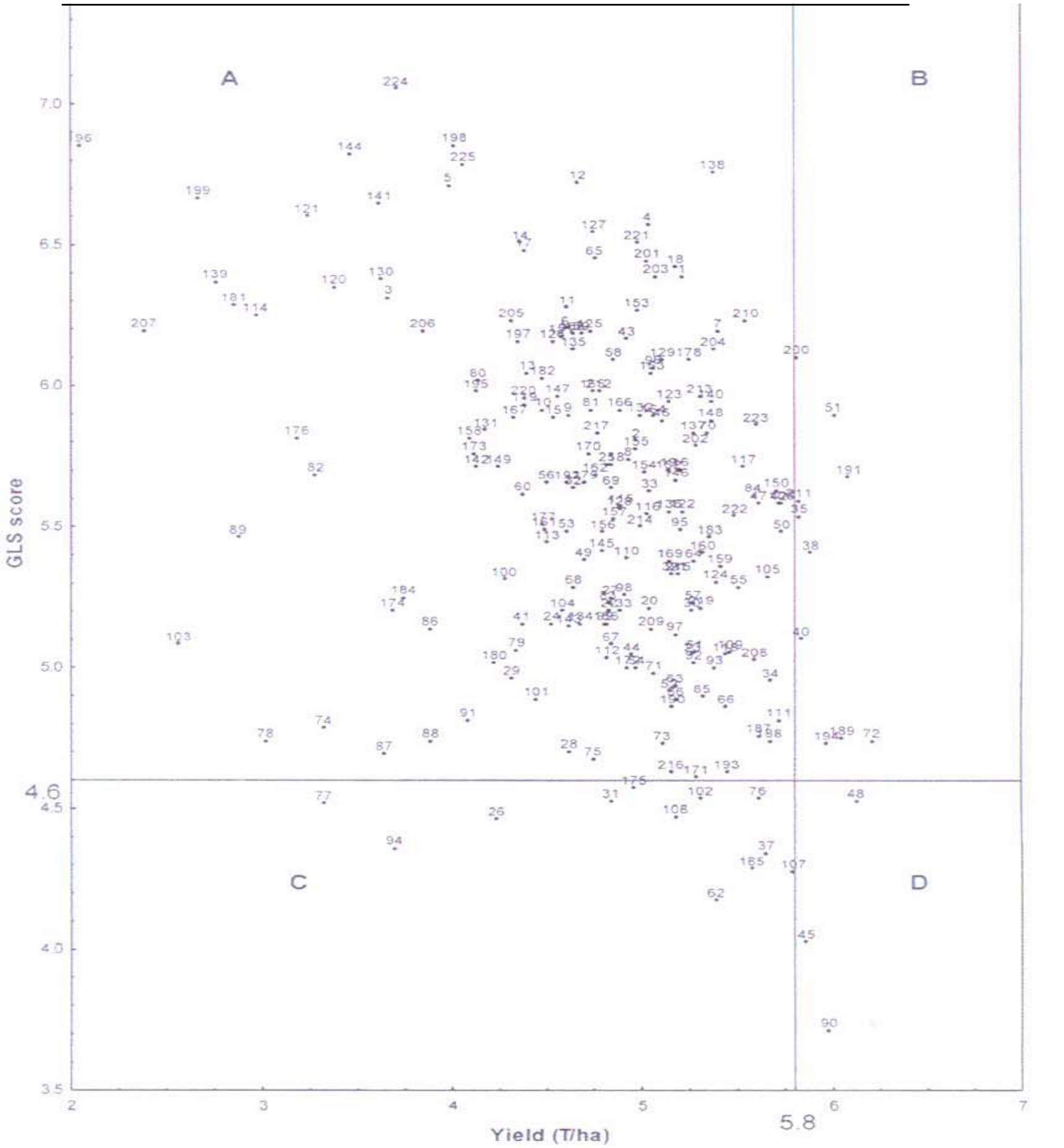
Table 7. Pairwise *p*-values for interaction effects among location x season on yield and GLS in this study.

	1	2	3	4	5	6	7	8	9	A
1	-	0.0133 *0.9955*	0.0022 *0.0371*	0.0001 *0.4209*	0.0280 *0.0379*	0.0001 *0.0003*	0.0001 *0.0001*	0.0001 *0.0547*	0.0001 *0.1020*	8/72 5/72
2	0.0133 *0.9955*	-	0.0001 *0.0375*	0.0001 *0.4240*	0.6932 *0.0383*	0.0001 *0.0003*	0.0001 *0.0001*	0.0001 *0.0541*	0.0001 *0.1030*	7/72 5/72
3	0.0022 *0.0371*	0.0001 *0.0375*	-	0.0120 *0.1567*	0.0001 *0.9909*	0.0001 *0.0204*	0.0001 *0.0001*	0.1399 *0.0008*	0.0001 *0.5769*	7/72 5/72
4	0.0001 *0.4209*	0.0001 *0.4240*	0.0120 *0.1567*	-	0.0001 *0.1596*	0.0026 *0.0013*	0.0339 *0.0001*	0.1946 *0.0119*	0.0008 *0.03670*	7/72 4/72
5	0.0280 *0.0379*	0.6932 *0.0383*	0.0001 *0.9909*	0.0001 *0.1596*	-	0.0001 *0.0200*	0.0001 *0.0001*	0.0001 *0.0008*	0.0001 *0.5846*	7/72 5/72
6	0.0001 *0.0003*	0.0001 *0.0003*	0.0001 *0.0204*	0.0026 *0.0013*	0.0001 *0.0200*	-	0.1863 *0.0001*	0.0002 *0.0001*	0.5324 *0.0071*	6/72 8/72
7	0.0001 *0.0001*	0.0001 *0.0001*	0.0002 *0.0001*	0.0339 *0.0001*	0.0001 *0.0001*	0.1863 *0.0001*	-	0.0027 *0.0003*	0.0635 *0.0001*	6/72 8/72
8	0.0001 *0.0547*	0.0001 *0.0541*	0.1399 *0.0008*	0.1946 *0.0119*	0.0001 *0.0008*	0.0002 *0.0001*	0.0027 *0.0003*	-	0.0001 *0.0021*	6/72 8/72
9	0.0001 *0.1020*	0.0001 *0.1030*	0.0001 *0.5769*	0.0008 *0.3670*	0.0001 *0.5846*	0.5324 *0.0071*	0.0635 *0.0001*	0.0001 *0.0021*	-	6/72 3/72

The Italicised are *p*-values for GLS respectively.
The 9 Environments or 9 location x seasons are:
1 =Uyole location year 2001season.
2 = Uyole location year 2002 season.
3 = Uyole location year 2003 season.
4 = Matanana location year 2001season.

5 = Matanana location year 2002 season.
6 =Matanana location year 2003 season.
7 =Nkundi location year 2001season.
8 = Nkundi location year 2002 season.
9 = Nkundi location year 2003 season.
A = % overall total significant effect of the season x location.

The pairwise *p*-values comparisons for the season x location interaction effects on yield and GLS are shown in Table 7. Research results revealed that the highest significant season x locations interaction effect (8/72) on maize yield was exhibited at Uyole site in the year 2001. While the lowest location x season interaction effect (6/72) on yield were exhibited at Matanana location in year 2003 and at Nkundi site from year 2001 to year 2003. The total location x season interaction effects on yield in this study was 60/72 (= 83.3 percent). The remaining location x season effects on yield was either 6/72 or 7/72, respectively. The level of gray leaf spot disease was significantly affected by season x location effects (8/72) at Matanana site in year 2003 and at Nkundi location in year the 2002. The lowest season x location effect on GLS disease (3/72) in the study period was at Nkundi in the year 2003. Matanana location in the year 2001 recorded relatively low (4/72) season x location effects on GLS. The other location x season interaction effects exhibited moderately low GLS effects (5/64) such as at Uyole site in all the three years of this experiment, and at Matanana location in the year 2002. The remaining location x season interactions recorded effects on GLS disease (6/72 or 7/72) which was also high. Generally, locations across all the three years of this study caused significant effects on GLS by 51/72 (= 70.8 percent), indicating that GLS disease severity is highly influenced by weather conditions and locations as well**.**



igure 5. 2. GLS score (Y-axis) and yield (X-axis) of 225 hybrids evaluated across thre
ocations and for three years in this study.

The distribution of hybrids with respect to yield (y-axis) and GLS scores (x-axis) is revealed in figure 2. The figure revealed that few hybrids recorded yields below 4T/ha and few crosses exhibited yields above 6T/ha. Also, few hybrids highly succumbed to GLS (rating of equal or more than 6.5) and few hybrids exhibited high level of GLS resistance. These hybrids which could be considered as moderately GLS resistant recorded GLS scores between 4.7 and 5.5, respectively. When considering both yield and GLS resistance as the most important agronomical traits for selecting commercial hybrids and using a 4.6 GLS score as a cut off point for GLS disease and 5.8 T/ha as a cut off point for grain yield, then this figure exhibited that hybrids 90, 48, and 45 are in the "D" quadrant. These hybrids could be considered as the top yielding and GLS resistant hybrids in this study. In Table 8 and student's t- test (data not shown) it is revealed that hybrid 90 recorded yield of 5.97, GLS score of 3.71, ranked number 6 (yield), and ranked number 1 (GLS resistance). This hybrid was statistically superior to 130 other experimental hybrids in terms of GLS disease resistance and 200 hybrids in terms of yield. Hybrid number 45 yielded 5.86, GLS score of 4.02, ranked number 2 (GLS resistance), ranked number 9 (yield) and differed with 123 hybrids in terms of GLS resistance and differed with 200 hybrids in yield respectively. Hybrid 48 (yield was 6.12, GLS score was 4.52) significantly differed from 56 other hybrids in terms of GLS sensitivity. Hybrid 48 ranked number 2 in terms of higher yield and ranked the 11.5 th among the GLS resistant hybrids. It differed with 200 hybrids in terms of yield. Furthermore, although not in the "D" quadrant (the highly GLS resistant and top yielding group) were hybrids 72 (yield 6.20), 189 (yield 6.04), 194 (yield 5.96) and 107 (yield 5.78). Their GLS scores were 4.74, 4.75 and 4.27 respectively. Hybrid 72 ranked number 1 (yield) and was number 26th in terms of GLS resistance. Therefore, generally, hybrids 90, 45 and 48 were commercially the best in this study. These were followed by hybrids 72, 189 and 107 which also had superior performances in terms of yield and GLS resistance. Finally, results (Table 8 and or figure 2) revealed that the highest GLS susceptible crosses were hybrids 224 (GLS = 7.05), hybrid 198 (GLS = 6.85), hybrid 196 (GLS = 6.82) and hybrid 144 (GLS = 6.86). While hybrid 90 (GLS = 3.71), hybrid 45 (GLS = 4.02), hybrid 62 (GLS = 4.17) and hybrid 107 (GLS = 4.27) were the most GLS resistant hybrids in this study. Likewise, in terms of grain yield hybrids 196 (yield = 2.04T/ha), hybrid 207 (yield = 2. 38T/ha), hybrid 103 (yield = 2.56T/ha) and hybrid 199 (yield = 2.66T/ha) exhibited lowest yields. While Hybrids numbers 72, 48, 189, 90 and 45 recorded the highest yields.

Table 8. The important agronomic traits of the top 4 hybrids in this study as compared to the lowest/highest trait hybrid performers.

Hybrid	Yield (T/ha)	GLS score	50 % silking	Ear length	Rows/ear	Kernels/row	GLS SD	GLS %CV	Yield SD	Yield %CV	Rank Yield	Rank GLS
72	6.20	4.74	90.22	19.50	14.14	42.25	1.88	30.82	2.43	31.26	1.00	26.00
48	6.12	4.52	93.22	19.02	13.77	40.77	1.71	33.95	1.67	27.35	2.00	11.50
90	5.97	3.71	95.00	19.16	13.04	39.62	1.72	46.41	2.70	45.33	6.00	1.00
45	5.86	4.02	93.22	18.78	14.00	41.25	1.39	34.52	2.05	35.12	9.00	2.00
189	6.04	4.75	92.11	18.80	13.70	41.96	2.35	49.00	2.26	37.44	4	28
194	5.96	4.73	91.96	19.14	13.62	42.14	2.60	55.04	2.86	47.00	7	22.5
107	5.78	4.27	73.92	18.60	13.62	40.70	1.24	29.00	2.20	38.00	14	4
highest	6.20	7.05	97.00	21.21	15.04	44.25	2.58	55.04	2.81	93.60	-	-
Lowest	2.04	3.71	88.04	12.75	11.40	28.55	1.21	26.17	1.37	27.35	-	-

Discussion

Phenotypic associations between different traits studied varied from r = 0.02 to r = 0.60. The correlation coefficients revealed that some traits are highly correlated to each other while others are not. Such information indicates the interrelated stability performance between traits across environments (Snedecor and Cochran, 1967, Steel and Torrie, 1980). Thus significant positive trait correlations can be used to select genotypes with several desirable traits concurrently and hence save time and money. For example, maize yield could be increased by selecting for long ears, more kernels/row, more rows/ear, planting GLS resistant varieties etc. The genetic cause of correlation is chiefly pleiotropy which is simply the property of a gene whereby it affects two or more characters so that if the gene is segregating it causes simultaneous variation in the characters it affects, though linkage is a cause of transient correlation particularly in populations derived from crosses between divergent strains (Falconer and Mackay, 1996). For example, Freymark *et al.,* 1993 reported that chromosomes 2, 4 and 8 had at least one marker with some resistance to *Setosphaeria turcica* at p = 0.05, and have also genes for GLS resistance (Bubeck *et* *al*., 1993). These genes appear to belong to a resistant gene cluster since *Setosphaeria turcica per se* does not contribute to GLS resistance.

Different yield loses have been reported due to GLS disease. For example, Ward *et al.,* 1997 observed that GLS reduced maize yield between 30 and 60 percent. Donahue *et al.* (1991) documented loss due to GLS to be 10-25 percent in endemic areas and Verma (2001) reported yield losses due to GLS between 28 and 54 percent. Results in this study revealed that yield is statistically reduced by GLS disease (r = - 0.34). These significant reductions of maize yield due to GLS disease are in line with the findings of Tembo and Pixley, (1999) who reported that GLS became important in the southern and eastern Africa region, where the incidence and severity of GLS epidemics have been increasing. Hence management of GLS disease in Tanzania is inevitable for increased and sustained high maize production.

Research results revealed that Uyole and Nkundi sites had higher associations for both yield and GLS scores (Table 3). This could indicate that these two sites might have similar environmental conditions. These observations are in line with those of Ramon Rea and De Sousa (2002) who reported that sugar cane clones evaluated across six sites had high pairwise correlations (r > 0.60) and their highest correlation was between Turbio and Matilde locations (0.82) in Venezuela. These results may help breeders to avoid testing new genotypes in inappropriate environments which have site correlations that are too low with respect to GLS disease. Selection of testing sites should be based on group of locations in which relative genotypic performance is similar and place locations in which relative genotypic performance differs into discrete clusters. One way is to calculate the distance between two environments based on performance data of a common set of genotypes (Bernardo, 2002). Finally, this study revealed that Matanana site had lower associations with other two sites for both grain yield and GLS score. This implies that Matanana location might have some different environmental factors that have greater impact on yield and GLS disease.

The general combing ability effects for gray leaf spot disease rating and grain yield (kg/ha) revealed that inbreds P62145, P621621, and P621321 were the three lines with the lowest GCA effects (shown by negative values) for GLS rating and produced good yields (shown by a positive GCA effects) as revealed in Table 4. These lines with the lowest negative GCA effects for GLS rating are classified as highly GLS resistant inbreds (Donahue *et al*., 1991; Gevers and Lake, 1994). Such lines can be used to introgress GLS resistant QTLs (as donors) to those inbreds that have good combining ability but do succumb to GLS. Also lines P627733, K5301482, K3758L36 and P62148 exhibited negative GCA effects for GLS rating indicating good level of resistance. Based on the GCA effects for the rating, the latter lines are expected to produce high to moderately GLS resistant hybrids when crossed. Using different maize lines, similar low negative values of GCA effects for GLS rating have been reported in other studies (Donahue *et al*., 1991; Thompson *et al*., 1987; Huff *et al*., 1988; Elwinger *et al*., 1990). Inbred lines with the GCA effects for GLS rating of zero exhibited intermediate GLS resistance. While those lines with highly positive GCA effects (e.g. line P62103) were classified as GLS susceptible lines (Donahue *et al*., 1991). The susceptible lines had low frequency of genes for GLS resistance (Gevers and Lake, 1994). The GCA effects for grain yield in some lines were negative indicating poor combing ability. These research results of GCA effects are similar to those of Donahue *et al*. (1991) who reported that some lines in the diallel crossing exhibited high, intermediate and low GCA effects for GLS rating as well as for grain yields.

Computations of inbred genetic variations based on GCA effects for GLS rating revealed that maize lines in the SHT reacted differently to the GLS pathogen. The GCA effects for GLS rating showed that the resistance to GLS is of additive nature. This is because large GCA effects for GLS rating indicated the presence of additive inheritance (Griffing, 1956; Nakawuka and Adipala, 1997). Furthermore, due to the additive nature of the GLS resistance, inbreds insensitive to GLS in the segregating populations could be selected for during inbreeding process especially from Population 62 of which most of the P62 lines were developed. These lines could then be used to produce GLS resistant hybrids for commercial use.

The SCA effects reflects the deviation of a cross from its expected performance (based on GCA effects) as documented by Olunju *et al*., 1990; Olurunju *et al*., 1992). In this study, however, the hybrid with the greatest SCA effects for GLS rating (line 6 x line 21) revealed a positive SCA effect for GLS rating. This positive effect indicated both of these lines may have the same resistant genes and not able to take the advantage of additive gene action (Donahue *et al*., 1991). Similar to this the SCA effect in fact suggests the presence of dominant or major gene action (Nakawuka *et al*., 1997). Generally the SCA effects for GLS rating of the diallel crosses differed significantly in their GLS disease ratings. The GCA effects for GLS rating (Table 4) of inbreds were accurately reflected in their crosses. For example crosses of line 18 x line 21, line 12 x line 13, line 1 x line 15 etc produced highly GLS resistant hybrids (Table 5). Combinations of line 6 x line 8, line 15 x line 3, line 13 x line 20 etc were moderately resistant. As expected, the crosses of line 14 x line 11, line 2 x line 16, line 11 x line 16 etc succumbed to GLS. But certain combinations of lines such as line 19 x line 5, line 11 x line 5, line 19 x line 20, line 13 x 15, line 9 x line 13, line 8 x line 14 etc exhibited SCA effects which were significantly better or worse than would be expected on the basis of their general combining ability. Similar findings were reported by Gevers and Lake (1994). Also, Verma (2001) in his findings documented that the performance of hybrids generally agreed with the GCA effects of lines but the relationship was not strong as there were several resistant hybrids whose parents were susceptible with low GCA effects. This implies that GCA effects alone is not sufficient to predict the performance of hybrids (Verma 2001). Tables 4 and 5 showed that both additive and non additive gene actions are important for GLS resistance in maize. The high positive SCA effects for GLS rating which indicates the presence of dominant gene means that such resistance gene can be fixed in commercial hybrid production.

It has been reported that variation in GLS severity among locations is a common phenomenon (Carson *et al.,* 1997) and is most frequently attributed to environmental conditions and tillage practices (Ward *et al.,* 1997). Results in this study showed that some hybrids exhibited mild GLS infections at Uyole and Nkundi, but the same hybrids exhibited higher infection rates at Matanana area. This observation is similar with that of Bubeck *et al.* (1993) who reported that variation in GLS severity may be due to differential sensitivities of maize genotypes to environmental conditions since the quantitative trait loci (QTLs) effects associated with GLS resistance are inconsistent over environments. The other reason could be due to presence of a more virulent GLS pathotype at Matanana location. This observation may need further research to confirm its validity since there have been reports of the existence of sexual reproductive structures like spermagonia and their role, if any, is still debatable (Saghai Maroof *et al.,* 1996; Latterell and Rossi, 1983). Sexual reproduction and mutations could also lead to the occurrence of new GLS pathotype.

It is documented that in variety trial experiments conducted across years and locations, in general, genotype x year effects has larger effects than genotype x environment to these experiments (Simmonds and Smartt, 1999), although both were observed to be nearly equivalent for switchgrass biomass yield (Hopkins *et al*., 1995). The combined analyses of variance in this study revealed a significant location effects, season effects, genotype effects, season x location effects and genotype x environment (hybrid x location, hybrid x seasons and hybrid x location x seasons) interaction effects. Similar results of G x E effects were observed on GLS disease in maize (Bubeck *et al*., 1993; Carson *et al.,* 1997;

Donahue *et al*., 1991). These G x E interactions were due to weather conditions that were favourable for GLS disease development, which varied during the three crop growing seasons of this study (weather data not shown). The 2001/2002 season was highly favourable for the disease especially during the vegetative growth stages up to the "milk stage". During 2002/2003, however, weather conditions at the vegetative stage was dry, but unexpected late rains which were associated with overcast days for two weeks and high relative humidity that came in after flowering stage favoured the development of GLS disease. In contrast, 2003/2004 was hot and dry during the vegetative stage and even after flowering. So the 2003/2004 season was completely unfavourable for GLS development. Thus during the three years of this research, the weather conditions were so variable to cause significant G x E interaction effects as revealed by statistical analyses (Tables 6 and 7). These results are important to breeders in the sense that small weather changes within a season and at any crop stage can cause a significant G x E effects on weather sensitive traits like GLS and yield which depend on the level of GLS infection and the level of genetic resistance of the varieties to the GLS pathogen. Also, results of this research regarding G x E interaction (Table 6 and 7) are in line with the observations reported by Sallah *et al*. (2004) when working on genotype x environment interaction in three maturity groups of maize cultivars documented that genotype x location x year interaction could significantly ($p = 0.01$) affect grain yield in three maturity group of maize. They also observed that genotype x year and genotype x location interaction were also significant in the intermediate and late maturity groups.

Results in Table 8 and figure 2 revealed that there was a continuous distribution of the hybrids tested to GLS disease and to yield responses but with little transgressive segregation. The highest GLS susceptible hybrids were hybrids 224, hybrid 198, hybrid 196 and hybrid 144. While hybrid 90, hybrid 45, hybrid 62 and hybrid 107 were the most GLS resistant hybrids in this study. Likewise, in terms of grain yield the transgressive segregates were the hybrids 196, hybrid 207, hybrid 103 and hybrid 199. The latter hybrids revealed lowest yields because they severely succumbed to the GLS pathogen as they lacked the genetic resistance to this disease. Results of hybrids that are highly susceptible to GLS were also reported by Verma (2001). Hybrids with low GLS resistance revealed low general combining ability effect (for yield) because of non additivity (Verma, 2001, Vivek *et al*., 2001). Furthermore, in Table 8 and figure 2, the hybrids 48, 45, and 90 could be recommended for the release as they exhibited outstanding agronomical performances such as consistently low average GLS scores across years and locations, ranked best in terms of GLS resistance and out yielded other hybrids. Hybrids such as 72, 189 and 107 also showed commercial agricultural values. These could be regarded as moderately resistant hybrids as they produced higher yields in the presence of the GLS pathogen. They can be released as commercial hybrid varieties well.

Conclusions

Evaluations based on field data in multienvironments provide useful information to determine adaptability and stability of new varieties. It also provides knowledge of the magnitude and cause of environmental effects in maize breeding programs. Statistical analyses in this study revealed that hybrids 48, 45 and 90 were the most resistant and top yielding in this study. Also, hybrids 72, 189 and 107 exhibited higher yields and were moderately resistant to the GLS pathogen. Thus, hybrids 48, 45, 90 and even 72, 189 and 107 could be used for commercial production in the Southern highlands of Tanzania. Alternatively, the last three hybrids could be recombined to make other types of GLS resistant hybrids like modified single crosses, three way crosses, double crosses, open pollinated populations etc in order to create genetically diverse hybrids against GLS breakdown of hybrids which might happen due to appearance of new races of the GLS pathogen. Finally, this study suggests that similar and careful emphases should be placed on sampling locations where by varieties must be grown in an adequate number which are truly representative of the full range of possible environmental conditions. Selection of sites for testing new varieties across environments should be based on locations that are clearly different in terms of altitude, vegetation, temperature, soil type, rainfall etc. One way to achieve this is to calculate the distance between two environments based on the performance data of a common set of genotypes as suggested by Bernardo, (2002). Breeders and agronomists should recommend to farmers new agricultural production alternatives (varieties, plant density etc) that are stable under different environmental conditions so as to minimize the risk of falling below a certain yield level.

Lastly, this research based on GCA and SCA effects for GLS rating, it would be stated that GLS resistance is of additive and non additive gene action. This implies that it is possible to select GLS resistant lines in an inbred line inbreeding program. These resistant lines could be used as donor parents for GLS resistant genes to those lines that have good combining ability for yield like P62103 but highly susceptible to GLS. Many lines derived from population 62 have high level of GLS resistance. So it is evident that Population 62 has a potential of producing many GLS resistance lines for commercial hybrid production. Also open pollinated varieties such as synthetics/composites/doubled haploid hybrids etc would be developed by using these GLS resistant inbreds. Molecular markers linked to GLS resistant genes can be developed which could be used with phenotypic data to increase the efficacy of selecting GLS resistant maize varieties.

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