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Adaptability and genotype by environment interaction of maize commercial hybrid varieties from East African seed companies in Rwandan environments

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Abstract: Maize (Zea mays L.) has known an unprecedented development for the past six years in Rwanda. *The major factor behind this great achievement was the Crop Intensification Program (CIP). However maize hybrid varieties had little impact on maize production increase because they were not available. Therefore, this study was undertaken to assess the adaptability of maize commercial varieties from East African seed companies in Rwanda and to identify those to* be used to increase maize production. *Fourteen commercial hybrids, four hybrid cultivars released in Rwanda and five Open Pollinated Varieties (OPVs) were evaluated in four sites of mi-altitudes (18 entries) and four sites of highlands (10 entries).* Results showed that RHM104, PAN53, PAN67, WH507, WH505, WH403 and RHM101 in mid-altitudes and H629, SC719, SC637, PAN691 and WH504 in highlands were high yielding and stable across environments. They were recommended to be used in Rwanda.

Key words: AMMI, Commercial varieties, Grain yield, Highlands, Mid-altitudes, Rwanda

INTRODUCTION

Maize (*Zea mays* L.) has become a leading crop in agriculture production and ranks first among pulse and grain crop production in Rwanda. It has known an unprecedented development and radical changes in the past seven years so that the national production in has increased from 96,662 t in 2006 to 525,679 t in 2011 (NISR, 2012). The most significant factor behind maize production increase was the introduction and implementation of Crop Intensification Program (CIP) in 2006 (Kathiresan, 2011). Other important factors behind this production increase also include the changes in cropping systems, changes in policies (Bizoza and Byishimo, 2013) and availability of markets at national and regional levels (FAO, 2013).

Maize, traditionally grown in highlands (Ngaboyisonga, 2004) is currently intensively cultivated in the whole country from altitudes of 900 masl in Bugarama to 3000 masl in the shores of volcanoes. The major production constraints include frequent drought especially in the East of the country, low soil fertility especially nitrogen and phosphorus deficiencies, soil acidity especially in volcanic highlands, very long growing cycle in the highlands, infestations by Maize Streak Virus (MSV), *Turcicum* Leaf Blight (TLB) diseases, *Striga* spp in Eastern and Southern zones of the country. New disease outbreaks of Maize Lethal Necrosis (MLN) (Adams et al., 2014), Grey Leaf Spot (GLS) (Okori et al., 2004) and Phaeospharea Leaf Spot (PLS) (Carson, 2005) are very serious threats to maize production in Rwanda. Farmers utilize only maize Open Pollinated Varieties (OPVs) especially the variety Kigega (ZM607) released in 2002 (Ngaboyisonga, 2003) and Tamira (Pool 9a) released in 1990s (Ngaboyisonga and Ndayire, 1999). The objective of this study was to select, among maize hybrid and commercial varieties commonly grown in Eastern Africa region, these adapted to Rwandan environments. The selected varieties will be used to substantially increase maize production. This study is the first to use AMMI model to analyze the interaction of maize genotypes with environments and to select adapted and stable varieties in Rwanda. It is the first to report the outbreak of Grey Leaf Spot disease in Rwanda.

Materials and methods

Fourteen commercial hybrid maize varieties commonly grown in East Africa countries from four seed companies, four hybrid cultivars released in Rwanda in 2011 and five Open Pollinated Varieties (OPVs) commonly grown were used in this study. They were classified in two groups: 18 varieties for mid-altitudes (Table 1) and 10 varieties for highlands (Table 2). The 18 varieties of mid-altitudes were evaluated in four sites: Rubona, Nyagatare, Karama and Bugarama (Table 3) in the seasons 2012-A, 2012-B and 2013-A hence making twelve evaluation environments (site × season). However only nine environments were achieved because the three remaining environments (Bugarama 2013-A, Rubona 2012-A, Rubona 2013-A) trials were destroyed by a drought. Moreover, the ten varieties of the highlands were also tested in four sites: Musanze, Kinigi, Rwerere and Tamira (Table 3) in

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the seasons 2012-A and 2013-A, hence making eight evaluation environments. However, only six environments were achieved because trials at Tamira-2012A and Kinigi-2013A were destroyed during the experimentation.

The experimental design was alpha-lattice (0,1) but it was analyzed as Randomized Complete Block Design (RCBD). A plot was made by three rows of 5-m length with a distance between rows of 0.75 m and a distance between hills of 0.25 m while planting was performed by two grains per hill followed by a thinning at one plant/hill three weeks after planting. Fertilizers were applied at rates of 51 kg/ha N, 51 kg/ha P_2O_5 and 51 kg/ha K_2O before planting,. Six weeks after planting, 46 kg/ha N using urea (46-0-0) were applied at a rate of 100 kg/ha. Water was supplied by rain, while weeding was performed as it was needed.

Table 1: Varieties from East African seed companies evaluated in mid-altitudes of Rwanda

No	Code	Name	Type	Seed Company
1	V01	PAN63	Hybrid Variety	PANNAR Seed
2	V02	PAN53	Hybrid Variety	PANNAR Seed
3	V03	PAN67	Hybrid Variety	PANNAR Seed
4	V04	WH504	Hybrid Variety	Western Seed Company Ltd
5	V05	WH505	Hybrid Variety	Western Seed Company Ltd
6	V06	WH507	Hybrid Variety	Western Seed Company Ltd
7	V07	WH403	Hybrid Variety	Western Seed Company Ltd
8	V08	WH105	Hybrid Variety	Western Seed Company Ltd
9	V09	SC637	Hybrid Variety	Seed Co
10	V10	SC403	Hybrid Variety	Seed Co
11	V11	SC513	Hybrid Variety	Seed Co
12	V12	RHM102	Hybrid Variety	Rwanda Agriculture Board (RAB)
13	V13	RHM103	Hybrid Variety	Rwanda Agriculture Board (RAB)
14	V14	Kigega	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
15	V15	ISARM101	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
16	V16	ISARM102	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
17	V17	RHM101	Hybrid Variety	Rwanda Agriculture Board (RAB)
18	V18	RHM104	Hybrid Variety	Rwanda Agriculture Board (RAB)

Table 2: Varieties from East African seed companies evaluated in highlands of Rwanda

No	Code	Name	Type	Seed Company
1	V01	PAN691	Hybrid variety	PANNAR Seed
2	V02	WH504	Hybrid variety	Western Seed Company Ltd
3	V03	WH505	Hybrid variety	Western Seed Company Ltd
4	V04	WH507	Hybrid variety	Western Seed Company Ltd
5	V05	SC719	Hybrid variety	Seed Co
6	V06	SC637	Hybrid variety	Seed Co
7	V07	Tamira	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
8	V08	ISARH071	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
9	V09	Ndaruhutse	Open Pollinated Variety	Rwanda Agriculture Board (RAB)
10	V10	H629	Hybrid variety	Kenya Seed Company Ltd

Grain yield (t/ha at 15 % grain moisture) was the trait recorded in all trials. Grain yields were obtained by weighing the total number of ears harvested in a plot and obtaining the fresh weight in kg (FW). At the same time, a sample of kernels was taken and used to determine the grain moisture in % (GM) using a portable moisture-meter. Ears were thereafter dried and weighted to have the dry weight (DW) in kg and then shelled to obtain the grain weight (GW) in kg. Taking A as the distance (in m) between rows and B the distance (in m) between hills at planting, C the row length (in m) at harvest and D the number of rows harvested, grain yield (GD) in t/ha at 15% of grain moisture was obtained by the following formula: $GY = 10 \times \frac{FW}{A \times (B + C) \times D} \times \frac{100 - GM}{100 - 15} \times \frac{GW}{DW}$.

The AMMI (Additive Main effects and Multiplicative Interactions) model was used to analyze data. The AMMI analysis of variance was performed using Genstat statistical computer package, Discovery Edition (Buysse et al., 2007) whereas AMMI1 biplots were constructed using the Excell spreadsheet.

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Table 3: Characteristics of evaluation sites

Sites	LON	LAT	ALT (m)	PRE (mmy^{-1})	AAT (°C)	Stresses
Rubona	29°46E	2°29S	1650	1180	18.7	Foliar diseases: moderate attacks of Turcicum Leaf Blight (TLB) and Maize Streak Virus (MSV) diseases , drought occurs occasionally
Bugarama	29°00E	2°28S	900	1000	28.0	Foliar diseases: hot spot of MSV, presence of TLB, drought occurs occasionally
Nyagatare-Cyabayaga	30°20E	1°20S	1450	830	22.4	Foliar diseases: hot spot of TLB and Grey Leaf Spot (GLS) diseases, drought occurs frequently
Karama	30°16E	2°17S	1350	810	20.8	Foliar diseases: moderate attacks of MSV and TLB, drought is very frequent
Tamira	29°21E	1°34S	2400	1234	13.0	Long cycle, frost, diseases
Kinigi	29°35E	1°27S	2200	1575	15.0	Long cycle, diseases
Musanze	29°37E	1°30S	1850	1350	16.0	Long cycle, diseases
Rwerere	29°53E	1°32S	2025	1371	15.3	Long cycle, diseases, pests

LON: Longitude LAT: Latitude AL: Altitude
PRE: Precipitation AAT: Average Annual Temperature

RESULTS

In mid-altitudes, the AMMI analysis of variance (Table 4) showed that variations due to genotypes, environments and GEI were highly significant ($p<0.01$). The genotype effects accounted for 18.4 % of the treatment Sums Squares (SS), environments 66.1 % while GEI explained only 15.5 %. The AMMI 1 biplot (Figure 1) indicated that the varieties: PAN53 (V02), PAN67 (V03), WH505 (V05), WH507 (V06), RHM101 (V17) and RHM104 (V18) were high yielding (grain yield > overall mean) and had IPCA1 scores between -0.5 and +0.5. Furthermore these varieties (excluded RHM108) formed a cluster. In fact, the variety RHM104 (V18) was the highest yield (mean > 8t/ha).

The AMMI1 further showed that seasons A (E3, E4, E7) were high yielding (means > 7.6 t/ha) than their counterpart seasons B (E2, E5, E8 and E9) (means < 6.3 t/ha) except the environment E1 (Nyagatare-2012 A) which was among the lowest yielding environments. At Nyagatare-Cyabayaga in 2012 A (E1), there was an outbreak of GLS that reduced significantly the grain yield of the varieties up to 4 t/ha on average. The regression coefficient was negative and high significant (P<0.001) indicating that grain yields significantly decreased when the severity of GLS increased (Figure 2).

In highlands, the AMMI analysis of variance (Table 5) showed that the variation due to genotypes, environments and GEI were highly significant (p<0.01). The genotype effects explained 13.4 % of the treatment SS, environments 75.5 % and GEI 11.2 %. The AMMI1 biplot showed that the varieties: H629, SC719, SC637 and PAN691 formed a cluster and had means superior to overall mean (5.4 t/ha) and had IPCA1 scores approximately equal to + 0.6. Furthermore, the variety WH504 had also high men (grain yield >5.7) but it was located in opposite position with the cluster. Besides, it further indicated that Musanze was the highest yield (grain yield > 6.8 t/ha) whereas Tamira was the lowest yielding site (grain yield<3.0 t/ha).

Table 4: AMMI analysis of variance for grain yield in mid-altitudes

Sources of variation	DF	SS	MS	F	P
Total	485	2421.7	4.99	-	-
Treatments	161	2012	12.50	10.88	<0.001
Genotypes	17	369.9	21.76	18.94	<0.001
Environments	8	1330.5	166.31	51.46	<0.001
Environments/Replications	18	58.2	3.23	2.81	<0.001
Environments × Genotypes	136	311.6	2.29	1.99	<0.001
IPCA1	24	102	4.25	3.70	<0.001
IPCA2	22	68.3	3.11	2.70	<0.001
IPCA3	20	63.5	3.17	2.76	<0.001
IPCA4	18	29.6	1.65	1.43	0.115
Residuals	52	48.1	0.93	0.81	0.826
Error	306	351.6	1.15	-	-

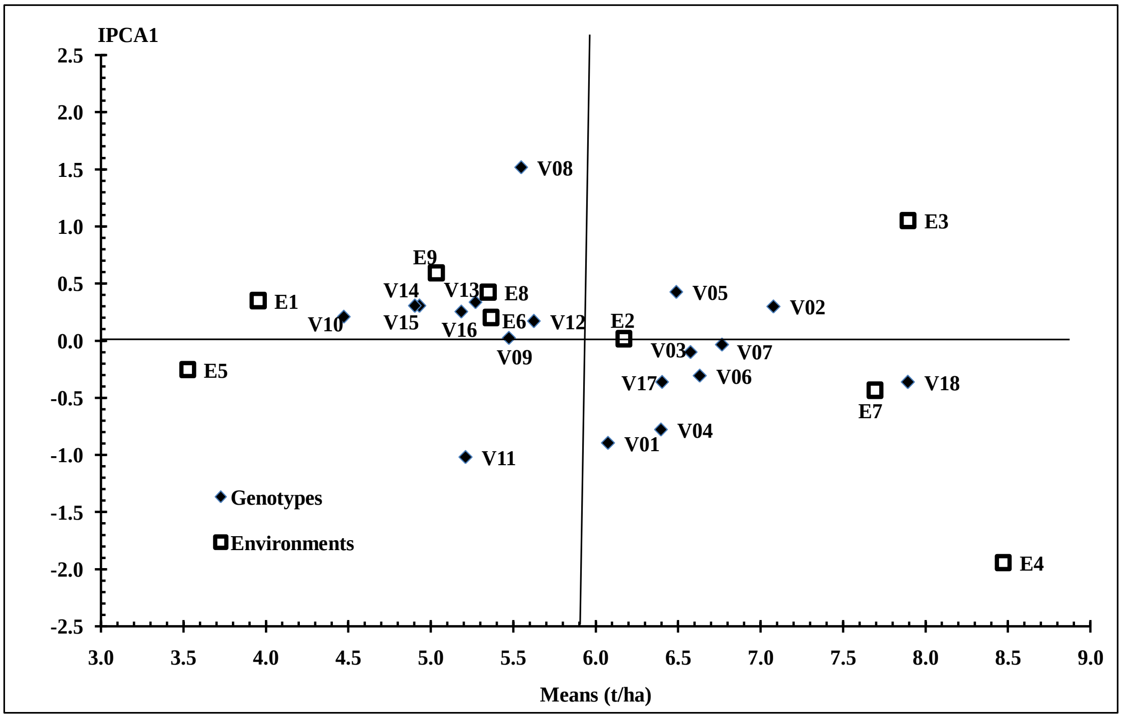
Table 5: AMMI analysis of variance for grain yield in highlands

Sources of variation	DF	SS	MS	F	P
Total	179	1040.6	5.81	-	-
Treatments	59	882.3	14.95	11.60	<0.001
Genotypes	9	117.9	13.10	10.16	<0.001
Environments	5	665.9	133.18	83.62	<0.001
Environments/Replications	12	19.1	1.59	1.24	0.269
Environments × Genotypes	45	98.5	2.19	1.70	0.014
IPCA1	13	56.9	4.38	3.40	0.000
IPCA2	11	22.1	2.00	1.56	0.123
Residuals	21	19.5	0.93	0.72	0.803
Error	108	139.2	1.29	-	-

DISCUSSION

In AMMI analysis of variance, the treatment variation is subdivided into three types of variations (variation due to genotyps main effects, variation due to environment main effects and variation due to GEI effects). These three types of variations pertain different opportunities: the genotype variation pertains to broad adaptations, the GEI variation is related to narrow adaptations while genotypes and GEI variations jointly determine mega-environments (Gauch, 2006). The variation due to environments was approximately two times larger than that of genotypes together with that of GEI in mid-altitudes three times larger in highlands indicating that environments were very diverse and effects due to individual environments were far important than that of mega-environments. Furthermore, broad adaptation was slightly important than narrow adaptation implying that varieties had tendency to be broadly adapted than to be adapted to specific environments. Several studies on various crops including maize indicated that environment variation was important than the two other components (Bayene et al., 2011; Mukherjee et al., 2013; Sadeghi et al., 2011 and Zhe et al., 2010). Also cases where either genotype or GEI variation was important have been frequently reported (Ananda et al., 2009; Arulselvi and Selvi, 2010).

In AMMI 1 biplot, the usual interpretation is that displacements along the abscissa indicate differences in main effects, whereas displacements along the ordinate indicate differences in interaction effects. If a genotype has high mean (mean > overall mean) and an IPCA1 score closer to zero (near the abscissa), it is considered as stable across environments (Yan et al., 2007). In mid-altitudes, the varieties: RHM104, PAN53, PAN67, WH507, WH505, WH403 and RHM101 had high grain yield means and were very closer to IPCA1 axis hence they were stable across environments whereas in highlands varieties: H629, SC719, SC637, PAN691 and WH504 had high grain yield means and were relatively close to IPCA 1 axis and hence they were also relatively stable across environments (Gauch, 2006; Yan et al., 2007).



E1=Nyagatare-2012A E2=Nyagatare-2012B E3=Nyagatare-2013A
E4=Karama-2012A E5=Nyagatre-2012B E6=Karama-2013A
E7=Bugarama-2012A E8=Bugarama-2012B E9=Rubona-2012B

Figure 1: Biplot of grain yield obtained by plotting the means (t/ha) against IPCA1 [(t/ha)$^{0.5}$] for 18 varieties evaluated in nine environments in mid-altitudes of Rwanda

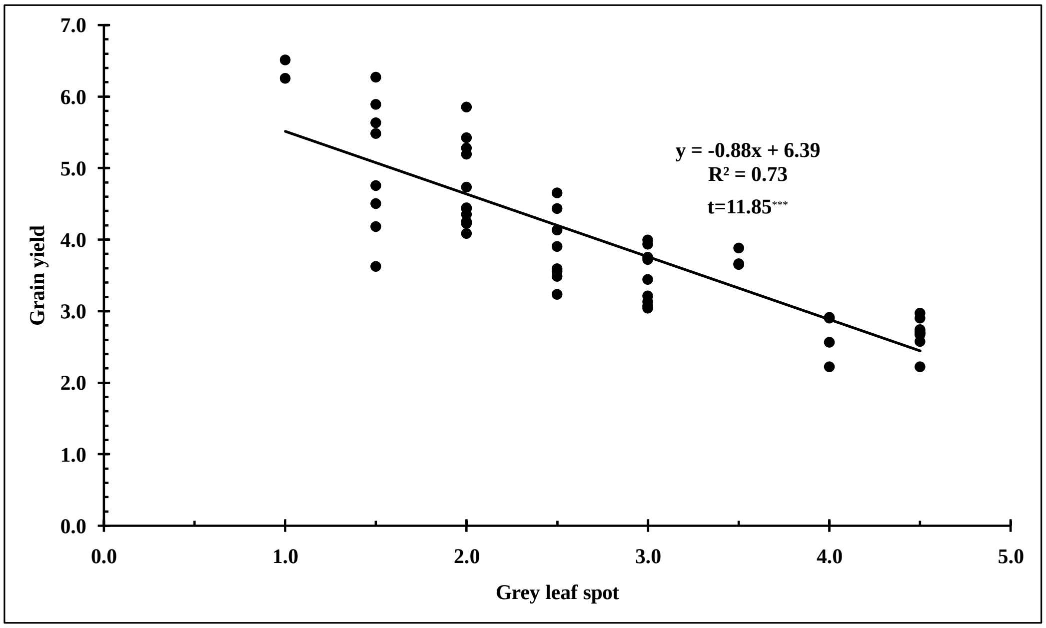


Figure 2: Regression of Grey Leaf Spot (GLS) severity onto grain yield

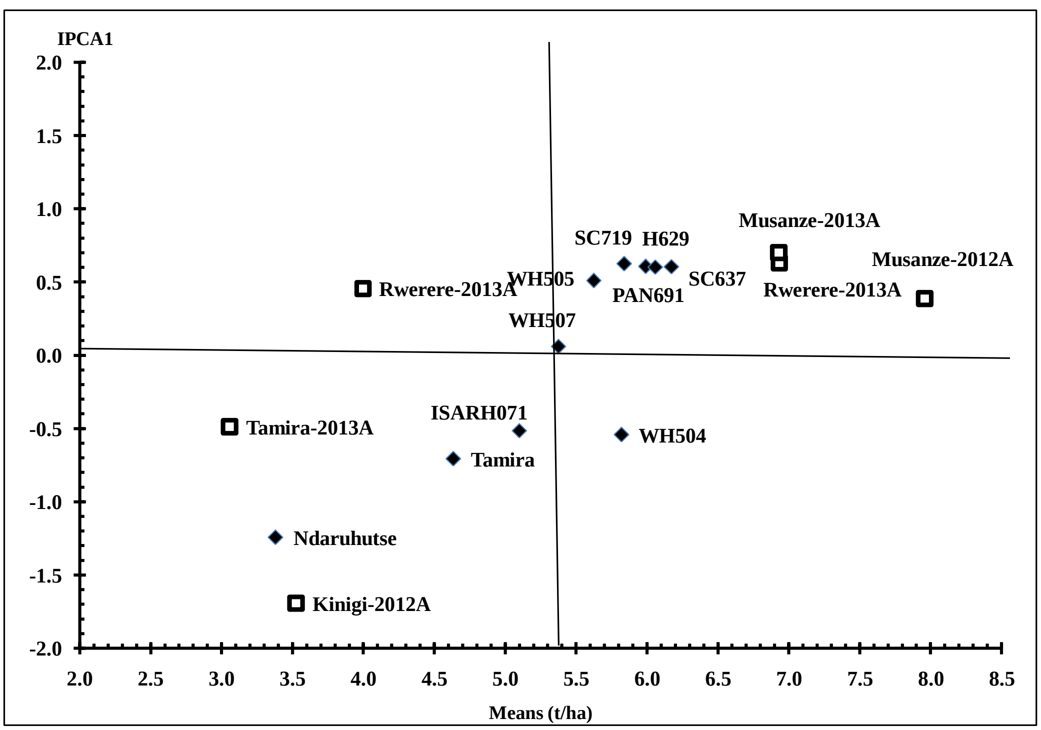


Figure 3: Biplot of grain yield obtained by plotting the means (t/ha) against IPCA1 [(t/ha)$^{0.5}$] for 18 varieties evaluated in nine environments in highlands of Rwanda

In this study, it has been shown that an outbreak of GLS occurred and reduced the performance of varieties causing the yield reduction of 49.9 % compared to Nyagatare-2012 B and Nyagatare-2013 A. Usually, yield losses between 30 % to 60 % under GLS infestation have been constantly observed (Okori et al., 2004).
There are other models used to study the Genotype × Environment interaction (Yan and Thinker, 2006) and the debate on the effectiveness of one model over another is underway (Gauch, 2006; Yan et al., 2007). However, it seems that AMM1 families are more effective as they incorporate the concept of high yielding genotypes in the stability analysis (Gauch et al., 2008).

CONCLUSIONS

Results indicated that environments were diverse and broad adaptation of maize varieties was slightly important than narrow adaptation. They further showed that RHM104, PAN53, PAN67, WH507, WH403, WH505 and RHM101 in mid-altitudes and H629, SC719, SC637, PAN691 and WH504 in highlands, were stable across environments and therefore they could be utilized in Rwandan environments to increase maize production. Furthermore they showed that maize varieties are high yielding in the season A than in the season B, except when an unusual stress occurs as it happened at Nyagatare in 2012 A with an outbreak of GLS.

The environments of Rwanda are heterogeneous and eight sites might not have represented all sub-sets of the country. However, this study has allowed identifying ten commercial hybrid varieties and two local hybrid varieties suitable for Rwandan environments. Furthermore is the first study to use AMMI model to analyze the interaction of maize genotypes with environments and to select adapted and stable varieties. This paper is the first to report the outbreak of Grey Leaf Spot in Rwanda.

Future research

The future research will concentrate on the acceptability of the identified twelve varieties in their specific environments by end-users who are farmers and seed companies. This will involve evaluating the selected varieties in key traits that are famers and Seed Company preferred.

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