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Full Length Research Paper

Genotype by environment interactions and yield stability of stem borer resistant maize hybrids in Kenya

Yoseph Beyene[1]*, Stephen Mugo[1], Charles Mutinda[2], Tadele Tefera[1], Haron Karaya[1], Sammy Ajanga[2], Jackson Shuma[2], Regina Tende[2] and Vincent Kega[2]

[1]International Maize and Wheat Improvement Center (CIMMYT), P.O. Box 1041 – 00621 Nairobi, Kenya.
[2]Kenya Agricultural Research Institute (KARI), P.O. Box 57811 – 00200 Nairobi, Kenya.

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In a maize breeding program, potential genotypes are usually evaluated in different environments before desirable ones are selected. Genotype x environment (G x E) interaction is associated with the differential performance of genotypes tested at different locations and in different years, and influences selection and recommendation of cultivars. Twenty one stem borer resistance maize hybrids and four commercial checks were evaluated in six environments in Kenya under infestation with *Chilo partellus* and *Busseola fusca* to determine the G x E interactions and stability of the hybrids. Analysis of variance was conducted for grain yield, days to flowering and plant and ear height. Stability for grain yield was determined using genotype plus genotype by environment interaction (GGE) biplot analysis. Variances due to genotype, environment and G x E interaction effects were highly significant for all traits. The GGE biplot showed that four experimental hybrids and two commercial checks had positive PC1 score indicating above average performance across environments. However, 10 experimental hybrids and two commercial checks had negative PC1 score, suggesting poor average performance. Experimental hybrids, CKIR07004 and CKIR07013, were highly desirable in terms of grain yield (>7.5 t/ha) and stability across environments. These hybrids could be released in Kenya and similar environments.

Key words: Genotype x environment (G x E) interactions**,** maize, stem borer resistant hybrids, stability.

INTRODUCTION

Stem borers, spotted stem borer (*Chilo partellus* Swinhoe) and African stem borer (*Busseola fusca*), are economically the most important field insect pests in maize cultivation in Africa (Pingali, 2001). The larvae feeds on the leaves and bores tunnels inside maize stems, thus destroying the pith and weakening the plant and reducing grain yield (García-Martí et al., 1996). De Groote (2002) reported that yield losses by stem borers in Kenya accounts for 13.5% of their maize harvest, which is equivalent to 400,000 tons of maize each year (De Groote, 2002). To tackle this problem, the Insect Resistant Maize for Africa (IRMA) project was launched in 1999 by the Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT), with the aim of developing and deploying maize varieties that are not only adapted to various agro-ecological zones, but also resistant to key insect pests, primarily the stem borers. Since its inception, maize germplasm including inbred lines, hybrids and open-pollinated varieties have been evaluated and new varieties released for various maize growing ecologies of Kenya (Mugo et al., 2001).

The CIMMYT multiple borer resistant (MBR) maize po-

*Corresponding author. E-mail: y.beyene@cgiar.org, Tel: +254 (0) 20 722 4654, Fax: +254 (0) 20 722 460.

Abbreviations: IRMA, Insect Resistant Maize for Africa; **KARI,** Kenya Agricultural Research Institute; **CIMMYT,** International Maize And Wheat Improvement Center; **MBR,** multiple borer resistant; **SCB,** sugarcane borer; **ECB,** European corn borer; **FAW,** fall armyworm; **G x E,** genotype × environment; **SREG,** sites regression; **GGE,** genotype plus genotype by environment interaction; **ASI,** anthesis to silking interval; **PC1**, non-crossover GE interaction.

pulation was developed by compositing global maize germplasm reputed to be "resistant" to a number of stem borer species (Mihm, 1997; Smith et al., 1989). CIMMYT developed a multiple borer resistance population by recombination and recurrent selection under infestation with Southern corn borer (SWCB), sugarcane borer (SCB), (*Diatrae sacharalis*), European corn borer (ECB), *Ostrinia nubilalis* and fall armyworm (FAW), (*Spodoptora*). This MBR was developed after noticing that a germplasm with resistance to a single species of insect pest was not as useful as one resistant to the complex problems in a given area (Mugo et al., 2001).

Grain yield is a complex trait that is greatly influenced by the environment. Although stem borer infestation could play a role in the interaction, other environmental factors should be considered. The differential response of a genotype for a given trait across environments is defined as the genotype (G) × environment (E) (G x E) interaction. G x E makes it difficult to select the best performing and most stable genotypes. It is an important consideration in plant breeding programs because it impedes progress from selection in any given environment (Yau, 1995). In breeding programs, genotype stability for yield and agronomic performance is an important breeding objective. Previous research suggests that selection of superior genotypes for grain yield and agronomic traits in maize hybrid performance trials is impacted by G × E (Butron et al., 2004; Lee et al., 2003 and Pixely and Bjarnason, 2002).

There are several methods for evaluating the performance of hybrids and their genotypic interactions with the environment (Cornelius et al., 1996; Crossa, 1990; Crossa and Cornelius, 1997 and Eberhart and Russell, 1966). These methods differ in the parameters used in the assessment, the biometric procedures employed, and the analysis. The sites regression (SREG) (Crossa and Cornelius, 1997) has been suggested as the appropriate model for analyzing multi environmental trials when large yield variation is due to environments (Yan et al., 2000). The SREG method supplies a graphical display called genotype plus genotype by environment interaction (GGE) biplot that identifies cultivars that are superior in different environments. The objectives of this study were to evaluate the presence of G × E, and to determine their stability for grain yield and agronomic performance in stalk borer resistance maize experimental hybrids and commercial cultivars in Kenya.

MATERIALS AND METHODS

Germplasm used

Three susceptible elite inbred lines, CML 202, CML 334 and CML 444, were crossed to 21 stalk borer resistant advance lines to obtain 21 single crosses (SC). The 20 SC served as parents in crosses with either CML395, CML312 and one advance stem borer resistant lines to obtain 21 three-way crosses hybrids (Table 1). The lines were selected because they are elite or advanced lines in the CIMMYT breeding program, and because they were significantly above average for stalk borer resistance in previous experiments (Mugo et al., unpublished data).

Field evaluations

Twenty-one hybrids (entry 1–21) and four checks (entry 22–24) were evaluated in a 5 x 5 alpha lattice design with three replications per location during the 2007 and 2008 long rains seasons (March–September). The hybrids were grown in six different environments (Kiboko 2007 and 2008; Embu 2007 and 2008, Kakamega 2007 and Mtwapa 2007) in Kenya. Some agro-climatologically characteristics of the sites are presented in Table 2. Environment is defined as a combination of year and location. Each entry was planted in two row plots of 5 m length. The rows were spaced 0.75 m apart and the hills were spaced 0.25 m apart. Two seeds per hill were planted, and thinned at three weeks after emergence to one plant per hill to give a plant population of 53,333 plants per hectare.

Three weeks after seedling emergence, 10 plants per plot were infested with 20 neonates per plant. The infestation was done with *C. partellus* at Kiboko and with *B. fusca* at Embu. Foliar damage was assessed two weeks after infestation by scoring each infested plant on a 1–9 scale; where, 1, no visible damage and 9, completely damaged. Plants with a leaf damage score of 0.0–3.0 rated highly resistant, 3.1–5.0 moderately resistant, 5.1–6.0 susceptible, 6.1–9.0 highly susceptible (Mihm, 1989). Data from each plot was recorded on days to 50% pollen shed, days to 50% silking, plant height (from the base to the flag leaf) and ear height (from the ground to the base of the first ear). Grain yield in tons per hectare (t/ha) adjusted to 12.5% moisture was calculated using shelled grain weight.

Data analysis

Analysis of variance (ANOVA) was done for each location separately, and combined across environments. For the combined analysis, variances were partitioned into relevant sources of variation to test for differences among genotypes and the presence of G × E interaction. The sites regression (SREG) model was used (Cornelius et al., 1996; Crossa and Cornelius, 1997). In the SREG method, principal component (PC) analysis is made on residuals of an additive model with environments as the only main effects. A two-dimensional biplot (Gabriel, 1971) called GGE biplot (G plus GE interaction) of the two first PCs was plotted (Yan et al., 2000). Genotypes and environments were displayed in the same plot. Each genotype and environment was defined by the genotype's and environment's scores on the two PCs respectively. The analysis was done using a SAS (SAS, 2003) program for graphing GE and GGE biplots developed by Burgueño et al. (2003). The environments were regarded as random effects while cultivars were regarded as fixed effects in the analysis.

RESULTS AND DISCUSSION

Analysis of variance

All hybrids were resistant to *C. partellus*, while they were moderately resistant to *B. fusca* (Table 1). Analysis of variance (ANOVA) revealed significant differences ($p<0.01$) among the hybrids for all traits (Table 3). G x E interaction were significant ($p<0.01$ or $P<0.05$) for grain yield, days to anthesis, days to silking and anthesis silking interval but not significant for plant and ear heights (Table 3). The environment main effects (E) were the

Table 1. List of hybrids, pedigree and stem borer leaf damage score.

Entry No.	Name	Pedigree	Leaf damage score(1-9)	
			C. partellus	*B. fusca*
1	CKIR07001	(CML334/MBR C5 Bc F114-1-1-3-B-8-2-B)//CML395	2.7	3.7
2	CKIR07002	(MBR C5 Bc F8-1-1-1-B-2-2-B/CML444)//CML395	1.8	5
3	CKIR06012	(CML202/MBR/MDR C3 Bc F21-1-1-2-B-8-2-B)//Pop. 390 MIRT C5 Bco S2 Comp.	1.8	3.2
4	CKIR07004	(CML334/MBR C5 Bc F108-2-3-1-B-5-2-B)//CML395	2.2	4
5	CKIR07005	(Pool B –36-B-4-3-B/MBR C5 Bc F108-2-3-1-B-5-2-B)//CML395	1.5	4.4
6	CKIR07006	(CML202/MBR C5 Bc F4-1-2-1-B-1-2-B)//CML395	2.8	3.8
7	CKIR07007	(MBR C5 Bc F4-1-2-1-B-1-2-B/MBR/MDR C3 Bc F1-1-1-1-B-3-2-B)//CML395	2.4	3.9
8	CKIR07008	(MBR C5 Bc F13-3-2-1-B-4-2-B/CML444)//CML395	1.9	4.4
9	CKIR07009	(EMAP1A-233-B-6-1-B/MBR C5 Bc F114-1-2-3-B-4-2-B)//CML395	2.4	4.4
10	CKIR06014	(CML202/MBR C5 Bc F8-1-1-1-B-2-2-B)//Pop. 390 MIRT C5 Bco S2 Comp.	1.8	3.5
11	CKIR07011	(MBR C5 Bc F8-1-1-1-B-2-2-B/CML444)//CML312	1.9	3.5
12	CKIR07012	(CML254/MBR C5 Bc F108-2-3-1-B-4-2-B)//CML312	1.9	4.4
13	CKIR07013	(CML334/MBR C5 Bc F108-2-3-1-B-5-2-B)//CML312	1.9	3.3
14	CKIR07014	(Pool B –36-B-4-3-B/MBR C5 Bc F108-2-3-1-B-5-2-B)//CML312	2	3.7
15	CKIR07015	(CML202/MBR C5 Bc F4-1-2-1-B-1-2-B)//CML312	2	4
16	CKIR07016	(MBR C5 Bc F4-1-2-1-B-1-2-B/MBR/MDR C3 Bc F1-1-1-1-B-3-2-B)//CML312	1.7	3.5
17	CKIR07017	(MBR C5 Bc F13-3-2-1-B-4-2-B/CML444)//CML312	1.8	4.2
18	CKIR07018	(EMAP1A-233-B-6-1-B/MBR C5 Bc F114-1-2-3-B-4-2-B)//CML312	1.9	4.4
19	CKIR06007	(MBR C5 Bc F4-1-2-1-B-1-2-B/MBR/MDR C3 Bc F1-1-1-1-B-3-2-B)//Pop. 390 MIRT C5 Bco S2 Comp.	1.4	3
20	CKIR06008	(EMAP1A-233-B-6-1-B/MBR C5 Bc F114-1-2-3-B-4-2-B)//Pop. 390 MIRT C5 Bco S2 Comp.	1.6	3.3
21	CKIR06009	(MBR C5 Bc F13-3-2-1-B-4-2-B/CML444)//Pop. 390 MIRT C5 Bco S2 Comp.	1.8	3
		Mean of experimental varieties	*2.0*	*3.8*
22	DH04	DH04	2.8	4.4
23	PH4	PH4	2.4	4.2
24	H513	H513	2.7	4.3
25	WS505	WH505	2.2	4.3
		Mean of checks	2.5	4.3
		Grand mean	2.1	3.9

Table 2. Agro-climatic description of trial site.

Site	Longitude	Latitude	Elevation (masl)	Rain fall (mm)	Temperature (0°C)		Soil texture
					Min	Max	
Kiboko	37° 75'E	2° 15S'	975	530	14.3	35.1	Sandy clay
Embu	37° 42'E	0° 449'S	1510	1200	14.1	25.0	Clay loam
Kakamega	34° 45'E	0° 16'N	1585	1916	12.8	28.6	Sandy loam
Mtwapa	39° 44'E	3° 50' S	15	1200	22.0	30.0	Sandy

most important source of variation accounting for 37.24% of the total sum of squares for yield, 94.39% for days to anthesis, 92.89% for days to silking, 81.67% for plant height and 82% for ear height (Table 4). Genotype main effect (G) accounted for 18.89% of the total sum of squares while G x E was 16.33% (Table 4). The environment effect appeared large for all traits except anthesis to silking interval (ASI). G x E effects of sums of squares for ASI, plant height and ear height were bigger than their genotypic effects.

Mean performance

Eight out of the 21 stalk borer insect resistant experimental hybrids produced higher grain yield than the best com-

Table 3. Mean squares and degrees of freedom from ANOVA for grain yield, and agronomic traits of 25 maize hybrids evaluated across locations in Kenya.

Source	df	MS					
		Grain yield ($t\ ha^{-1}$)	Days to anthesis	Days to silking	ASI (days)	Plant height (cm)	Ear height (cm)
Environment (E)	5	122.81**	6738.04**	6693.53**	7.77**	129764.45**	54048.52**
Genotype (G)	24	12.97**	44.53**	53.97**	3.02**	889.67**	482.45**
G x E	120	2.244**	2.883**	3.62*	2.14**	323.97ns	129.42ns
Error	300	1.51	1.96	2.77	0.91	284.51	107.31

MS = Mean squares, df = degrees of freedom, ASI = Anthesis silking interval.

Table 4. The portion of sums of squares (SS) attributed to the environments, genotype, and genotype x environments interaction as the percentage of the total sums of squares.

Source	% SS					
	Grain yield (tha^{-1})	Days to anthesis	Days to silking	ASI (days)	Plant height (cm)	Ear height (cm)
Environment (E)	37.24	94.39	92.89	6.04	81.67	82.00
Genotype (G)	18.89	2.99	3.60	11.31	2.69	3.51
G x E	16.33	0.97	1.21	40.11	4.89	4.71
Error	27.55	1.65	2.30	42.54	10.74	9.77

%SS = percentage of sum of squares, ASI = Anthesis Silking interval.

mercial check (Table 5) based on combined analysis, the five genotypes that had the highest grain yield were ‘CKIR07004’ (7.66 t/ha), ‘CKIR07013’ (7.59 t/ha), ‘CKIR07005’ (7.03 t/ha), ‘CKIR07017’ (6.98 t/ha) and ‘CKIR07001’ (6.87 t/ha) (Table 5). Eighteen stem borer insect resistant experimental hybrids were earlier maturing than the best commercial check (WH505). However, only three genotypes matured earlier than DH04 (the earliest maturing commercial check). Many genotypes had shorter plant and ear height than the commercial checks (Table 5).

Stability analysis

Various studies (Crossa et al., 2002; Yan et al., 2000) have stated that in the two-dimensional biplot (Figure 1), if the primary effects of the sites from the SREG model are all of the same nature (positive/negative) as it was in the present study (Figure 1), PC1 presents a non-crossover GE interaction. A genotype with a larger PC1 score has a greater average yield and its performance varies across environments in direct proportion to the environment PC1 score. The first two PCs of the SREG model explained 83.11% of GGE variation (Figure 1). The two dimensional biplots showed that entry 4, 13, 25, 12, 17, 11, 15 14, 7 and 24 had positive PC1 scores suggesting above average performance. On the contrary, entries 23 and 22 (commercial varieties) and 19, 20 and 21 (experimental hybrids) had high negative PC1 scores, suggesting poor average performance. Entry 13 (CKIR07013) and entry 4 (CKIR07004) hand near zero PC2 score while entry 14 (CKIR0714) and 24 (H513) had high PC2 score. Therefore, entry 13 (CKIR07013) and entry 4 (CKIR07004) appeared as a high yielding and stable genotypes because it showed a large PC1 score and a near-zero PC2 score. On the other hand, entry 19 (CKIR06007) had zero PC2 and high negative PC1 score suggesting that it is a stable but low yielding genotype across the environments.

Although the experiments were carried out on different locations and years, the sources of variation in the analysis of variance, except error, explained 72.5% of the total variation (Table 4), showing good experimental accuracy. The mean grain yield of stalk borer resistant maize hybrids differed across environments which may be due to differing environmental conditions over time and locations. The locations themselves differ greatly in altitude, temperature and rainfall, a fact that affects performance (Table 2). The significant effects of genotypes and the genotype × environment interaction in the ANOVA (Table 3) suggested differential response of the genotypes across environments. Similar observations were reported by Butron et al. (2002) in which he indicated that G x E effects for grain yield in maize were mainly due to environmental yield limiting factors such as the mean minimum temperature and relative humidity. Variation due to genotype (G) was larger than that due to the G x E interaction, but G x E interaction was significant (Table 3 and 4), indicating that the differences among

Table 5. Means for grain yield in each environment and agronomic traits averaged across environments of 25 maize hybrids evaluated in Kenya in 2009.

Entry	Pediree	Yield (t ha^{-1})							Mean across environment			
		Mtwapa	Kiboko		Embu		Kakamega	Mean				
		2007	2007	2008	2007	2008	2007		AD	ASI	PH	EH
1	CKIR07001	5.3	6.4	7.1	6.7	8.3	7.5	6.9	71.2	3.0	223.5	126.2
2	CKIR07002	4.6	4.6	5.5	5.1	8.2	8.1	6.0	70.6	2.9	203.4	115.7
3	CKIR06012	4.6	5.4	5.4	5.5	7.7	5.2	5.6	68.7	2.1	211.0	117.1
4	CKIR07004	5.6	6.2	6.7	8.3	10.8	8.1	7.7	71.6	2.6	223.5	123.0
5	CKIR07005	5.1	4.3	6.3	8.3	10.3	7.7	7.0	69.9	2.1	216.5	123.6
6	CKIR07006	4.6	5.7	5.6	5.9	7.5	7.3	6.1	71.7	2.8	212.2	114.7
7	CKIR07007	4.6	5.7	6.0	7.1	7.9	7.2	6.4	69.6	2.6	226.9	116.8
8	CKIR07008	4.6	5.5	6.2	6.4	8.7	5.4	6.2	70.7	3.1	210.9	116.4
9	CKIR07009	4.6	5.0	5.5	7.3	8.3	6.3	6.1	70.1	2.6	215.9	118.2
10	CKIR06014	4.0	5.0	5.8	4.6	6.0	5.2	5.0	68.2	2.3	207.5	116.3
11	CKIR07011	4.7	6.3	6.5	5.9	10.0	7.2	6.8	67.7	1.7	210.6	112.0
12	CKIR07012	5.2	5.6	6.4	7.5	8.6	8.6	7.0	70.3	2.1	213.0	113.8
13	CKIR07013	5.6	6.8	7.6	7.7	9.9	8.2	7.6	69.8	2.0	223.5	119.1
14	CKIR07014	5.5	6.2	5.4	6.8	6.1	8.5	6.4	67.8	1.8	213.2	115.6
15	CKIR07015	5.2	5.5	5.5	6.5	8.6	8.2	6.6	69.1	1.9	210.5	110.5
16	CKIR07016	5.1	5.5	6.5	5.8	9.5	8.6	6.9	67.4	1.9	209.5	107.4
17	CKIR07017	4.5	5.6	7.0	7.4	8.9	8.4	7.0	68.5	2.1	210.0	110.2
18	CKIR07018	4.7	5.7	6.3	5.4	9.5	5.9	6.2	68.3	2.3	214.4	110.9
19	CKIR06007	3.3	5.3	5.0	4.8	7.3	4.8	5.1	65.9	2.2	203.5	108.2
20	CKIR06008	3.6	3.5	4.3	5.0	7.6	4.7	4.8	66.0	2.4	206.2	112.0
21	CKIR06009	4.3	5.2	5.2	4.4	6.1	5.2	5.1	67.0	2.7	199.9	109.1
22	DH04	4.0	4.6	5.4	5.7	8.1	4.1	5.4	67.6	1.8	212.9	111.6
23	PH4	5.1	4.3	4.9	4.5	7.8	3.5	5.0	71.6	2.9	211.4	115.8
24	H513	4.7	5.7	5.5	6.0	10.3	5.9	6.3	69.4	2.2	219.0	122.7
25	WH505	6.1	6.8	7.1	6.6	10.6	7.2	6.7	71.6	0.0	221.3	119.7
	Mean	4.8	5.5	6.0	6.2	8.5	6.7	6.3	69.2	2.3	213.2	115.4
	LSD	1.0	1.7	1.3	1.7	2.4	1.8	0.7	1.0	0.6	9.4	5.0
	CV	10.7	14.9	11.1	13.2	14.0	13.2	13.6	1.9	3.4	5.5	5.4

AD, Number of days to anthesis; ASI, anthesis silking interval; PH, plant height (cm); EH, Ear height (cm).

genotypes vary across environments. Van Eeuwijk et al. (1995) also found that variation due to the G x E interaction was small in relation to the G variation for silage dry matter content of 18 Dutch maize varieties. However, a higher G x E interaction than G for grain yield has been reported in a study with early maize hybrids tested in about 30 locations in northern France (Epinat-Le Signor et al., 2001).

The SREG GGE biplot method graphically displays the ability of the genotypes to adapt to the environment (estimates given by the results of PC1) and their stability (represented by PC2). Analysis of stability as measured by GGE biplot indicated that nearly half of the genotypes had above average performance across environments (Figure 1). The top five best performing genotypes (entry 4, 13, 12, 5 and 17) were the stem borer resistant experimental hybrids. These experimental hybrids also out-performed all the commercial checks (DH04, PH4, H513 and WH505). These results indicate that selection for stalk borer resistant did not result in yield penalty. Unlike the present study, other authors have reported losses of yielding ability after selection for insect resistance (Butron et al., 2002; Nyhus et al., 1989; Russell et al., 1979).

Productive and stable genotypes have high scores for PC1, but scores close to zero for PC2, as for genotype 4 and 13 (Figure 1). Entry 23 (DH04, a commercial check) had negative PC1 score, implying that these genotypes were unstable across environments (Figure 1).

Conclusions

The GGE biplot approach used in this study could help breeders to make better decisions on what genotypes should be recommended for release in the region. Expe-

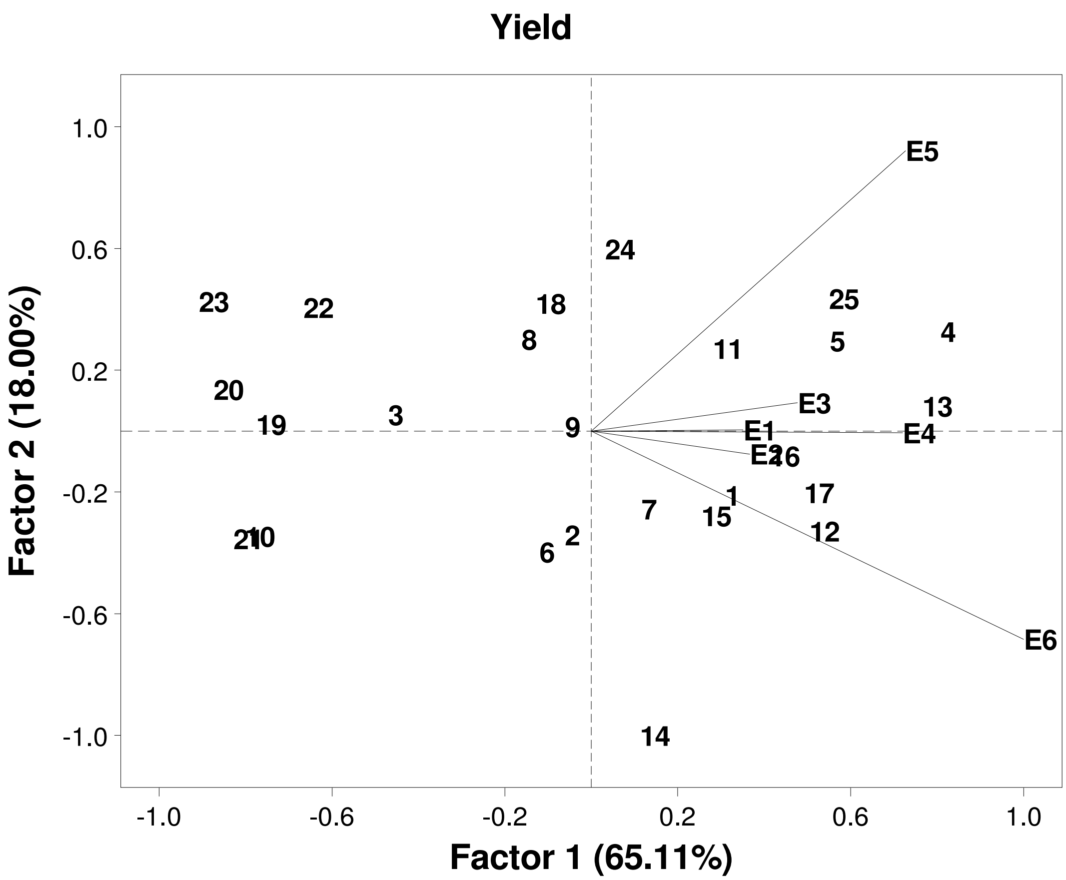

Figure 1. Graph of the SREG GGE biplot analysis based on grain yield of 25 maize hybrids evaluated across 6 environments in Kenya.

rimental hybrids, CKIR07004 and CKIR07013, were highly desirable in terms of grain yield (>7.5 t/ha) and stability across environments. These hybrids could be released in Kenya and other similar environments in sub-Saharan Africa for commercialization.

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REFERENCES

Burgueño J, Crossa J, Vargas M (2003). SAS programs for graphing GE and GGE biplots: Downloaded from http://www.Cimmyt.org/Research/ Biometrics/bsu.htm.

Butron A, Velasco P, Orda´ sA, Malvar R (2004). Yield evaluation of maize cultivars across environments with different levels of pink stem borer infestation. Crop Sci. 44: 741-747.

Butron A, Widstrom N, Snook M, Wiseman B (2002). Recurrent selection for corn earworm (Lepidoptera: Noctuidae) resistance in three closely related corn southern synthetics. J. Econ. Entomol. 95: 458-462.

Cornelius P, Crossa J, Seyedsader M (1996). Statistical test and estimators of multiplicative models for genotype-by-environment interaction. In Kang MS, Gauch HG (eds.): Genotype-by-environment interaction. Boca Raton, FL: CRC Press, pp. 199-234.

Crossa J (1990). Statistical analyses of multilocation trials. Adv. Agron. 44: 55-85.

Crossa J, Cornelius P (1997). Sites regression and shifted multiplicative model clustering of cultivar trial sites under heterogeneity of error variances. Crop Sci. 37: 406-415.

Crossa J, Cornelius P, Yan W (2002). Biplots of linear bilinear models for studying crossover genotype × environment interaction. Crop Sci. 42: 619-633.

De Groote H (2002). Maize yield losses from stem borers in Kenya. Insect Sci. Appl. 22: 89-96.

Eberhart S, Russell W (1966). Stability parameters for comparing varieties. Crop Sci. 6: 36-40.

Epinat-Le Signor C, Dousse S, Lorgeou J, Denis J, Bon-homme R, Carolo P, Charcosset A (2001). Interpretation of Genotype x environment interactions for early maize hybrids over 12 years. Crop Sci. 41: 663-669.

Gabriel K (1971). The biplot graphic display of matrices with application to principal component analysis. Biometrika 58: 453-467.

García-Martí F, Comelles C, Pérez F (1996). Las plagas agrícolas. Phytoma 1.

Lee E, Doerksen T, Kannenberg L (2003). Genetic components of yield stability in maize breeding populations. Crop Sci 43: 2018-2027.

Mihm J (1997). Insect resistance maize; Recent advances and utilization. Proceedings of an International Symposium held at the International Maize and Wheat Improvement Center (CIMMYT) 27th November- 3rd December 1994. International symposium held at the International Maize and Wheat Improvement Center (CIMMYT) 27th November- 3rd December 1994, pp. 156.

Mihm JA (1989). Insect resistant maize. Recent advances and utilization. In CIMMYT (ed.): Toward insect resistance maize for the Third World: Proceedings of the International Symposium on methodologies for Developing Host Plant Resistance to Maize Insects. Mexico, D.F.: CIMMYT, pp. 175.
Mugo S, Bergvinson D, Hoisington D (2001). Options in developing stem borer-resistant maize: CIMMYT approaches and experiences. Insect Sci. Appl. 21: 409-415.
Nyhus K, Russell W, Guthrie W (1989). Changes in agronomic traits associated with recurrent selection in two corn synthetics. Crop Sci 29: 269-275.
Pingali P (2001). CIMMYT 1999-2000 World maize facts and trends. Meeting world maize needs: Technological opportunities and priorities for the private sector. Mexico, D.F.: CIMMYT.
Pixely K, Bjarnason M (2002). Stability of grain yield, endosperm modification, and protein quality of hybrid and open-pollinated quality protein maize (QPM) cultivars 2002. Crop Sci. 42: 1882-1890.
Russell W, Lawrance G, Guthrie W (1979). Effects of recurrent selection for European corn borer resistance on other agronomic characters in synthetic cultivars of corn. Maydica 24: 33-47.
SAS (2003). SAS ® 9.1 for Windows. Cary, NC,: SAS Institute Inc.
Smith M, Mihm J, Jewell D (1989). Breeding for multiple resistance to temperate, sub-tropical, and tropical maize insect pests at CIMMYT: Toward insect resistant maize for the third world. Proceedings of the international symposium on methodologies for developing host plant resistance to maize insects. Mexico, D.F.: CIMMYT, pp. 222-234.
Van Eeuwijk F, Keizer L, Bekker J (1995). Linear and bilinear models for the analysis of multi-environment trials: II. An application to data from the Dutch maize variety trials. Euphytica 84: 9-22.
Yan W, Hunt L, Sheng Q, Szlavnics Z (2000). Cultivar evaluation and mega-environment investigation based on the GGE biplot. Crop Sci 40: 597-605.
Yau S (1995). Regression and AMMI analyses of genotype x environment interactions: An empirical comparison. Agron. J. 87: 121-126.