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Effect of *Striga hermonthica* (Del.) Benth on Yield and Yield Components of Maize (*Zea mays* L.) Hybrids in Western Kenya

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Abstract

Striga hermonthica (*Striga*) weed is widespread in Kenya, where it causes significant cereal crop losses, particularly when susceptible varieties are grown. The use of maize (*Zea mays* L.) genotypes that support reduced *Striga hermonthica* emergence can form an important basis for developing resistant cultivars. The objective of this study was to evaluate the response of diverse maize hybrids to *Striga* weed infestation and to identify high yielding and stable hybrids. Six experimental maize hybrids and three commercial hybrid checks (DK8031, PhB3253 and H513) were evaluated under *Striga* and *Striga* free conditions at Nyahera and Maseno in western Kenya in 2011 and 2012 growing seasons. The data collected included grain yields and other yield components; emerged *Striga* counts and *Striga* damage rating (on a scale of 1-5) at 8 and 10 weeks after planting (WAP). Significant differences ($P < 0.05$) were observed in grain yield and yield components; emerged *Striga* counts and *Striga* damage syndrome in both years. Negative correlation (r) was observed between emerged *Striga* and yield as well as between *Striga* damage ratings and yield. Maseno experimental hybrids produced much better grain yields and were more stable compared to commercial varieties under *Striga* infestation and in *Striga* free fields. Deployment of the tolerant/resistant high yielding well adapted hybrids coupled with other management options such as rotation with legumes and cultural practices could possibly help in depletion of *Striga* seed bank in the soils in western Kenya. EH12 and EH14 maize hybrids were formally released for commercialization in the *Striga* endemic areas of western Kenya.

Keywords: maize, *Zea mays* L., *Striga hermonthica*, grain yield, correlation, stability

1. Introduction

Maize (*Zea mays* L.) is one of the most important food crops in the world and, together with rice and wheat, provides at least 30% of the food calories to more than 4.5 billion people in 94 developing countries (Shiferaw et al., 2011). It is the third most important cereal crop in the world, after rice and wheat (Poehlman, 1979), and mainly used as human food, animal feed and extensively in industrial products, including production of bio fuels (Saleh et al., 2002). Maize is currently produced on nearly 100 million hectares in 125 developing countries (FAOSTAT, 2010). In parts of Africa, maize alone contributes over 20% of food calories (Shiferaw et al., 2011). In Kenya, maize is the main staple food, averaging over eighty percent of total cereals (FAO, 1998). Maize production in Kenya is a highly relevant activity because it is an important and a dominant food crop (Mantel & van Engelen, 1997). It is also important in Kenya's crop production patterns; accounting for roughly 20 percent of gross farm output from the small-scale farming sector (Jayne, et al., 2001). It is mostly produced under rain fed conditions. The total land area under maize production in Kenya is about 1.6 million hectares with seventy to ninety percent from small-scale farms. However, maize production has lagged behind and its production capacity has not kept pace with increasing demand for food. The low yields recorded in the country are attributed to abiotic and biotic constraints such as drought incidences, pests, diseases and most importantly the parasitic weed *Striga* which takes up water and nutrients from its host and also causes toxicity effects (Pieterse & Pesch, 1983; Musselman, 1987; Stewart, 1990; Khan et al., 2006).

There are nine *Striga* species found in Kenya with the predominant species considered dangerous being *Striga hermonthica* which is found in the densely populated western parts of the country around the Lake Victoria basin (Dogget, 1965; MacOpiyo et al., 2010). This is where it infects the major cereal crops: maize, sorghum, rice and finger millet. *S. asiatica* is predominantly found in the coastal region infecting upland rice (Gethi et al., 2005) and exists sporadically in Isiolo, Busia and Naivasha (Mohamed et al*.,* 2001). *Striga gesneriodes*, a species adapted as a pest of legumes has a wide geographical distribution in Kenya compared to the other species. It occurs as far as Kilifi (Coastal province of Kenya) spreading to Homa hills (Nyanza province, western Kenya) infecting cow pea.

Striga hermonthica has the potential to threaten food security in many countries and is particularly significant in Africa (De Groote et al., 2007). It decimates maize which is the main staple food crop for close to 300 million people in Africa (Aliyu et al., 2004; Ejeta, 2007) with yield loss estimated at 10 million tons grain worth $ US 7 billion (Khan et al., 2001; Venne et al., 2009). In Kenya, the parasite is reported to be infecting about 217,000 ha^{-1}, causing annual crop loss of US $53 million (Woomer & Savala, 2009). Results of a survey done on 83 farms in Western Kenya revealed that 73% of the farms are severely infected with *S. hermonthica* (Woomer & Savala, 2009). The potential maize yield in the Western Kenya is 4-5 ton/ha (Vanlauwe et al., 2008) with the average yield loss attributed to *Striga* infection being 1.15 tons per hectare for maize (MacOpiyo et al., 2010). The losses can reach as high as 2.8 tons per ha in maize and sorghum in some areas with high *Striga* densities (Andersson & Halvarsson, 2011). The recorded damage represents 12.3% of the 2.4 million metric tons of maize that Kenya produces annually. This translates to approximately 39.6 kg of maize loss per capita, amounting to about 20% of a person's annual food needs (Atera et al., 2013). The problem of *Striga* in these areas have been aggravated by intensive land use as a result of high population pressure resulting in the abandonment of the traditional African cropping systems such as prolonged fallow, rotations and intercropping. Continuous mono-cropping with no fallow in turn has led to increased *Striga* seed bank in the soil and decline in soil fertility greatly reducing crop yields (Oswald, 2005).

Development and introduction of resistant maize cultivars in *Striga* infested maize growing regions has been a major goal of maize breeders to effectively minimize yield losses when breeding for resistance (Verkleij & Kuijper, 2000; Haussmann & Hess, 2000; Rich & Ejeta, 2008). The use of host plant resistance or tolerance is considered the most economically feasible and sustainable approach for reducing the effects of the parasitic weed (DeVries, 2000; Badu-Apraku et al., 2004, 2005). *Striga* tolerance refers to the ability of the host plants to withstand the effects of the parasites already attached whereas resistance describes the ability of the host plants to prevent attachment resulting in a reduced amount of parasites and the number of *Striga* seeds that are reproductively viable (Kim, 1994). Attempts to produce high yielding locally acceptable resistant cultivars have been less successful (Ogborn, 1987; Parker & Riches, 1993; Ramaiah, 1987). However, some interesting and durable materials have been bred from wide crosses between maize and the wild maize progenitor teosinte (*Zea diploperennis*) (Kling et al., 2000). Resistance to *Striga* has also been identified in the tetraploid apomictic wild relative of maize, *Tripsacum dactyloides* L. where post attachment resistance and high level of tolerance has been displayed (Hearne, 2009). A host variety that combines superior levels of resistance and tolerance is an obvious breeding objective and has been proposed in several studies (Kim, 1991; DeVries, 2000; Kling et al., 2000; Hausmann et al., 2001a, 2001b; Pierce et al., 2003, Showemimo, 2003; Rodenburg et al., 2005). These efforts provide an important part of the solution to the *Striga* menace to the resource poor farmers (Kim, 1991). Previous work done at International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Center (CIMMYT) have identified some maize genotypes with potential tolerance/resistance to *Striga.* However these genotypes have not been widely tested under *Striga* prone western region of Kenya. The resistant varieties developed still lack good yields and adaptation to local environmental constraints.

Maseno University maize breeding program has embraced a breeding approach focusing on local landraces to develop lines that sustain low *Striga hermonthica* damage symptoms and improved grain yields. The ultimate aim has been to develop genotypes that support low emerged parasites to reduce parasite seed reproduction and the subsequent buildup of seed bank in the soil. This has resulted in the development of hybrids that should be evaluated for yield stability. Several methods of analysis for stability have been proposed for predicting cultivar responses in multi-environment trials, of which the additive main effects and multiplicative interactions (AMMI) model combines standard analysis of variance with principal component analysis (Zobel et al., 1988). The AMMI model has been extensively applied in the statistical analysis of multi environment cultivar trials (Kemptom, 1984; Gauch & Zobel, 1997; Crossa et al., 1999). The results of AMMI analysis are presented graphically in the form of bi-plots (Gabriel, 1991) for easy interpretation of genotype and environment interaction.

The current popular maize varieties in Kenya have not shown total resistance to *Striga* in the field. The major challenge therefore is to develop varieties that will help small scale resource poor farmers control *Striga* effectively within a sustainable and profitable farming system (Dogget, 1988). Therefore there was a need to evaluate and identify high yielding maize varieties with *Striga* tolerance. The objectives of this study were to (i) Evaluate diverse maize hybrid performance for yield and yield components under *Striga* infestation in western Kenya; (ii) Identify high yielding and stable hybrids both under *Striga* and *Striga* free environment in Western Kenya.

2. Materials and Methods

2.1 Site Description

The field studies were done at Maseno University of Kenya and at Nyahera in Kenya. Maseno university site is *Striga* free and lies along the Equator at latitude 0^o, longitude $34^o30'$E at an altitude of 1515 meters above sea level. The soils at Maseno are well drained, extremely reddish brown and friable clay. The soils vary in color, consistence and texture. They are classified as dystric nitisols (Jaetzold et al., 2006). The location experiences mean minimum and maximum temperatures of 15.4 ^oC and 29.9 ^oC respectively with an annual rainfall of between 1100 mm-1500 mm (Jaetzold et al., 2006). Nyahera, a *Striga* hot spot, lies at latitude E $34^o53.452'$, longitude N $0^o35.977'$ at an altitude of 1490 m a.s.l. The soils are well drained, shallow to moderately deep dark yellowish brown to reddish brown, friable, stony sandy clay loam to gravelly sandy clay. They are classified as ferralic, humic and dystric cambisols (Jaetzold et al., 2006). The average annual rainfall is 1650mm per annum (Jaetzold et al., 1982). The two sites have a bimodal type of rainfall where the first peak falls between April and August (Long rains season) and the second peak between September and December (short rains season). The short rains season, however are sometimes unreliable.

2.2 Experiment 1: Experimental Hybrids Evaluation

A study was conducted in the long rains (April to August) and short rains (September to December) of 2011 and 2012 to evaluate the performance of six selected experimental maize hybrids developed by the Maseno University *Striga* resistance breeding program and three commercial hybrid varieties under *Striga* infestation and non *Striga* infested conditions. The experimental hybrids tested were EH21S, EH11M, EH21H, EH11S, EH14 and EH12. Commercial hybrids DK8031, H513 and PHB3253 were used as susceptible checks.

Experimental design was a randomized complete block design with three replications. Each plot consisted of four maize rows of 5 metres long, spaced 0.75 metres apart with 0.25 metres spacing between plants within the row. Within a row, two seeds were planted per hill and thinned to one plant after emergence to attain a population density of 53,333 plants ha^{-1}. Under *Striga* infestation, each hole was infested with about 5000 germinable seeds per hill using infestation method developed by IITA maize program (Kim, 1991; Kim & Winslow, 1991). The *Striga* seeds used were collected from fields at Kibos, Kenya at the end of the 2010 growing season and mixed with finely sieved sand in the ratio of 1:99 by weight. Except for *Striga* seed infestation, all management practices for both Infested and non-infested experiments were the same. A compound fertilizer was applied at the rates of 60 kg N, 60 kg P, and 60 kg K ha^{-1} at the time of sowing. Additional 60 kg N ha^{-1} was applied as top dressing 4 weeks later. Hand hoe weeding was done prior to *Striga* emergence and thereafter weeds were hand pulled in the *Striga* experiment.

Data was collected on two central rows (net plot) in both the *Striga* infested and non *Striga* infested fields. Assessment of the effect of *Striga* included emerged *Striga* counts at 8 and 10 WAP (weeks after planting) and *Striga* damage rating per plot at 8 and 10 WAP on a scale of 1-5; where 1 = no damage, indicating normal plant growth and high level of tolerance, and 5 = complete collapse or death of the maize plant, that is, highly sensitive/intolerant. Grain yield adjusted to 15% moisture was estimated from the shelled kernel dry weight. Other traits recorded wherever possible included plant and ear heights measured as the distance from the base of the plant to the height of the first tassel branch and the node bearing the upper ear respectively; Ear aspect, Plant aspect and Gray leafspot disease.

2.2.1 Data Analysis

Analysis of variance (ANOVA) was conducted separately for data collected from *Striga* infested and non-infested environments for selected traits of the cultivars. To reduce heterogeneity of *Striga* count variances a log transformation was done. A combined across environment analysis was performed on plot means for grain yield for the hybrids. In the combined ANOVA, the environments were considered as random effects while the effects of genotypes were regarded as fixed. Additive, Main effects and Multiplicative Interaction (AMMI) was used to test the stability of genotypes.

2.3 Experiment 2: Kenya Plant Health Inspectorate Services-National Performance Trials Evaluations

2.3.1 Materials and Methods

Experimental maize hybrids, EH12 and EH14 were submitted for evaluation as candidates to Kenya Plant Health Inspectorate Services (KEPHIS) in National Variety performance trials alongside three cultivars; Ua Kayongo, GFVC04 and PhB3253 at eight *Striga* infested locations in western Kenya. Ua Kayongo is a herbicide resistant maize coated with imazapyr, a systemic imidazolinone herbicide at 30 g/ha. The evaluation sites were Alupe, Busia, Homabay, Kibos, Luanda, Nyahera, Ndori and Rarieda. Kibos and Alupe sites were artificially inoculated whereas the rest of the sites were farmer's fields with natural *Striga* infestation. The cultivars were evaluated in 4 row plots and data taken on the two central rows. Grain yield and *Striga* counts were computed across sites and the two hybrids data combined over two and three years respectively to allow assessment for commercial release.

3. Results

3.1 Maize Hybrid Evaluation under Striga at Nyahera during the Short Rains of 2011

Results for the hybrid evaluation under *Striga* infestation at Nyahera in the short rains season of 2011 is shown in Table 1. Mean grain yield of the hybrids ranged from 0.29 to 6.27 tons ha^{-1}. Significant differences ($P < 0.05$) were observed amongst the hybrids for grain yield. The highest yielding hybrid was EH14 while the lowest yielding hybrid was Pioneer hybrid PhB3253.

Significant differences ($P < 0.05$) were observed among the hybrids for *Striga* damage symptoms at 8 and 10 weeks after planting. Commercial hybrids H513 and PhB3253 had higher *Striga* damage symptoms and higher emerged *Striga* plants at 8 and 10 weeks after planting and low yield. Negative correlations ($r = -0.98$; $r = -0.79$) and co-efficient of the relationships ($R^2 = 0.96$; $R^2 = 0.62$) were observed between the hybrid grain yields and *Striga* damage ratings at 8 and 10 weeks respectively (Figures 1 and 2).

Table 1. Mean of grain yields, *Striga* damage rating and *Striga* emergence at Nyahera under *Striga* infestation in 2011 short rains season

Variety	Grain yield (tons ha^{-1})	*Striga* damage rating (1-5)		Number of emerged *Striga* plants	
		8 WAPᵵ	10 WAPᵵ	8 WAPᵵ	10 WAPᵵ
EH14	6.27^a	1.0^b	1.0^c	4.7^{ab}	50.0^{abc}
EH12	6.25^a	1.0^b	1.0^c	2.0^b	17.3^c
EH11M	5.72^a	1.0^b	1.0^c	4.0^{ab}	34.7^{bc}
EH21S	5.65^a	1.0^b	1.2^c	6.0^{ab}	35.7^{bc}
EH21H	5.37^a	1.0^b	1.0^c	5.7^{ab}	43.7^{abc}
DK8031*	4.99^a	1.2^b	1.3^c	6.7^{ab}	50.3^{abc}
EH11S	4.75^a	1.0^b	1.2^c	3.7^{ab}	25.7^{bc}
H513*	0.58^b	2.8^a	4.0^a	9.7^a	79.7^a
PHB3253*	0.29^b	2.8^a	3.5^b	4.0^{ab}	64.0^{ab}
$LSD_{(0.05)}$	1.75	0.3	0.5	7.0	41.0

Note. *: Commercial hybrid check; ᵵ: Weeks after planting.

Means in a column followed by the same letter are not significantly different at $p < 0.05$ by Duncan's multiple range test.

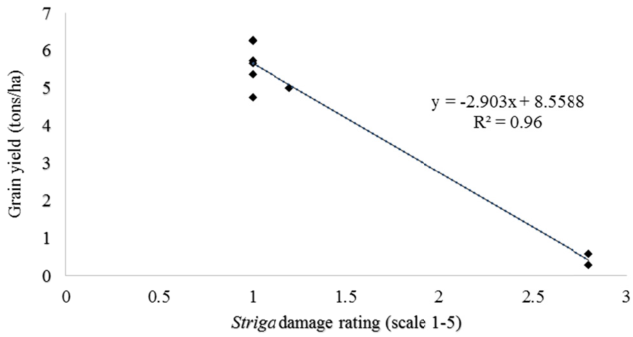

Figure 1. Regression of Grain yield of hybrids with *Striga* damage rating at 8 WAP (weeks after planting) during the short rains of 2011 at Nyahera

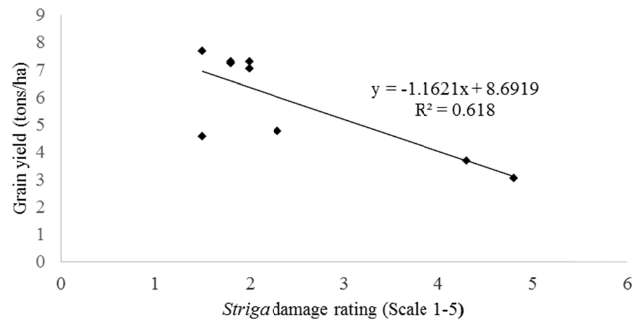

Figure 2. Regression of grain yield of hybrids with *Striga* damage rating at 10 WAP (weeks after planting) during the short rains of 2011 at Nyahera

3.2 Maize Hybrid Evaluation under Non Striga Infestation at Maseno during the Short Rains of 2011

Hybrid evaluation results under non *Striga* infestation at Maseno in short rainy season of 2011 is shown in Table 2. Analysis of variance showed significant differences ($P < 0.05$) among genotypes for grain yield and other yield components. The mean grain yield ranged from 3.74 to 7.39 tons per hectare. The highest yielding hybrid was EH11M followed by EH14. The lowest yielding hybrids were the commercial checks, H513, DK8031 and PHB3253.

Table 2. Means of Hybrids in a trial at Maseno under no *Striga* infestation in 2011 short rain season

Variety	Grain yield (tons ha^{-1})	DMP	Plant Height (cm)	Ear Height (cm)	Ear Aspect (1-5)	Plant Aspect. (1-5)	Turc (1-5)	GLS (1-5)
EH11M	7.39^{a}	68.3^{ab}	226.0^{a}	99.7^{ab}	1.8^{d}	2.0^{bc}	1.8^{c}	1.5^{bc}
EH14	6.30^{ab}	70.3^{ab}	236.7^{a}	112.7^{ab}	2.0^{cd}	1.7^{cde}	1.0^{e}	1.7^{bc}
EH12	5.99^{abc}	71.0^{a}	216.7^{ab}	118.7^{a}	1.5^{d}	1.7^{cde}	1.5^{d}	1.7^{bc}
EH21S	4.98^{bc}	69.7^{ab}	226.0^{a}	115.3^{ab}	1.5^{d}	1.2^{f}	1.5^{d}	1.5^{bc}
EH11S	4.69^{bc}	70.3^{ab}	230.3^{a}	112.3^{ab}	1.7^{d}	1.5^{def}	2.0^{b}	1.5^{bc}
EH21H	4.55^{bc}	68.7^{ab}	213.0^{ab}	104.7^{ab}	1.5^{d}	1.3^{ef}	1.5^{d}	1.7^{bc}
H513*	4.44^{bc}	68.0^{ab}	188.0^{b}	95.7^{ab}	2.5^{bc}	2.3^{b}	2.0^{b}	2.5^{ab}
DK8031*	3.90^{c}	66.3^{b}	205.7^{ab}	85.7^{b}	2.8^{b}	1.8^{cd}	1.0^{e}	1.0^{c}
PHB3253*	3.74^{c}	67.7^{ab}	220.3^{ab}	95.3^{ab}	3.8^{a}	3.2^{a}	2.5^{a}	3.3^{a}
$LSD_{(0.05)}$	2.35	4.6	35.0	30.7	0.7	0.5	0.2	1.1

Note. *: Commercial hybrid check; DMP: Days to mid pollen shed; Turc: turcicum disease; GLS: Gray Leafspot disease.

Means in a column followed by the same letter are not significantly different at $p < 0.05$ by Duncan's multiple range test.

3.3 Maize Hybrid Evaluation under Striga at Nyahera during the Short Rains of 2012

Hybrids evaluation results under *Striga* infestation at Nyahera in long rainy season of 2012 is shown in Table 3. Significant differences ($P < 0.05$) were observed among the hybrids for grain yield under *Striga* infestation. Mean grain yield of the cultivars ranged from 3.05 to 7.68 tons ha^{-1}. The highest yielding hybrid was EH14 while the lowest yielding hybrid was Pioneer hybrid PhB3253.

There were significant differences ($P < 0.05$) amongst the hybrids for *Striga* damage symptoms at 8 and 10 weeks after planting. H513 and PhB3253 hybrids had high *Striga* damage symptoms score and high emerged *Striga* plants at 8 and 10 weeks after planting and low yield. Negative correlations ($r = -0.79$; $r = 0.79$) and coefficient of relationships ($R^2 = 0.62$; $R^2 = 0.6$) were observed between the hybrid grain yield and *Striga* damage rating at 8 and 10 weeks respectively (Figures 3 and 4).

Table 3. Means of hybrids along with checks included in a trial evaluated at Nyahera under *Striga* infestation in 2012 long rains season

Variety	Grain yield (tons ha^{-1})	*Striga* damage rating (1-5)		Number of Emerged *Striga* Plants	
		8 WAP ŧ	10 WAPŧ	8 WAPŧ	10 WAPŧ
EH21S	7.31^{a}	1.3^{c}	2.0^{cd}	18.6^{c}	47.3^{b}
EH11M	7.23^{a}	1.5^{c}	1.8^{de}	42.3^{bc}	143.0^{ab}
DK8031*	4.56^{b}	1.5^{c}	1.5^{be}	58.3^{bc}	128.0^{ab}
EH21H	7.05^{a}	1.5^{c}	2.0^{cd}	26.3^{bc}	106.3^{ab}
EH11S	7.31^{a}	1.2^{c}	1.8^{de}	36.0^{bc}	137.7^{ab}
EH14	7.68^{a}	1.3^{c}	1.5^{e}	26.6^{bc}	87.3^{b}
H513*	3.69^{b}	3.0^{b}	4.3^{b}	118.0^{a}	199.7^{a}
EH12	4.78^{b}	1.3^{c}	2.3^{c}	40.6^{bc}	120.7^{ab}
PHB3253*	3.05^{b}	3.8^{a}	4.8^{a}	80.3^{ab}	192.7^{a}
$LSD_{(0.05)}$	1.77	0.5	0.5	54.3	100.8

Note. *: Commercial hybrid check; ŧ: weeks after planting.

Means in a column followed by the same letter are not significantly different at $p < 0.05$ by Duncan's multiple range test.

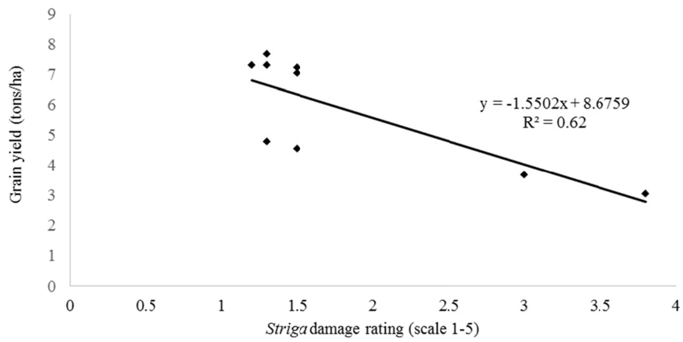

Figure 3. Regression of grain yield of hybrids with *Striga* damage rating at 8 weeks after planting during the long rains of 2012 at Nyahera

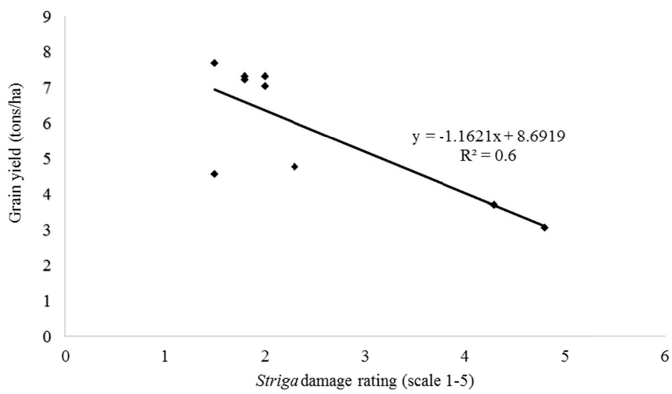

Figure 4. Regression of grain yield of hybrids with *Striga* damage rating at 10 weeks after planting during the long rains of 2012 at Nyahera

3.4 Maize Hybrid Evaluation under Non Striga at Maseno during the Short Rains of 2012

Hybrids evaluation results under non *Striga* infestation at Maseno in long rainy season of 2012 is shown in Table 4. Significant differences ($P < 0.05$) were observed among the hybrids for mean grain yield and yield components.

Table 4. Means of hybrids evaluated at Maseno University farm without *Striga hermonthica* infestation in 2012 long rains season

Variety	Grain Yield (tons ha^{-1})	DMP	Plant Height (cm)	Ear Height (cm)	Ear Aspect (1-5)	Plant Aspect (1-5)
EH21S	9.72^{a}	72.0^{abc}	251.7^{ab}	126.7^{a}	1.8^{b}	1.8^{bc}
EH11M	9.50^{a}	72.3^{ab}	228.3^{cd}	105.0^{bc}	1.5^{b}	1.8^{bc}
DK8031*	9.09^{ab}	70.7^{bcd}	183.3^{f}	71.7^{d}	1.8^{b}	1.0^{d}
EH21H	8.90^{abc}	73.3^{ab}	245.0^{abc}	120.0^{ab}	1.5^{b}	1.3^{bcd}
EH11S	8.89^{abc}	71.3^{abcd}	235.0^{bcd}	110.0^{ab}	1.7^{b}	1.8^{bc}
EH21	8.81^{abcd}	72.0^{abc}	256.0^{a}	128.0^{a}	2.5^{ab}	1.8^{bc}
H513*	8.31^{bcd}	69.0^{cd}	218.3^{de}	110.0^{ab}	2.3^{ab}	3.2^{b}
EH12	7.85^{cd}	74.0^{a}	236.7^{abcd}	109.7^{ab}	1.5^{b}	2.0^{c}
PHB3253*	7.66^{d}	68.7^{d}	206.7^{e}	88.3^{cd}	3.3^{a}	3.8^{a}
LSD $_{(0.05)}$	1.18	3.2	20.3	21.3	1.5	0.6

Note. *: Commercial hybrid check; DMP: Days mid pollen shed.

Means in a column followed by the same letter are not significantly different at $p < 0.05$ by Duncan's multiple range test.

3.5 Maize Hybrid Genotypes Combined Grain Yield and Stability under Striga Infested and Striga Free Environments

Combined mean grain yield of the nine genotypes ranged from 3.69 to 7.46 tons ha^{-1}. The highest yield was obtained from genotype EH11M. The highest ranking genotype was EH11M and the lowest in rank was PhB3253. The maximum maize grain yield values at each environment are underlined (Table 5). A combined analysis of variance constructed to determine the effects of environments (E), genotypes (G) and genotypes by environment interaction shows that grain yields of the maize hybrid genotypes were significantly ($P < 0.001$) affected by environments (Table 6). Also, considering the IPCA1 scores of G × E biplot analysis (Figure 5) the most unstable genotypes were the commercial hybrids DK 8031, H513 and PhB3253. Genotypes adapted to *Striga* infestation were EH12, EH21, EH11M, EH21S and EH11S. The most stable genotypes based on IPCA1 scores were 4 (EH11M) and 2 (EH12).

Table 5. Mean grain yield (tons ha^{-1}) of 9 maize hybrids tested in 4 environments under *Striga* and non *Striga* infestation

Genotype	*Striga* infested		Non *Striga* infested		Mean
	2011	2012	2011	2012	
	Nyahera	Nyahera	Maseno	Maseno	
EH14	<u>**6.27**</u>	<u>**7.68**</u>	6.30	8.81	7.27
EH12	6.25	4.78	5.99	7.85	6.22
EH11M	5.72	7.23	<u>**7.39**</u>	9.50	7.46
EH21S	5.65	7.31	4.98	<u>**9.72**</u>	6.92
EH21H	5.37	7.05	4.55	8.90	6.47
EH11S	4.75	7.31	4.69	8.89	6.41
DK8031*	4.99	4.56	3.90	9.09	5.64
H513*	0.58	3.69	4.44	8.31	4.26
PHB3253*	0.29	3.05	3.74	7.66	3.69
Mean	4.43	5.85	5.11	8.75	6.03

Note. Underlined values are highest yields at each test environment; *: Commercial hybrid check.

Table 6. Combined analysis of variance of grain yield of 9 hybrid maize genotypes tested across two environments *Striga hermonthica* infested and non *Striga hermonthica* infested in 2011 and 2012

Source of Variation	Df	SS	MS	F	P	Explained (%)
Environment	1	73.788	73.788	36.49***	0.00	50
Genotype	8	57.465	7.183	3.55**	0.05	39
Environment*Genotype	8	16.178	2.022	0.54^{ns}	0.81	11
Error	18	67.348	3.742			
Total	35	214.779				

Note. ***: highly significant (P < 0.001); **: significant (P < 0.05), ns-non significant.

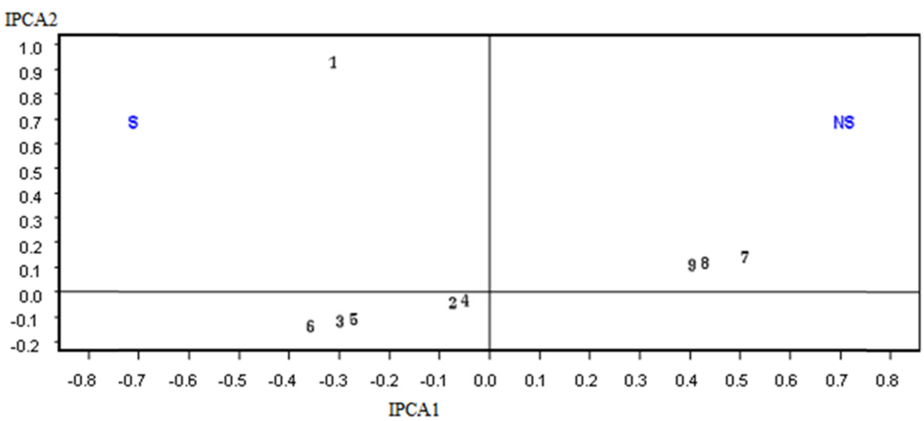

Figure 5. Additive, Main effects and Multiplicative Interaction (AMMI) Bi-Plot of Genotype* Environment of the nine Maize hybrids evaluated under *Striga* (S) and Non-*Striga* (NS) infestation

Note. 1 = EH14; 2 = EH12; 3 = EH21S; 4 = EH11M; 5 = EH21H; 6 = EH11S; 7 = H513; 8 = PHB3253; 9 = DK8031; S = *Striga* infested Environment Nyahera; NS = Non *Striga* infested Environment Maseno University.

3.6 National Performance Trials

National performance trial results for the two hybrids EH12 and EH14 show their relative yield performance and *Striga* damage rating compared to popular commercial checks PhB3253, Ua-Kayongo and OPV GFVC04 (Table 7). They exhibit higher yields, tolerance to *Striga hermonthica* and stability over environments. EH12 and EH 14 had a co-efficient of determination (R^2) of 0.91 and 0.94 across environments respectively (Table 7).

Table 7. Two and three years Stability parameters for Grain yields and *Striga* damage rating

NPT years	Variety	Source	Yield (t/ha)	R^2	Stability Estimate				SDR
					Sd_i		b_i		
					Estimate	P-Value	Estimate	P-Value	
2	EH14*	Maseno University	6.21	0.91	0.58	0.71	1.26	0.03	1.30
2	Ua-Kayongo	CIMMYT	4.27	0.83	0.67	0.60	0.96	0.74	1.60
2	GFVC04	KARI	4.20	0.82	0.50	0.82	0.81	0.07	2.10
2	PhB3253	Pioneer Seeds	4.13	0.88	0.39	0.92	0.89	0.23	1.90
3	EH12$^{\infty}$	Maseno University	4.69	0.94	0.41	0.96	1.36	0.00	4.02
3	Ua-Kayongo	CIMMYT	3.98	0.83	0.55	0.84	0.89	0.19	2.40
3	GFVC04	KARI	3.95	0.80	0.56	0.83	0.82	0.05	2.50
3	PhB3253	Pioneer Seeds	3.48	0.87	0.45	0.93	0.95	0.53	4.10

Note. NPT: National Performance Trials; SDR: *Striga* damage rating (Scale 1-5) at 12 weeks after planting; b_i: regression co-efficient; *, ∞: Variety released by the National Variety release Committee (NVRC) in 2012 and 2013 respectively; KARI: Kenya Agricultural Research Institute; CIMMYT: International maize and wheat improvement centre.

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials report 2012.

4. Discussion

4.1 Maize Hybrid Evaluation under Striga and Non Striga Infestation at Nyahera and Maseno during the Short Rains of 2011 and Long Rains 2012

For all the hybrid evaluations under *Striga hermonthica* infestation there were varietal differences in response to *Striga hermonthica* damage. Commercial hybrids H513 and PhB3253 hybrids had higher *Striga* damage symptoms and higher emerged *Striga* plants at 8 and 10 weeks and low yield. This was in comparison to experimental hybrids that had high yields under *Striga hermonthica* infestation. It has been reported that the severity of infestation vary with genotypes (Ransom et al., 1990). The differences among the cultivars/genotypes in the level of yield reduction could be due to differences in the level of resistance/tolerance of the maize genotypes studied (Akaogu et al., 2012).

Mean grain yield of the maize genotypes varied among the two environments. Generally, the mean grain yields at Maseno, a non *Striga hermonthica* infested location was higher than the mean grain yields at Nyahera, a *Striga hermonthica* infested area. This suggests that low grain yield can be associated with *Striga* damage symptoms and number of emerged *Striga* plants. Grain yield reduction of up to 42 percent under *Striga* infestation has been reported (Badu-Apraku et al., 2004). The mean grain yield ranged from 3.76 to 5.85 and 5.85 to 8.75 tons ha^{-1} under *Striga hermonthica* infestation and non *Striga hermonthica* infestation respectively. This means that the average grain yield of cultivars under *Striga* infestation was between 65-75% of that under *Striga* free conditions. The observed large loss in grain yield, high host plant damage syndrome rating and large number of emerged *Striga* plants recorded are clear indications of the severe parasite pressure achieved during the evaluation of the cultivars at *Striga hermonthica* infested location at Nyahera.

The significant and negative correlations between the grain yield and *Striga* damage ratings shows that these traits/parameters are highly associated in a nonlinear way. It appears that the most susceptible hybrids with high severity rating like PhB3253 and H513 tended to have low grain yields and vice versa. These results are not unusual since low grain yield of varieties under *Striga* infestation have been associated with high *Striga* damage symptoms as well as high emerged number of *Striga* plants (Menkir et al., 2007). The high negative significant correlation between grain yield and host plant *Striga* damage rating is consistent with the results of earlier studies (Kim, 1991, 1994; Efron, 1993; Kim & Adetimirin, 1995, 1997; Badu-Apraku et al., 2004) and confirms that *Striga* damage is an appropriate trait for the assessment of *Striga* tolerance under *Striga* infestation.

4.2 Maize Hybrid Genotypes Combined Grain Yield and Stability under Striga Infested and Striga Free Environments

The development of maize hybrids which are high yielding and relatively stable when grown in different environments is of fundamental importance to commercial maize production (Gamma & Hallauer, 1980). At the same time yield stability in maize is under genetic control and thus suitable for selection (Scott, 1967). Combined analysis of variance of grain yield showed that the grain yields of the maize hybrid genotypes were significantly affected by environment which explained 50% of the total variation (G+E+GEI), whereas genotype and genotype × environment interaction accounted for 39% and 11% respectively (Table 6). Evaluation of genotypic performances of hybrid maize cultivars in a number of environments provides useful information to identify their adaptation and stability (Crossa et al., 1990).

Stability of expected grain yield is one of the most desirable properties, in order to recommend hybrid use (Radomir et al., 2009). The most accurate model for AMMI can be predicted using the first two PCAs (Gauch & Zobel, 1996; Yan et al., 2000; Annicchiarico, 2002). By plotting both the genotypes and the environments on the same graph, the associations between the genotypes and the environment can be seen clearly (Figure 3). The IPCA (Principal Component Analysis) scores on the genotype in the AMMI analysis are an indication of the stability or adaptation over environments (Gauch & Zobel, 1996; Purchase, 1997; Alberts, 2004). The greater the IPCA scores, the more specific adapted is a genotype to certain environments. The more the IPCA scores approximate to zero, the more stable or adapted it is over all the environments sampled. Genotypes adapted to *Striga* infestation were EH12, EH14, EH11M, EH21S and EH11S. The most stable genotypes based on IPCA1 scores were 4 (EH11M) and 2 (EH12). Hybrids 9 (DK8031), PhB3253 and H513 fall within the NS (Non *Striga*) component of the bi-plot meaning that they do well under *Striga hermonthica* free conditions. The rest of the hybrids fall under the S (*Striga hermonthica* infested)-component of the biplot which means they tolerate *Striga hermonthica* infestation. However the ideal genotype is EH 14 denoted by 1 in the S-biplot component showing excellent performance under *Striga hermonthica* infestation.

4.3 The National Performance Trials

EH14 generally had the least *Striga* damage rating of 1.3 and highest yield suggesting it was resistant to *Striga* damage. EH12 had a higher damage rating and high yield suggesting it is exhibiting tolerance. Resistance to *Striga* refers to the ability of the host plant to stimulate the germination of *Striga* seeds but prevent the attachment of the parasite to its roots, or kill the attached parasite. When under infestation, the resistant genotype, like EH14, supports significantly fewer *Striga* plants and produces higher yield than a susceptible genotype like PhB3253 (Dogget, 1988; Ejeta et al., 1992; Haussmann et al., 2000; Rodenburg et al., 2006). A *Striga* tolerant genotype on the other hand germinates and supports as many *Striga* plants but produces more grain (Kim, 1994).

Linear regression coefficient (b_i) for the mean grain yield of a single genotype on the average yield of all genotypes in each environment resulted in regression coefficient (b_i values) ranging from 0.81 to 1.36 for grain yield (Table 7). This large variation in regression coefficient explains different responses of genotypes to environmental changes (Akcura et al., 2005). Genotypes with high mean yield, a regression coefficient equal to the unity ($b_i = 1.0$) and small deviation from regression ($\delta_{ij} = 0$) are considered stable (Finlay & Wilkinson, 1963; Eberhart & Russell, 1966). Genotypes EH12 and EH 14 had a co-efficient of determination close to unity and lower deviation from regression. R^2 Values were as high as 0.91 and 0.94 across the *Striga* environments respectively (Table 7) confirming their stability in *Striga* infested areas. It is therefore not surprising that the varieties, EH14 and EH12 were officially released for commercialization in *Striga hermonthica* infested areas in western Kenya.

5. Conclusion

The study supported the hypothesis that different maize genotypes respond differently to *Striga hermonthica* infection. The maize genotypes identified in this study that are high yielding, supports fewer emerged *Striga hermonthica* plants, have low *Striga* damage ratings and broad adaptation can contribute significantly to the integrated efforts to eradicate *Striga* menace. Their parents should be used in breeding programs focused on developing resistant maize cultivars that support fewer parasites and thus add less parasite seeds into the soil for subsequent crop. The parental lines of the Maseno experimental hybrids exhibiting tolerance/resistance were previously selected from maize landraces from western Kenya and the finding from this study suggest that they have potential sources of *Striga* weed tolerance genes that could be used in breeding programs. EH12 and EH14 maize hybrids have since been released for commercial production targeting *Striga* endemic areas of western Kenya. The rest of the cultivars, EH11M, EH21S, EH11M and EH11S should be also be extensively tested in on farm and national performance trials and vigorously promoted for adoption for commercialization in *Striga* endemic areas in the sub region.

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