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International Maize and Wheat Improvement Center

Herbicide-resistant MAIZE to control STRIGA in Eastern and Central Africa

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Introduction

Striga hermonthica (witchweed) infestation on farmers' fields is one of the major factors responsible for the low maize yields achieved in sub-Saharan Africa [average of 1.5 tons/ha against a world average of 4.2 tons/ha, (FAO, 2003)]. A single Striga plant produces over 50,000 seeds, which can remain viable in the soil up to 20 years, and it is estimated that 10-40 billion seeds are added to the soil each year. Approaches like crop rotation, the use of organic and inorganic fertilizers, and Striga-tolerant cultivars can partially allay the problem.
A new technology, which combines low doses (<30 g/ha) of Imazapyr™ herbicide applied as a seed coating to conventionally bred imidazolinone-resistant (IR) maize seed, has been developed. The herbicide coat kills the weed off before or during the weed's attachment to maize roots, making possible dramatic crop yield gains even within the first season of use. It also depletes the Striga seed bank in the soil.

Objectives

To convert elite mid-altitude and lowland CIMMYT maize OPVs to IR using conventional backcrossing.
To determine the performance of these IR OPVs under Striga free and Striga infested conditions in east Africa.


It is estimated that 10-40 billion seeds are added to the soil each year

Materials and Methods

Conversion of elite OPVs to IR

The initial testing of the low-dose herbicide seed treatment technology was on the IR maize hybrid, PH 3245-IR, developed by Pioneer Seeds. This hybrid is a temperate material and is highly susceptible to maize diseases prevalent in the tropics. In 1996, PH 3245-IR was used by CIMMYT's Applied Biotechnology Center to convert 2 CMMYT Maize Lines (CML202 and CML204) to IR. In 2000, CIMMYT Kenya initiated the conversion to IR of elite CIMMYT lines and OPVs adapted to eastern and southern Africa conditions.

Early and intermediate stress tolerant OPVs developed under the Africa Maize Stress (AMS) and the Southern Africa Drought and Low Soil Fertility Projects (SADLF) were crossed with the IR single cross CML202-IR x CML204-IR. The BC_0F_1 crosses were planted along with the recurrent parents and four weeks after planting or after the first irrigation; the BC_0F_1 plants were sprayed with imazapyr (15 g a.i. ha^{-1}) as 25% ArsenalTM. Plants without the IR-gene died while those that were heterozygous were severely deformed. At flowering, bulked pollen of the recurrent parents was used to pollinate the resistant plants of BC_0F_1 crosses. The BC_1F_1 crosses and the recurrent parents were planted to form the BC_0F_1 using the same procedure. During the formation of the BC_3F_1, 30 g imazapyr a.i. ha^{-1} of herbicide was applied. The BC_3F_1 were recombined twice; however, the seeds were coated with imazapyr at the rate of 30 g a.i. ha^{-1} instead of the plants being sprayed.

Herbicide use

Spraying: Ten liters of water was mixed with 6 ml of 25% ArsenalTM in a 20-liter backpack sprayer and applied to maize plants at 8-10 leaf stage for selecting homozygous plants in an area of 500 m^{-2}.Thus the imazapyr application rate was to 30 g a.i. ha^{-1}.

Coating procedure: Seeds were coated with the herbicide by mixing 54 gm of 20% a.i. lindane and 26% a.i. thiram-containing commercial seed-dressing powder (Murtano) with 600 ml water and 30 g imazapyr to make slurry. The seeds for control treatments were only treated with the insecticide/fungicide powder. The slurry was added to 18 kg of IR-maize seed (seed rate/ha), to give a coating of about 0.56 mg a.i. imazapyr/seed, (30 g a.i. ha^{-1}, at a density of 53,300 plants ha^{-1}). Treated seeds were then air dried before planting.

Artificial Striga infestation: Trials under Striga-infested plots required artificial infestation. An inoculum was prepared by mixing about 5 g Striga seeds (25% purity and 25% viability) thoroughly with 5 kg fine sand. The inoculum was then added to an enlarged planting hole at a depth of 7-10 cm (directly below the maize) to ensure that each maize plant was exposed to a minimum of 5,000 viable Striga seeds in addition to those already in the field.

Trial management

The trial was composed of 22 IR open pollinated varieties (IR-OPVs), two commercial checks, and one local check and was grown at 6 locations in Kenya, 2 locations in Uganda and 1 location each in Ethiopia and Sudan in 2004. The experimental design was a 5 x 5 simple lattice with 2 replications. Plot size was 2 rows at all locations but plant density differed by location. The trial was grown at 12 Striga-infested sites and 10 Striga-free sites. At Alupe and Kibos in Kenya, the trial was artificially infested with Striga seeds at planting while at other locations the trials were planted in fields naturally infested with Striga. All agronomic and cultural practices were carried out as recommended at each location. Data were recorded on plot basis on all important agronomic characters under both Striga-free and Striga-infested conditions. Under Striga-infestation, the number of emerged Striga plants at 8, 10, and 12 weeks after planting was recorded and expressed as Striga plants m-2. Plots were hand-harvested and the weight of the ears was used to calculate grain yield, adjusted to 80% shelling percentage and 15% grain moisture.


The field is Striga-free during the active growing period

Statistical Analysis

Individual location analyses of variance were done by PROC MIXED of SAS (SAS, 2001). Genotypes were considered fixed effects while replications and environments were considered random effects. Across environments analysis of variance for each trait was conducted using PROC GLM of SAS. Only data for locations where there was significant variance for grain yield and Striga counts was used for the across site analysis. Sixteen sites showed significant differences for grain yield and Striga counts. Data of the local check was omitted from the across site analysis. Simple linear correlation analysis was performed among agronomic traits and number of Striga plants.

Results and discussion

Under Striga-free conditions, significant differences ($P<0.01$) were detected for grain yield, anthesis date, and ear height among genotypes (Table 1). Genotype x environment interaction was significant for all traits except plant and ear height. Under Striga-infested conditions, both genotype and genotype x environment interaction were significant ($P<0.01$) for grain yield, plant height, ear height and Striga counts 10 and 12 weeks after planting, showing differences in performance among the varieties as well as differential response of the varieties at different locations (Table 2). Under Striga-free conditions, grain yield averaged 3.0 Mg ha^{-1} and ranged from 1.6 Mg ha^{-1} to 3.8 Mg ha^{-1} (Table 3). The best IR variety (ECA-STRIGOFF-VE-206) out-yielded the Striga tolerant commercial check KSTP94 (3.8 vs. 3.4 Mg ha-1) by 11%. Four OPVs significantly out-yielded the commercial check WS202. The IR-OPVs and the checks were of the same maturity (about 68 days to silk); therefore, the yield differences among the IR-OPVs and the checks may not be due to the differences in maturity. Under Striga infestation, across environments the 20 IR-OPVs averaged 1.7 Mg ha^{-1} vs. 0.9 Mg ha^{-1} for the checks (Table 3). Eighteen IR-OPVs significantly out-yielded the Striga tolerant commercial check (1.5-2.5 vs. 0.7 Mg ha^{-1}) showing a clear grain yield advantage of the IR-OPVs under Striga infestation. The best IR-OPV under Striga infestation gave 66% higher grain yield than the Striga tolerant commercial check. This is an indication that farmers in Striga infested areas would harvest more grain if they adopted the adapted IR-OPVs.

All IR-OPVs supported a significantly lower number of Striga plants m^{-2} compared to the Striga tolerant commercial check. The number of emerged Striga plants m^{-2} 10 weeks after planting ranged from 0-1 plants for the IR-OPVs compared to an average of 4 plants for the check varieties (Table 3, Figure 1). However, few Striga plants emerge on the IR-OPVs by 12 weeks, but they do not mature to produce viable seeds. This prevents addition of new Striga seeds to the soil. A slight variation in the number of Striga plants under the IR-OPVs was observed possibly due to heterogeneity of the field that may have led to water logging in some parts. In such spots, some of the herbicide could have been leached or washed away before it killed all the Striga seed around the sown maize seeds. Striga-infestation led to a reduction in plant and ear height in all varieties, with the exception of 2 OPVs. Grain yield was negatively correlated with the number of Striga plants m^{-2} ($r=-0.22^{**}$), and the number of Striga plants 8 and 10 weeks after planting ($r=-0.11$ and $r=-0.14^{*}$, respectively). In some cases, very low grain yield was observed even where the number of Striga plants was zero, indicating that yield reduction was due to other factors such as drought and low soil fertility, or phytotoxicity of the Striga attack.

Table 1. Analysis of variance for agronomic traits of 24 maize varieties evaluated at Striga-free sites in 2004.

Source	df‡	GY†	AD	ASI	PH	EH	EA	HC
Environment (E)	4	162.04**	774.31**	84.63**	168467.36**	102853.76**	11.16**	1879.50**
Rep(E)	5	0.99	16.19**	10.88*	638.72	66.81	0.27	4.11
Genotype (G)	23	4.26**	46.52**	10.68	222.73	253.08**	0.49	116.42
G*E	92	1.07**	4.69**	8.29**	206.36	71.44	0.44**	94.93**
Error	115	0.51	2.74	3.27	275.87	59.41	0.21	25.48

*Significant at P<0.05, **Significant at P<0.01
†AD=days to anthesis, ASI=anthesis silking interval, EA=ear aspect, EH=ear height, PH=plant height, GY=grain yield, HC=husk cover.
‡df for E, Rep(E), G*E and Error differed for traits. These were 5, 6, 115 and 138 for AD; 2, 3 46, and 69 for ASI, PH, EH, and EA; 3, 4, 69, 92 for HC.

Table 2. Analysis of variance for agronomic traits and Striga counts of 24 maize varieties evaluated at Striga-infested sites in 2004.

Source	df‡	GY†	PH	AD	HC	EA	EH	Striga1	Striga2	Striga3
Environment (E)	7	32.24**	9602.43**	588.07**	4640.56**	2.56**	8549.58**	50.85**	213.69**	10.10**
Rep(E)	8	2.56**	831.81**	4.51	179.35	1.34	1479.80**	13.27**	33.26**	0.94
Genotype (G)	23	4.91**	1830.91**	16.12**	1605.72	2.26**	623.87**	5.00*	15.82**	26.32**
G*E	161	0.52**	582.61**	5.53*	1063.98**	0.78	200.59**	3.13**	2.85**	2.60**
Error	184	0.22	156.33	3.46	177.44	0.59	88.92	1.05	1.4	1.11

*Significant at P<0.05, **Significant at P<0.01; †AD=days to anthesis, ASI=anthesis silking interval, EA=ear aspect, EH=ear height, PH=plant height, GY=grain yield, HC=husk cover, Striga1=Striga plants m-2 8 weeks after planting, Striga2= Striga plants m-2 10 weeks after planting, Striga3= Striga plants m-2 12 weeks after planting, STR=Striga plants/m2;, ‡df for E, Rep(E), G*E and Error differed for traits. These were 6, 7, 138 and 161 for PH and Striga3; 3, 4, 69, and 92 for AD, HC, and EA; 4, 5, 92 and 115 for EH; 5, 6, 115, and 138 for Striga1.

Table 3.Performance of selected maize varieties under Striga-free and Striga-infested conditions across 16 sites in 4 countries in 2004.

		Grain yield (t/ha)		Striga plants m^{-2}	
	Variety	Striga- free	Striga-infested	10 WAP	12 WAP
7	ECA-STRIGOFF-VE-206	3.8	2.5	1.1	1.2
9	ECA-STRIGOFF-VE-208	3.5	2.2	0.6	0.2
11	ECA-STRIGOFF-VE-210	3.4	2.1	0.7	0.8
12	ECA-STRIGOFF-VE-211	3.4	2	1.0	0.3
13	ECA-STRIGOFF-VE-212	3.1	2	0.9	0.5
16	ECA-STRIGOFF-VE-215	3.4	2.1	1.0	0.3
17	ECA-STRIGOFF-VE-216	3.7	2.4	0.8	0.3
18	ECA-STRIGOFF-VE-217	3.6	2.2	0.9	0.2
23	KSTP (Striga tolerant check)	3.4	0.7	5.2	6
24	WS202 (commercial check)	2.7	1.1	2.2	4
	LSD (0.05)	0.9	0.5	1.2	1.2

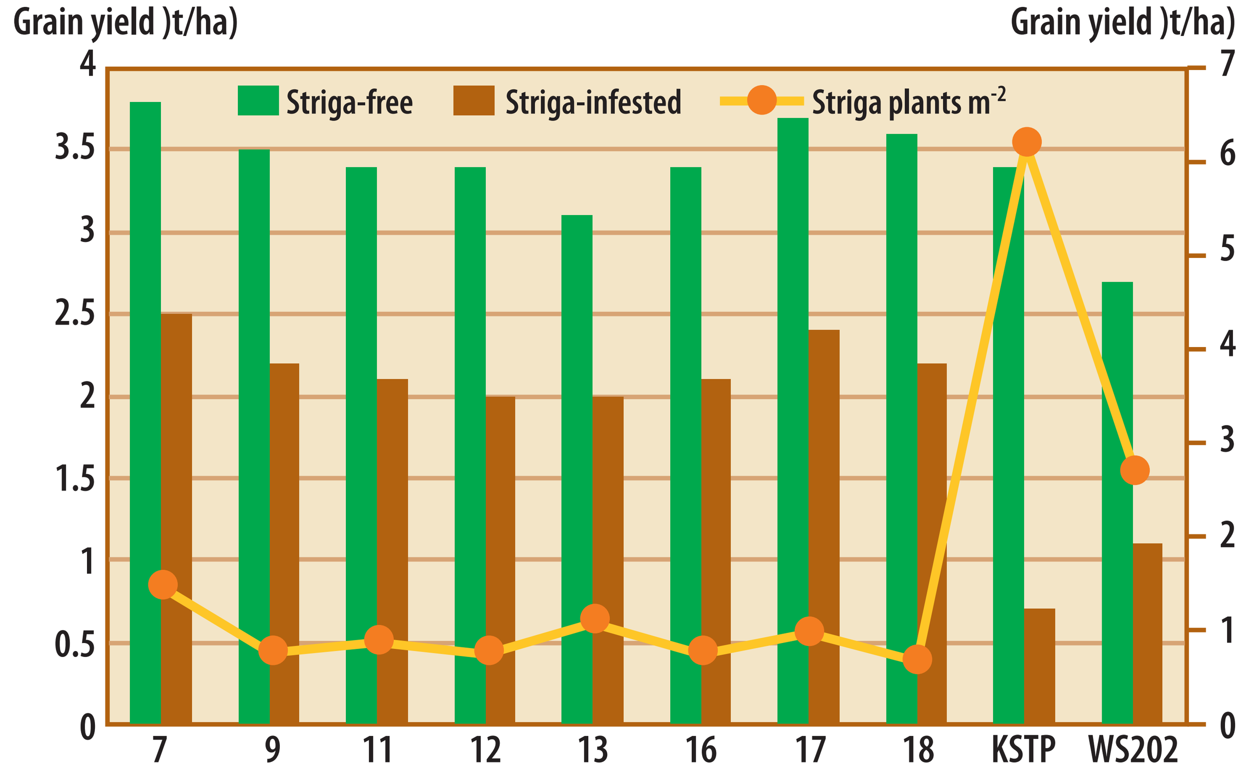

Figure 1. Grain yield (t ha-1) and Striga count (plants m-2) of selected herbicide resistant OPVs compared to two checks tested across 16 sites in four countries in 2004.

Conclusions

The IR gene has been introduced into locally adapted germplasm which could be used to convert other germplasm.
The IR technology allows farmers to increase their maize yield per unit area, and, importantly, depletes the Striga seed bank in the soil. Adoption of these varieties can go a long way in improving maize production in areas where Striga is endemic in SSA. Therefore, this technology will impact positively the livelihood of poor subsistence farmers in cereal-based agricultural systems. To fully realize the potential benefit of the technology, there is need to integrate it with other Striga control methods to effectively deplete the Striga seed bank and enhance soil fertility.
IR-maize will act as stopgap technology to help African farmers in Striga-endemic areas achieve good maize yields, until maize varieties with adequate genetic resistance become available.

References

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