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Effectiveness of Imazapyr Coated Hybrids and Selected Striga-tolerant Varieties on *S. hermonthica* Management and Maize Yield Performance in Western Part of Kenya

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Abstract: *Striga hermonthica*, an obligate root hemi-parasite, is a massive biological constraint that hinders maize (*Zea mays* L.) production in western part of Kenya particularly when susceptible varieties are used. Use of Imazapyr resistant hybrids coated with small doses of imazapyr herbicide offers potential for management of *Striga hermonthica* and increase maize production. A study was conducted to evaluate the effectiveness of Imazapyr Resistant Maize (IRM) and selected striga tolerant varieties on *S. hermonthica* management and yield of maize. Field trials were conducted during two successive cropping seasons (2018 and 2019) at Alupe Research Station (artificial inoculation), farmer's field in Rangwe (natural infestation) and Koibatek Agricultural Training College (striga free) in Busia, Homa Bay and Baringo Counties respectively. The genotypes were evaluated in randomized complete block design with three replication. Test materials comprised of two IRM (H528IR, FRC425IR), two striga tolerant (KSTP94, GAF4), five susceptible commercial hybrids (DK8031, H513, DUMA43, DH04, Haraka 101) and two local landraces (*Shipindi, Nya Uyoma*). All striga and crop data collected were subjected to analysis of variance and means separated using Tukey's HSD test. Results showed that IRM varieties significantly ($P \leq 0.05$) reduced number of emerged striga plants by 56 and 69% compared to the local landraces and commercial hybrids, respectively. Similarly, IRM varieties produced 50.3 and 79.5% higher grain yields compared to striga tolerant (KSTP94 and GAF 4) and susceptible hybrids, respectively under striga infestation. However, the grain yields recorded at Koibatek ATC (striga free) were 67 and 70% higher than at the Rangwe and Alupe sites, respectively. These findings show that use of Imazapyr resistant technology in maize production contributes to improved striga management and enhances maize grain yields. This technology can be integrated with other measures to contain striga in infested areas.

Keywords: Striga, Parasitic Weed, IR, Herbicide, Seed Banks, Imazapyr, Imidazolinone Resistant, Metsulfuron-methyl, Resistance, Integrated Control

1. Introduction

Witch weed (Striga spp.) is a massive root parasite of significant economic importance in much of Africa and parts of Asia where it hinders the production of maize (*Zea mays* L.) and other cereal crops. The weed causes yield losses estimated at US$7 billion that directly affects the livelihood of about 300 million people in Sub Saharan Africa (SSA) [13, 24]. In Kenya, *Striga hermonthica* is the predominant species that poses a serious threats to maize production sometimes leading to total crop loss [35]. It's widespread and the most damaging to many other cereal crops, finger millet (Eleusine coracana), rice (Oryza sativa L.), and sorghum (Sorghum bicolor L. Moench). Under extreme infestation, a single host plant can support over a hundred parasitic weeds, each capable of producing tens of thousands of seeds [40]. These seeds persistently remain in the soil spoiling the fields against future cereal production.

Beyond the burden of losing food and water to the parasitic weed, the host maize plants suffer from a characteristic malady resembling the symptoms of severe drought, including leaf scorching and increased root to shoot ratios [41]. It causes crop damage through hormonal perturbations particularly in ABA, inducing harmful phytotoxic chemicals that alter host–water relations and reduces photosynthesis through competition for water, nutrients, and light [14, 15, 39]. *Striga hermonthica* has heavily infested western part of Kenya, a region where maize is the major staple food crop, resulting to paltry harvest of less than 1 t ha^{-1} against an existing huge potential of 5 t ha^{-1} [17]. This situation has been worsened by depleted soil fertility, degraded land and soil moisture deficit, conditions best suited for striga growth [19, 33]. In addition, rapid expansion of maize production into marginal areas with minimal use of external inputs has intensified the effects of striga parasitism [16]. Additionally, farmers in these areas practice poor farming practices such as mono-cropping of cereals as opposed to crop rotation and intercropping farming practices.

Management of striga has been complicated by its nature of prodigious seeds production that only germinate when they perceive strigolactones produced by suitable host [19]. In the absence of host roots' stimulants, the seed persistently remain dormant in the soil for a period of up to 20 years [12]. Its early parasitism results to substantive yield losses of up to 75% just before emerging from the ground [9]. Striga is managed through various cultural practices, genetically manipulation of crop plants and optimal crop growth conditions [40]. Infestation is generally much less severe where water and soil fertility are optimal for crop growth [19]. However, growing conditions are rarely optimal in much of Africa production systems. Available technologies including crop rotation, intercropping with legumes and use of biological methods [1, 22]. These approaches aims at reducing existing soil seeds bank and prevent new introductions.

Bio-control options such as inoculation with Fusarium isolates, arbuscular mycorrhizal (AM) fungi, suppression through intercropping with allelopathic legumes have been widely deployed with minimal success [26, 30, 42]. In the short-run, improved crop varieties with tolerance to striga remain the most feasible technology for the small-holders farmers since it is most practicable and sustainable solution [32]. Furthermore, it has the ability to manage striga parasitism at its early growing period thereby depleting striga seed bank and it is mostly compatible with the existing farming system [21]. Integrating various management options with improved agronomic practices generally enhances the adeptness of management and cost of striga management in many African growing systems [13].

Early studies have indicated that coating imazapyr resistant (IR) maize with small doses of imazapyr herbicide coated on imazapyr resistant hybrids inhibit synthesis of branched amino acids by the parasitic weed thus reducing the losses attributed to striga [23]. In order to use imazapyr herbicide coating on IR maize a foreign gene was incorporated into elite maize varieties through single nucleotide substitution resulting into development of mutants 1 and 2 that are cross-tolerant to all acetohydroxyacid synthase (AHAS) inhibiting herbicides [37]. Upon absorption of the herbicide by the germinating IR maize, the herbicide systemically moves within the plant system forming a protective mechanism that kills attaching haustoria approaching the crop in the root zones while the unabsorbed herbicide disperses into the surrounding soil killing dormant, germinated and not attached seeds [20].

To prevent development of resistance to imazapyr and protect this advanced gains, there is need for farmers to plant IR-hybrids without herbicide coating at certain intervals in striga infested fields to prolong the potential effectiveness of the herbicide [28]. However, limited research generated information on the field efficacy of IRM technology on striga management and maize productivity is available. Field studies were thus conducted to evaluate the effectiveness of the existing Imazapyr Resistant (IR) varieties and selected striga tolerant varieties on Striga hermonthica management and yield of maize in western part of Kenya.

2. Materials and Methods

2.1. Study Sites

Field experiments were conducted at two sites where *S. hermonthica* is a major parasitic weed of maize and a third site which is free of striga. The study sites included KALRO Alupe Research Station (0°30′N, 34°07′E) that lies at 1157 m elevation in Lower Midland (LM3) agro-ecological zone (AEZ) in Busia County; natural striga infested farmer's field in Rangwe (0°37'S, 34°37'E) which lies at 1700 m elevation in Lower Midland (LM2) AEZ in Homa Bay County and the striga free site, Koibatek Agricultural Training College (10° 35′S, 36°66′E) which lies at 1890 m elevation in upper midland (UM4) AEZ in Baringo County. KALRO Alupe site is dominated by Ferralsol soils with sandy clay texture, which are deep, well drained and have good water holding capacity; soils at the Rangwe site are predominantly Nitosols of sandy loam texture and well drained with good water holding capacity and Koibatek ATC site is dominated by vitric soils with moderate to high soil fertility and well drained deep to sandy loam [18].

2.2. Study Materials

A total of nine (9) early maturity (110-120 days) maize genotypes were planted, during the short rains of 2018 and long rains of 2019, in a randomized complete block design (RCBD) with three replicates in each site. Test materials comprised of two IR maize obtained from Kenya Seed Company (H528IR) and Freshco Seed Company (FRC425IR), two striga tolerant varieties obtained from KALRO Kakamega (KSTP94, GAF4), five commercial hybrids (DK8031, H513, DUMA 43, DH 04, Haraka 101) and two open pollinated local landraces, considered as striga tolerant, Shipindi obtained from farmers in Alupe and *Nya Uyoma* from farmers in Rangwe (Table 1).

Table 1. *Variety, source, year of release and striga reaction status.*

No	Genotype	Source	Year of release	Striga reaction status
1	FRC 425-IR	Fresco Seed company	2013	Tolerant
2	H528-IR	Kenya Seed company	2009	Tolerant
3	H513	Kenya Seed company	1995	Susceptible
4	HARAKA 1010	Western seed Company	2015	Susceptible
5	'*Nyar Uyoma*'	Farmers	Local landrace-Homabay	Tolerant
6	'*Shipindi*'	Farmers	Local Landrace-Busia	Tolerant
7	DK8031	Monsato seed	2015	Susceptible
8	DUMA43	Seedco Seed company	2009	Susceptible
9	DH04	Kenya Seed company	2001	Susceptible
10	KSTP 94	KALRO Kakamega	2008	Tolerant
11	GAF 4	KALRO Kibos	Under trial	Tolerant

2.3. Experimental Procedures

Each experimental plot measuring 4.5 m by 5.0 m was planted with maize at 0.75 m and 0.25 m inter and intra-row spacing, respectively. Two maize seeds were placed in each hill and covered with lighter soil and later thinned, 14 days after planting, to one maize plant per hill giving a final expected plant population of 53,333 ha^{-1}. At KALRO Alupe site, the experimental plots were artificially inoculated with preconditioned S. hermonthica seeds on the eve of planting day. The preconditioned striga seeds were mixed in a ratio of one tea spoonful (2.5 g) of preconditioned striga seeds to 5 kg sand prior to planting [34]. A farm with history of heavy striga infestation was purposefully selected in Rangwe and experimental plots relied on natural infestation from the striga seeds in the soil seed bank. All experimental plots received 60 kg N and 50 kg P_2O_5 ha^{-1} with diammonium phosphate (DAP; 18:46:0) and calcium ammonium nitrate (CAN; 26%) as sources of the two nutrient elements. CAN was applied in two splits at 4 weeks after planting (WAP) and when crop was nearing booting stage. Weed flora other than striga were carefully hand pulled at 2, 4 and 8 weeks after planting (WAP). Scouting and spraying against fall armyworm was done at first appearance of infestation and subsequently an intervals of two weeks using synthetic insecticide, Match 50EC at 500 ml ha^{-1}.

2.4. Data Collection

On both striga infested sites, (Alupe and Rangwe), the sampling unit consisted of three central rows in each experimental plot. Data were collected on days to 1^{st} striga shoot appearance, plant height taken at 12^{th} weeks after planting (WAP), striga counts taken at 8 and 10 WAP and striga damage severity rating was scored per plot on a scale of 1-9, where 1=no damage, indicating normal plant growth, and 9=complete collapse or death of the maize plant according at 10 WAP (coincides with full silking of maize) [10, 25]. Data were also collected on grain yield (t ha^{-1}) and yield components. At the striga free site, Koibatek Agricultural Training College, data were only collected on maize plant height, grain yield and yield components. Assuming a shelling percentage of 80% and grain moisture content of 12.5% for safe storage, grain yield (t ha^{-1}) was computed as:

$$\text{Grain Yield (g ha}^{-1}\text{)=Cob weight x } \sum(100 - \mathrm{M})/100 - 125)\text{x } 0.81)$$

Where, M is the measured moisture content in the grain harvested [22].

3. Data Analysis

All data on striga counts were first transformed using square root transformation of x+0.5 before subjecting to analysis of variance (ANOVA) in SAS Proc GLM (SAS Institute 2011) [17]. All agronomic data on maize yield and yield components were subjected to ANOVA and treatment means separated using Tukey's HSD test at $P \leq 0.05$.

4. Results

Results showed clear discernible differences in striga-related data and response by maize genotypes to *S. hermonthica* infestation (Table 2). The duration (days) to striga emergence and subsequent striga counts were significantly ($P \leq 0.05$) affected by the cropping season, maize genotype and the cropping season by maize genotype interactions at the Alupe and Rangwe experimental sites. Similar result trends were recorded for maize agronomic traits of grain yield and yield components. IR maize genotypes, H528IR and FRC425IR, significantly delayed the emergence of striga by 69-86% to 50-54 days compared to 29-32 days for the commercial susceptible hybrids (DK8031, DH04, GAF4, DH04) and local landraces (*Nyar Uyoma* and *Shipindi*) (Table 3) at both sites. The two local landraces, Nyar Uyoma and Shipindi, recorded 10 and 28% delay in striga emergence at Rangwe and Alupe sites respectively.

Generally higher numbers of striga counts were observed in Alupe by 79.1% compared to Rangwe (Table 3). In Rangwe IRM (H528IR, FRC425) reduced the number of shoots per m2 by 58.5% to 2.27-5.47 compared to local genotype (*Nyar Uyoma*), by 79.5% to 2.27-11.09to compared to commercial genotypes (H513, Duma43, Haraka101, DH04 and DK8031), and by 70.6% to 2.27-7.73 compared to open pollinated (KSTP94 and GAF4). In Alupe IRM genotypes had fewer number of striga shoot intensity supported by 56% to 2-3 shoots per m^2, compared to 69-78% to 8-58 shoots per m^2 observed in both open pollinated striga-tolerant varieties and commercial genotypes (Table 3).

Striga damage rating score that was measured as parameter indicating the level of host tolerance to striga weed damage. There was higher striga damage rating by 5% in Alupe (4.85) compared to Rangwe (4.63) (Table 3). Across variety and location the highest striga rating score of 8.20 was recorded in susceptible check (DK8031) and the lowest rating of 2.2 was recorded on H528IR, while local genotypes scored 3.00, and striga tolerant varieties (KSTP94, GAF4) recording 4.00 in Alupe (Table 3). In general use of IR coated genotypes reduced the damage score by 69.5% compared to susceptible checks, 37.5% to open pollinated genotypes and 17% to the local landraces. Similar observation were made in Rangwe (Table 3).

There was general variation within genotypes in their response to the number of striga shoots that had flowered by the 10th week after planting per m^2. In general more shoots flowered in Alupe by 27% compared to Rangwe at 10 WAP. IRM (FRC425IR, H528IR) had fewer number of shoots that had flowered at the 10WAP compared to all other test varieties used by 89.9% to 1.18-11.76 shoots per m2 in Alupe (Table 3).

Stunted growth was used as a measure of susceptibility of maize genotypes in response to striga weed damage. In general results revealed that variation in height within maize genotype in response to *Striga hermonthica* damage.

Plant height ranged between 146.9 cm (Duma43) to 252 cm (local landraces) in Rangwe to 138.5 cm (DK8031) to 202.2 cm (KSTP94) in Alupe. In the control environment (Koibatek ATC) plant height ranged between 176.8 cm (GAF4) to 267.6 cm (KSTP94). In general plants were 16.7% taller in Koibatek compared to Rangwe (Table 4) and 22.5% to Alupe (Table 3), similarly plants were 7.0% taller in Rangwe than in Alupe (Table 3).

Table 2. *ANOVA for striga related data and maize agronomic traits for Rangwe and KALRO Alupe sites for two cropping seasons (2018/2019)*

Source of Variation	df	DAE	SC10	SF10	HT12	GY	1000KWT
		Rangwe					
Season	1	5.4**	20.03**	0.03**	395.2**	1.47**	7971.67**
Variety	9	344.93**	47.89**	15.67**	110206.1**	3.13**	34081.67**
S*V	9	17.77NS	4.29**	0.27**	1803.1**	0.1**	1511.27**
Error	38	18.29	3.18	1.07	20266.3	0.09	1254.12
		KALRO ALUPE					
Season	1	3.7**	4466.0**	37.94**	1585.99**	2.63**	21808.45**
Variety	9	333.5**	1932.21**	51.9**	1746.99**	2.04**	21995.77**
S*V	9	13.2NS	231.4**	8.7**	447.23**	0.19**	10747.6**
Error	38	17.02	46.41	2.29	387.79	0.13	4097.43

Key: DAE=days to striga emergence, SC10=striga counts at 10 weeks after planting (WAP), SF=flowered striga counts at 10WAP, HT12=maize plant height (cm) at 12 WAP, GY=grain yield (t ha^{-1}), 1000 KWT=1000 kernel weight (g) ** Significant at P≤0.05, NS not significantly different

Results of grain yield performance indicated that there was significant differences (P<0.05) in grain yield among the maize genotypes in both sites (Table 2). The highest yields were obtained from IRM genotypes 2.5 t/ha (H528IR), 2.63 t/ha (FRC425IR) as compared to 0.54-0.62 t/ha from (DH04, Duma43 and DK8031), and 1.18-1.45 t/ha from (KSTP94, local, GAF4 and Haraka101) (Table 3). Overall IRM genotypes performed better by 50.3% compared to open pollinated genotypes and 79.5% compared to commercial genotypes within striga infested conditions. Additionally, both varieties performed extremely well in Koibatek ATC by 70% compared to Rangwe and 67% compared to Alupe (Table 4).

Thousand kernel weight was measured as one of the yield component that ultimately determined the optimal grain yield since the grain weight of the grain correlate positively with the yield of grain. Significant difference (P≤0.05) was observed for thousand kernel weight in response to number of striga shoots attached (Table 2). The highest weight for a thousand kernel was recorded in local variety *shipindi* as 248 g in Alupe and 263g in Rangwe and the lowest thousand kernel weight was recorded in commercial check (130 g) DK8031 in both condition (Table 3).

Results indicate that there was variation in yield difference between maize genotypes grown in Striga free environment (Koibatek ATC) and striga infested condition (Alupe and Rangwe) (Table 4). Comparison between yields difference in Koibatek ATC, Alupe and Rangwe were such that: DK8031 (88.56%), DH04 (86.86%), Duma43 (83.72%), H513 (79.96%), *shipindi* (73.48%), GAF4 (73.12%), Haraka101 (67.34%) KSTP94 (57.43%) and IR genotypes (H528 and FRC425IR) recorded a relative yield loss of 48.13% and 37.13% respectively (Table 4). Similar trends were also noted when compared to Alupe (Table 4).

Table 3. *Mean performance for yield and yield components of IR maize and selected striga tolerant varieties grown under natural S. hermonthica infested field in Rangwe and artificial infested condition in KALRO Alupe for two seasons of 2018/2019.*

Variety	Rangwe DAE	SC10	SF10	HT12	STR	GY	1000KWT
FRC425IR	54.83^{a}	2.49^{c}	1.27^{ed}	240.40^{a}	2.50^{ed}	2.64^{a}	195.00^{a}
H528IR	50.33^{a}	2.27^{c}	2.15^{e}	247.50^{a}	2.30^{e}	2.50^{a}	178.33^{a}
H513	37.50^{b}	8.89^{ab}	4.80^{bc}	161.56^{b}	5.80^{ab}	0.98^{bced}	168.33^{c}
KSTP94	37.16^{b}	7.73^{ab}	3.57^{bcd}	173.50^{b}	4.00^{cd}	1.31^{bc}	200.00^{abc}
Duma43	37.00^{b}	8.74^{ab}	4.90^{b}	146.94^{b}	5.50^{bc}	0.77^{ced}	198.33^{abc}
Nyar uyoma	36.00^{b}	5.47^{bc}	2.89^{ced}	252.11^{a}	4.00^{cd}	1.18^{bcd}	263.33^{ab}
HRK101	35.33^{b}	8.53^{ab}	4.36^{bc}	138.89^{b}	4.70^{bc}	1.45^{b}	211.67^{abc}
GAF4	32.68^{b}	7.73^{ab}	4.05^{bcd}	151.00^{b}	4.60^{bc}	1.18^{bcd}	178.33^{ab}
DH04	32.68^{b}	7.13^{abc}	4.10^{cbd}	154.95^{b}	5.70^{ab}	0.54^{e}	186.67^{abc}
DK8031	32.67^{b}	11.09^{a}	7.08^{a}	159.95^{b}	7.20^{a}	0.62^{ed}	130.00^{bc}
Mean	38.62	7.01	3.92	182.68	4.63	1.32	191.00
HSD (0.05)	8.29	3.48	2.08	12.64	1.54	0.59	124.09
Cv %	11.04	25.44	26.36	22.40	17.18	23.16	25.37
		KALRO ALUPE					
FRC425IR	50.33^{a}	3.78^{d}	1.41^{c}	162.79^{cb}	2.20^{d}	2.63^{a}	232.17^{ab}
H528IR	51.67^{a}	3.07^{d}	1.18^{c}	170.30^{cb}	2.40^{d}	2.44^{a}	272.90^{a}
H513	34.83^{b}	52.56^{ab}	5.48^{b}	168.49^{abc}	5.50^{ab}	1.22^{b}	200.77^{ab}
KSTP94	36.67^{b}	40.33^{bc}	4.48^{b}	202.23^{a}	3.00^{ab}	1.12^{b}	230.27^{ab}
Duma43	34.64^{b}	32.72^{c}	5.44^{b}	178.80^{ab}	4.60^{bc}	1.15^{b}	208.03^{ab}
Shipindi	37.00^{b}	34.72^{c}	6.11^{b}	181.27^{ab}	5.00^{ed}	1.38^{b}	248.33^{ab}
HRK101	34.50^{b}	37.05^{c}	6.95^{b}	153.67^{cb}	5.70^{bc}	1.46^{b}	227.53^{ab}
GAF4	33.67^{b}	36.24c	5.64^{b}	176.87^{ab}	4.70^{cd}	1.33^{b}	222.00^{ab}
DH04	29.33^{b}	35.47c	5.14^{b}	165.33^{abc}	7.20^{cd}	0.87^{b}	177.23^{b}
DK8031	32.17^{b}	58.78^{a}	11.76^{a}	138.58^{c}	8.20^{a}	1.08^{b}	93.20^{c}
Means	37.48	33.47	5.36	169.83	4.85	1.47	211.24
HSD (0.05)	7.99	13.32	2.93	38.17	1.54	0.69	78.06
Cv %	11.00	20.32	28.24	11.59	17.18	24.14	19.06

Key; *DAE days to striga emergence, SC Striga hermonthica emergence count at 10 weeks after planting (WAP), HT maize plant height in centimeters at 12th WAP, STR striga damage rating SF10 count of striga flowered at 10th WAP, GY grain yield in tonnes per hectare, KWT thousand seed weight in grams. Means followed by the same letters are significantly the same.*

Table 4. *Maize yield differential between striga free environment (Koibatek ATC) and striga infested environment (Rangwe and KALRO Alupe) for two season of 2018/2019.*

SITE	Koibatek*	Rangwe	Alupe	%yield differential		Koibatek*	Rangwe	Alupe
VARIETY	GY	GY	GY	RYL	RYL	1000KWT	1000KWT	1000KWT
DK8031	5.42	0.62	1.08	88.56	80.07	447	224	130
FRC425IR	4.20	2.64	2.63	37.14	37.38	357	230	195
H528IR	4.82	2.50	2.44	48.13	49.38	375	270	157
H513	4.89	0.98	1.22	79.96	75.05	470	248	168
HRK101	4.44	1.45	1.46	67.34	67.12	433	208	212
DH04	4.11	0.54	0.87	86.86	78.83	423	406	187
Gaf4	4.39	1.18	1.33	73.12	69.70	370	240	178
KSTP94	3.08	1.31	1.12	57.47	63.64	450	222	200
Duma43	4.73	0.77	1.15	83.72	75.69	330	297	198
Shipindi	4.45	1.18	1.38	73.48	68.99	577	197	263
Means	4.45	1.32	1.47			423	254	189
HSD (0.05)	0.9	0.59	0.69			42	124.09	68.65
Cv (%)	15.4	23.16	24.14			6.9	25.37	18.7

Key: GY- Grain yield in tones per hectare, RYL relative yield losses in %., KWT 1000 kernels weight *Koibatek was used as a reference in compute the maize yield differential.

5. Discussions

Suggestions have been made by different scholars on management of striga. Duration in days to striga shoot emergence was delayed amongst the coated genotypes. This was probably due to systemic protection induced by imazapyr herbicide that was absorbed by the germinating maize seed. Herbicide seed coating protects the maize crop against early parasitism that otherwise results into competition for growth factors.

In an early study results indicated that use of small doses (30 g/ha) of imazapyr herbicide prevented attachment of haustoria onto maize roots at the earliest stage of growth [20]. The herbicide eliminates induction of phytotoxic chemicals to the crop before emergence of the striga from the soil. Additionally, imazapyr that is not absorbed by the maize seedling disperses into the nearby soil destroying germinating striga seeds. In a previous study conducted revealed that treating maize with Atrazin + hoe weeding at 6 WAP significantly prolonged the number of days to first striga shoot emergence thereby reducing the striga weed density [31]. Similarly, it has been showed that maize response to striga damage depends on their susceptibility to striga [2].

Findings from this study further revealed that using herbicide coated seeds reduced striga weed density by 56-69% compared to the susceptible commercial genotypes. Planting Imazapyr Resistant Maize genotypes in striga infested plots delayed seed germination, reduced the prolificacy flowering and setting of striga seeds, thereby reducing the amount of seed that is added into the soil. IRM genotypes varieties reduced the number of shoots that had flowered in both locations. This results correlate with other studies [8, 22]. Similarly, it has been noted that using herbicide coated seed reduced striga weed density in the farmer's field by 4.9-7.9 compared to when susceptible varieties were used [29]. This further shows that use of imazapyr treated seeds can be used by small holder farmers to effectively manage striga weeds through depleting soil striga seed bank and improving crop yield in each cropping season. Equally, it has been indicated that the variation in terms of emerged striga shoots and striga damage rating at the 8 and 10 WAP reveals existence of high variability in the levels of maize genotype resistance to *S. hermonthica* damage [7].

Stunted growth observed in commercial genotypes used in this study was attributed to early striga parasitism and high weed density that caused maize–weed competition for water, nutrients and light. Additionally, it has also been indicated that using IR coated genotypes reduces the effects of striga weed on maize height [8]. In a study on harmful effects of weeds on maize performance results showed that competition for growth factors by weeds reduces the height of maize and ultimately the yield [36, 38]. In addition, results indicates that striga parasitization on maize roots inhibits cell elongation at the apical cells prompting to reduced plant height [28].

Higher grain yield observed on plots treated with IR was probably associated with fewer shoots and delayed germination of striga which promoted vigorous growth that led to accumulation of more biomass. In a similar study, it was revealed that using IR coated maize genotype significantly increased the yield of maize in striga infested condition [22]. Additionally, findings indicated that when maize crop was left under weeds for a whole season, competition for soil moisture, nutrients and light greatly reduced grain yield [11]. Low yields observed in plots where commercial genotypes were used was associated to early parasitism, higher weed density and high damage rating score. This shows that the low grain yields obtained in commercial susceptible varieties can be linked to effects of striga damages. Similarly, results showed that in areas where fewer striga shoots were attached to grain yield was high [27]. Low grain yield observed in Rangwe despite fewer striga shoots density was possibly linked to other factors such as low inherent soil fertility. Low grain yield have previously reported in areas where fewer striga shoots emerged mainly due to other inherent conditions such as low soil fertility and poor agronomic practices [6].

In general the low thousand seed weight observed in commercial susceptible genotypes used was attributed to increased maize-weed competition for soil moisture, light and mineral nutrients essentially for growth. Previous studies reported that thousand seed weight increased with increased weeding frequency [3]. In a study conducted to determine the effects of striga weed on sorghum growth and yield results showed that infestation of striga on sorghum caused reduction in growth and subsequent loss of yields [5].

Higher yield difference observed amongst the genotypes grown under striga free environment and striga infested condition shows that when striga weed emerges early in the season and remains in the field for long it leds to reduced maize yields. Low relative yield loss exhibited by IRM genotypes point out that IR genotypes can be able to reduce striga damage and can enable farmers get substantive yield. Similarly, it has been reported that when maize was left under heavy weed infestation throughout the growing period an average yield loss of 60-90% was incurred as a result of competition for water, light and nutrients by weeds, [11]. In a previous study it was revealed that the level of yield reduction observed in different striga infested locality depends on the differences in striga weed infestation, soil fertility level and level of maize genotype resistance to striga damage [4].

6. Conclusions

Research findings from this study showed that IR hybrids have the potential of managing striga weed and reducing yield losses in maize in Kenya and enable farmers get substantive yield. The two IR coated hybrids FRC425 IR and H528IR used in this study delayed emergence of striga plants, reduced the striga damage and fewer striga plants emerging, resulting in high yields in both condition. These genotypes are recommended for integration with other management strategies to manage striga in striga endemic areas. To protect this advanced gains farmers are encouraged to remove rare emerged striga shoots IR maize fields and on some occasion plant IR hybrids that is not coated with the herbicide.

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