



Disconnect Between *Striga* Suppression and Maize Yield Improvement by Local *Fusarium oxysporum* Strains in Western Kenya.

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ABSTRACT :

Striga hermonthica is a devastating parasitic weed, causing significant yield losses in maize, the staple crop for millions in sub-Saharan Africa. Biological control using the fungus *Fusarium oxysporum* f. sp. *Strigae* (FOS) has emerged as a promising, eco-friendly strategy. While the ability of local FOS strains to suppress *Striga* has been demonstrated, the resulting impact on the agronomic performance of the maize crop under varied field conditions is less understood. This study aimed to evaluate the effect of five Kenyan FOS strains on the growth and yield of a local maize cultivar ('Rachar') and to identify factors that may influence this relationship. The objective of this study was to determine the effect of infection by local *F. oxysporum* f. sp. *Strigae* strains on the growth parameters and yield components of maize grown in *Striga*-infested fields in Siaya County, Kenya. A field experiment was conducted during the long and short rain seasons of 2013 at three distinct sites (Bar Olengo, Bondo, and Sagam) in Siaya County. Five local FOS strains (FK1-FK5) were used as seed treatments on the susceptible maize variety 'Rachar', alongside an untreated control, in a complete randomized block design with three replications. Data were collected on maize height, leaf number, stover weight, cob weight, and grain yield. Soil properties and rainfall data were also recorded. All five FOS strains significantly reduced *Striga* emergence compared to the control, with FK3 and FK5 showing the highest efficacy. However, these reductions did not translate into consistent or statistically significant improvements in maize growth or yield in most cases. While FK3 and FK5 demonstrated a trend toward higher stover, cob, and grain weight, significant yield increases were only observed at the Sagam site during the short rain season. Grain yields across all sites remained low (mean: 1.1 – 1.74 t/ha). The lack of a consistent yield response was strongly associated with low soil pH (< 5.5) at Bar Olengo and Bondo, and erratic rainfall patterns during the study period, which likely limited nutrient availability and overall plant vigor. This study confirms that local FOS strains, particularly FK3 and FK5, are effective bio-control agents for *Striga*. However, their beneficial effect on parasite suppression is insufficient to overcome other major abiotic constraints to maize productivity in Siaya County. Soil acidity and poor water availability appear to be overriding factors limiting yield. For successful integrated *Striga* management in the region, biological control must be combined with soil fertility management practices such as liming and fertilization to create conditions that allow maize to benefit from reduced parasitic pressure and achieve its yield potential.

Keywords: Biocontrol, *Fusarium oxysporum*, *Striga hermonthica*, Maize yield, Soil acidity, Kenya.

Introduction

Maize (*Zea mays* L.) is the cornerstone of food security and a primary source of livelihood for millions of smallholder farmers in sub-Saharan Africa (SSA) (Atera et al., 2013; Chemiat & Makone, 2015). In Kenya, it is the staple food for over 90% of the population, with the western region being a key production area (Wambugu et al., 2012). Despite its importance, maize productivity in this region remains critically low, averaging 1.5 t ha⁻¹, far below the global average of 4.2 t ha⁻¹ (Atera et al., 2013; Kiplangat et al., 2013). This yield gap is attributed to a complex interplay of factors, including poor soil fertility, erratic rainfall, low external inputs, and biotic constraints, of which the parasitic weed *Striga hermonthica* (Del.) Benth is a primary driver of loss (Oswald, 2005; Khan et al., 2008).

Striga hermonthica, commonly known as witchweed, is a hemiparasitic plant that severely infests cereal crops, attaching to host roots and extracting water, nutrients, and photosynthates (Gressel et al., 2004; Yonli et al., 2005). The damage is often substantial before the weed emerges above ground, leading to stunted growth, chlorosis, and ultimately, significant yield losses, ranging from complete crop failure to reductions of 40-100% in susceptible varieties (Atera et al., 2013; Gressel et al., 2004). The weed's prolific seed production and long seed bank longevity in soil make it exceptionally difficult to manage with a single approach (Mourik, 2007).

Various control strategies have been developed, including cultural practices (hand-pulling, crop rotation, push-pull technology), chemical herbicides, and the use of resistant or herbicide-tolerant maize varieties (Kanampiu et al., 2003; Khan et al., 2008; Suprpta & Khalimi, 2012). However, these methods are often hampered by high costs, environmental concerns, technical complexity, or limited effectiveness for resource-constrained smallholder

farmers (Chitere & Omolo, 1993; Oswald, 2005). Consequently, there is a pressing need for affordable, sustainable, and locally-adapted management options. Biological control using soil-borne pathogens has emerged as a promising alternative, with fungi of the genus *Fusarium* receiving considerable attention (Abbasher et al., 1995; Ciotola et al., 1995; Marley et al., 1999).

Fusarium oxysporum f. sp. *strigae* (FOS) is a host-specific pathogen that causes wilt disease in *S. hermonthica*. It is considered a promising mycoherbicide due to its ability to persist in soil, infect the weed's vascular system, and reduce its emergence and seed production (Yonli et al., 2005; Zarafi et al., 2015). While isolates from West Africa, such as *Foxy* 2, have shown high efficacy in their native environments, their performance has been found to be inconsistent when introduced elsewhere (Avedi et al., 2014). This highlights the critical importance of identifying and using locally adapted strains, which are better suited to the specific edaphic and climatic conditions of a target region.

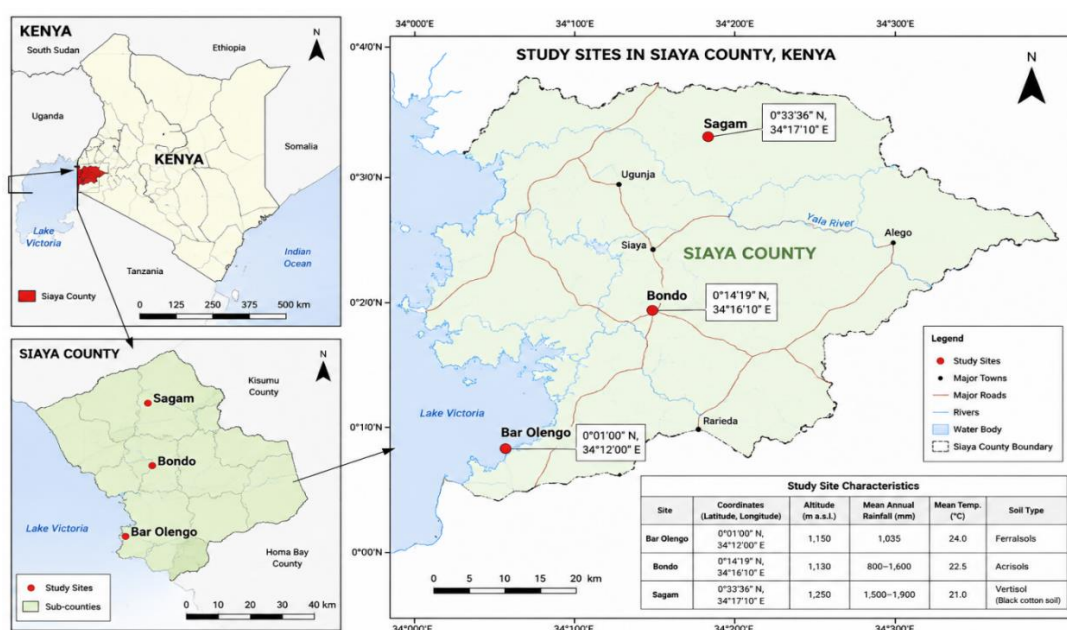
Recent research in western Kenya identified local FOS strains that exhibited promising biocontrol potential under greenhouse conditions, achieving *Striga* mortality rates of over 50% (Kagot et al., 2014). However, these strains had not been rigorously evaluated under field conditions, nor had their impact on the agronomic performance of local maize varieties been documented. Furthermore, while reducing *Striga* emergence is a primary goal of biocontrol, it does not automatically translate to an increase in crop yield. Other environmental and soil factors can act as overriding constraints to maize productivity. For example, the acidic soils prevalent in western Kenya ($\text{pH} < 5.5$) cause nutrient deficiencies (e.g., phosphorus and nitrogen) and aluminum toxicity, which can severely limit plant growth and mask any benefits gained from weed suppression (Woomer et al., 2004; Kiplangat et al., 2013).

Given this context, a field study was designed to evaluate five locally isolated FOS strains (FK1-FK5) on local maize ('Rachar') in Siaya County. The primary aim was two-fold: (1) to determine the strains' efficacy in suppressing *Striga* under field conditions, and (2) to assess their effect on key maize growth and yield parameters across diverse farm sites and seasons. We hypothesized that while the local FOS strains would effectively reduce *Striga* emergence, the benefits to maize yield would be significantly influenced by, and potentially masked by, non-target abiotic stresses such as soil acidity and moisture availability. Understanding the relationship between successful parasite control and actual crop response is crucial for developing effective and realistic recommendations for integrated *Striga* management in the region. This paper therefore investigates the disconnect between *Striga* suppression and maize yield improvement in an effort to identify the underlying factors that determine the success or failure of this biocontrol strategy on smallholder farms in western Kenya.

Materials and Methods

Study Sites and Characterization

The field experiments were conducted during the long (March–June) and short (September–November) rain seasons of 2013 at three farmer-owned sites in Siaya County, western Kenya, each with a documented history of *Striga hermonthica* infestation (Fig. 1). The sites were selected to represent the diverse edaphic and agro-ecological conditions of the county. Bar Olengo Site ($0^{\circ}1'0''$ N, $34^{\circ}12'0''$ E) is characterized by warm, dry, and humid climate with an average annual rainfall of 1035 mm and mean temperature of 24°C . The soil was classified as Ferralsols, which are inherently low in fertility. Bondo Site ($0^{\circ}14'19''$ N, $34^{\circ}16'10''$ E) experiences a warm, dry, and humid climate with mean annual rainfall ranging from 800–1600 mm and a mean temperature of 22.5°C . The soil was classified as Acrisols, which are sandy loams, shallow, and prone to acidity. Sagam Site ($0^{\circ}33'36''$ N, $34^{\circ}17'10''$ E) receives higher rainfall amounts (1500–1900 mm per annum), with a mean temperature of 21°C . The soil was classified as clayey black cotton soil (Vertisol), which is deep, well-drained, and nutrient-rich.



Source: Administrative boundaries – IECB (2019); Water bodies – DIVA-GIS; Roads – Kenya Roads Board (2018)
Coordinate System: WGS 84

Figure 1. Location of the three experimental field sites (Bar Olengo, Bondo, and Sagam) in Siaya County, western Kenya.

Prior to planting, composite soil samples were collected from each site at a depth of 0–30 cm using a soil corer. Samples were air-dried, sieved (2 mm), and analyzed for key properties following standard procedures (Okalebo et al., 2005). Soil pH was determined in a 1:2.5 soil-water suspension using a calibrated pH meter. Total nitrogen was determined by the Kjeldahl method, organic carbon by the Walkley-Black method, and available phosphorus by the Bray-1 method. Cation exchange capacity (CEC) was measured using the ammonium acetate method.

Experimental Design and Treatments

The experiment was laid out in a complete randomized block design (CRBD) with three replications at each site. Each site measured 28 × 25 m and was divided into three blocks, with each block containing six plots. Each plot measured 5.5 × 3.75 m (approximately 20.6 m²). A 0.75 m strip separated blocks, and a 1 m path separated plots within blocks. Each plot had nine rows, with eight planting stations per row, giving a total of 72 maize plants per plot.

The six treatments consisted of five locally isolated *Fusarium oxysporum* f. sp. *strigae* (FOS) strains (designated FK1–FK5) and an untreated control (C). The treatments were randomly allocated to plots within each block. The maize variety used was the local landrace 'Rachar', a white-kernel, small-sized maize type commonly grown by smallholder farmers in the region due to its relative drought tolerance.

Fungal Strains and Maize Seed Dressing

Five FOS strains were isolated from diseased *S. hermonthica* plants collected from various locations in western Kenya (Table 1). The strains were morphologically identified using the criteria of Leslie and Summerell (2006) and molecularly confirmed via DNA sequencing of the translation elongation factor 1-alpha (TEF-1α) gene region, following the protocol of Tamura et al. (2011). Phylogenetic analysis confirmed all five strains as *F. oxysporum* and placed them within a single clade.

Table 1: Sources of the five local *Fusarium oxysporum* f. sp. *strigae* strains used in the study.

Treatment	Source Location
FK1	Kosele Centre
FK2	Kosele Farm
FK3	Siaya ATC
FK4	Bondo
FK5	KALRO CIMMYT-Kibos
C	Untreated control

For seed inoculation, maize seeds were primed in water for 10 hours and then coated with each FOS strain at a rate of 40 g of fungal inoculum per 600 seeds, following the protocol of Woomer et al. (2004). The inoculum was prepared from 14-day-old cultures grown on potato dextrose agar (PDA) at 25°C. Control seeds were primed similarly but not coated with any fungal inoculum. All seeds were air-dried under shade for five hours before planting.

Field Establishment and Management

All sites were prepared using ox-drawn ploughs during the long rain season and manually using hand hoes during the short rain season. *S. hermonthica* seeds were obtained from the KALRO-CIMMYT collaborative facilities at Kibos and mixed with sand to a uniform concentration (Berner et al., 1997). Approximately one tablespoon (≈100 seeds) of the seed-sand mixture was placed in each planting hole to ensure uniform and high *Striga* infestation.

Maize seeds were sown in ridges with a spacing of 70 cm between rows and 30 cm within rows. Two seeds were planted per hole, and seedlings were thinned to one plant per hole two weeks after emergence. Diammonium phosphate (DAP) fertilizer was applied at planting at a rate of 46 kg P₂O₅ and 60 kg N per hectare. Hand weeding was performed every two weeks for all weeds except *S. hermonthica*, to prevent competition and to ensure that observed effects were solely due to the parasitic weed.

Each experimental site was protected by a 0.5 m wide and 1 m deep trench and a barbed wire fence to prevent interference from surrounding environments and unauthorized access. A footbath containing disinfectant (HighChem East Africa Ltd, Nairobi, Kenya) was placed at the entrance for decontamination of personnel upon entry and exit.

Data Collection

Striga Emergence and Infection Rates

From week 4 to week 10 after planting, data were collected at 7-day intervals. *Striga* emergence was assessed by counting the number of emerged *S. hermonthica* plants within a 15 cm radius around each of 20 tagged maize plants per plot. The total number of emerged *Striga* plants was summed over

the monitoring period.

Striga infection rates were determined by counting the number of emerged *Striga* plants showing signs of wilting, necrosis, or other disease symptoms indicative of FOS infection. Infection rate (%) was calculated as:

Infection Rate (%) = (Number of infected *Striga* plants / Total number of emerged *Striga* plants)

$$IR = \left(\frac{NISP}{TNESP} \right) \times 100$$

Where IR is Infection Rate (%), NISP is the number of infected *Striga* plants and TNESP is the Total number of emerged *Striga* plants

Maize Growth Parameters

Twenty maize plants per plot were randomly tagged at week 3 after emergence and monitored throughout the growing season. The following growth parameters were recorded weekly from week 4 to week 10:

- **Plant Height (cm):** Measured from the stem base to the apex of the youngest fully expanded leaf using a ruler.
- **Number of Leaves:** Total number of fully expanded leaves per plant were counted.

Maize Yield Components

At physiological maturity (week 14), all tagged plants were harvested. The following yield parameters were measured:

- **Stover Weight (g):** Aboveground biomass (excluding cobs) was weighed per plot using a portable electronic scale.
- **Cob Weight (g):** All cobs from the tagged plants per plot were weighed.
- **Grain Yield (t ha⁻¹):** Cobs were shelled, and grain moisture content was determined using a grain moisture meter (GMK-303A, G-won Hitech Co., Ltd, Seoul, South Korea). Grain yield was calculated using the formula described by De Groote et al. (2002):

$$\text{Grain Yield (t ha}^{-1}\text{)} = [\text{FW} \times (100 - \text{MC1}) / (100 - \text{MC2}) \times \text{S}] / \text{P} \times 10^{-3}$$

Where:

- FW = fresh weight of harvested cobs (kg)
- MC1 = moisture content (%) in grains at harvest
- MC2 = required moisture content for storage (13%)
- S = shelling percentage (85%)
- P = plot size (m²)

Data Analysis

All data were subjected to analysis of variance (ANOVA) using the Statistical Analysis System (SAS) software, version 9.1. The model included the fixed effects of treatment (FK1–FK5 and control), site (Bar Olengo, Bondo, Sagam), season (long rains, short rains), and their interactions. Replications within sites and seasons were treated as random effects. Where significant differences were detected, means were separated using Fisher's Least Significant Difference (LSD) test at the 5% probability level.

Results

Soil Properties Across Study Sites

The three study sites exhibited distinct soil characteristics that varied substantially in their fertility and suitability for maize production (Table 2). Bar Olengo and Bondo sites were characterized by highly acidic soils with pH values of 4.0 and 4.1, respectively, which are well below the recommended minimum of pH 5.5 for optimal maize growth. In contrast, Sagam site had a near-neutral pH of 6.4.

Total nitrogen content was low at both Bar Olengo (0.17%) and Bondo (0.15%), but comparatively higher at Sagam (0.35%). Similarly, organic carbon followed the same trend, with Sagam recording the highest value (1.49%) compared to Bar Olengo (1.12%) and Bondo (0.83%). Available phosphorus was highest at Bar Olengo (23.4 mg/100g), followed by Bondo (17.6 mg/100g) and Sagam (13.4 mg/100g). Cation exchange capacity (CEC) was substantially higher at Sagam (95.3 meq/100g) compared to Bondo (68.9 meq/100g) and Bar Olengo (38.2 meq/100g).

Table 2: Selected soil properties of the three study sites in Siaya County.

Site	Soil Type	pH	Total N (%)	Total P (mg/100g)	Organic C (%)	CEC (meq/100g)
Bondo	Acrisol	4.1	0.15	17.6	0.83	68.9
Sagam	Vertisol (Black Cotton)	6.4	0.35	13.4	1.49	95.3
Bar Olengo	Ferralsol	4.0	0.17	23.4	1.12	38.2

Striga Emergence

All five FOS strains significantly reduced *Striga* emergence compared to the untreated control across most sites and seasons ($P \leq 0.05$; Table 3). During the long rain season, *Striga* emergence in control plots ranged from 43.8 to 53.0 plants per plot, while FOS-treated plots exhibited substantially lower emergence, ranging from 4.8 to 23.4 plants per plot. Among the strains, FK5 consistently demonstrated the highest suppression, with mean emergence values of 8.6, 4.8, and 5.8 at Bondo, Sagam, and Bar Olengo, respectively, during the long rains. FK3 also performed well, with emergence values of 11.2, 8.2, and 6.6 across the same sites.

During the short rain season, a similar trend was observed, with FK3 and FK5 showing the lowest *Striga* emergence across all sites, except at Bar Olengo where differences among treatments were not statistically significant ($P = 0.49$). The control plots consistently recorded the highest *Striga* emergence, with values ranging from 24.7 to 31.7 plants per plot.

Overall, the Sagam site recorded the lowest *Striga* emergence among the three sites, with a mean of 15.2 and 11.6 plants per plot during the long and short rain seasons, respectively. In contrast, Bondo site consistently showed higher emergence levels, particularly in the long rain season where the control plot averaged 53.0 emerged *Striga* plants.

Table 3: Mean *Striga* emergence during the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. Values followed by different letters within a column are significantly different at $P \leq 0.05$. NS = Not significant.

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	23.4 a	11.2 a	16.6 a	11.0 a	15.3 a	17.0 a
FK2	14.8 b	11.4 a	22.2 a	12.6 a	12.3 a	9.7 a
FK3	11.2 c	8.2 b	6.6 b	5.7 b	3.7 b	5.3 a
FK4	14.4 b	12.0 a	11.2 b	11.0 a	6.7 b	11.0 a
FK5	8.6 c	4.8 b	5.8 b	6.0 b	5.7 b	6.7 a
Control	53.0 d	43.8 c	46.6 c	31.7 c	25.7 c	24.7 b
Mean	20.9	15.2	18.2	13	11.6	12.4
LSD(0.05)	2.3	2.3	3.2	7.4	2.8	2.8 (NS)
CV (%)	7.8	9.4	8.4	7.4	7.1	5.8

Striga Infection Rates

Striga infection rates, expressed as the percentage of emerged plants showing disease symptoms, were significantly higher in FOS-treated plots compared to the untreated control ($P \leq 0.05$; Table 4). During the long rain season, FK5 consistently exhibited the highest infection rates across all

sites, with values of 45.2%, 59.4%, and 57.4% at Bondo, Sagam, and Bar Olengo, respectively. FK3 also showed high infection rates, particularly at Sagam (53.6%) and Bar Olengo (52.7%). In contrast, FK4 and FK2 demonstrated lower infection rates, with FK4 averaging only 14.2% at Bar Olengo during the long rains.

The short rain season showed a similar pattern but with generally higher infection rates overall. FK5 achieved the highest infection rate recorded in the entire study at Sagam (77.4%), followed by FK3 at the same site (61.3%). FK3 and FK5 consistently outperformed other strains across all sites during both seasons, while FK1 and FK2 showed intermediate efficacy, and FK4 was generally among the least effective.

Notably, the control plots showed negligible infection rates ($\leq 7.6\%$), confirming that the observed infections were primarily due to the introduced FOS strains and not endemic pathogens.

Table 4: Mean Striga infection rates (%) by *F. oxysporum* f. sp. *strigae* strains during the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. Values followed by different letters within a column are significantly different at $P \leq 0.05$.

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	32.8 a	29.5 a	25.4 a	34.8 a	21.2 a	31.1 a
FK2	33.8 a	37.4 a	12.7 b	36.1 a	33.1 b	21.4 b
FK3	42.7 b	53.6 b	52.7 c	53.3 b	61.3 c	53.9 c
FK4	25.0 a	18.5 a	14.2 b	42.7 b	25.8 a	41.9 b
FK5	45.2 b	59.4 b	57.4 c	53.7 b	77.4 c	59.0 c
Control	0.0 c	1.5 c	0.8 d	1.7 c	7.6 d	3.4 d
Mean	29.9	33.4	27.2	37.1	37.7	35.1
LSD(0.05)	14.3	4.6	3.5	3.8	11.9	8.4
CV (%)	5.5	6.5	8.4	5.2	6.9	5.9

Maize Growth Parameters

Plant Height

Despite significant reductions in *Striga* emergence and high infection rates in FOS-treated plots, there were no significant differences in maize plant height between treated and control plots, nor among the five FOS strains, across all sites and seasons ($P > 0.05$; Table 5). Plant heights were generally low across all sites, ranging from 57.0 to 146.4 cm during the long rain season and 68.6 to 106.9 cm during the short rain season.

The Sagam site consistently recorded the tallest plants, with mean heights of 123.5 cm and 91.4 cm during the long and short rain seasons, respectively. In contrast, Bar Olengo had the shortest plants, with mean heights of 78.8 cm and 78.3 cm across the two seasons. Although FOS-treated plants tended to be numerically taller than control plants in most instances, these differences were not statistically significant (LSD values ranged from 43.9 to 72.9 cm).

Table 5: Mean maize height (cm) during the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. NS = Not significant; no significant differences were detected among treatments within each site and season ($P > 0.05$).

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	126.7	117.7	58.3	68.6	87.5	77.5
FK2	136.5	129.3	72.3	73.1	85.6	76.3
FK3	128.4	142	95.3	74.3	105.2	81.5
FK4	146.4	123.5	88.7	73.9	86.2	74.2

FK5	142.6	135	101.3	85.7	106.9	80.9
Control	114.7	94.7	57	70.5	78.2	79.2
Mean	132.5	123.5	78.8	74.3	91.4	78.3
LSD(0.05)	72.9 (NS)	67.5 (NS)	43.9 (NS)	44.1 (NS)	52.5 (NS)	52.7 (NS)
CV (%)	8.7	13.6	24	8	12.5	3.6

Number of Leaves

Similar to plant height, the number of leaves per plant did not show significant differences between FOS-treated and control plots, nor among the five strains, across all sites and seasons ($P > 0.05$; Table 6). The mean number of leaves ranged from 8.75 to 12.50 during the long rain season and 8.97 to 11.80 during the short rain season.

Despite the lack of statistical significance, FK3 and FK5 generally showed numerically higher leaf counts compared to other treatments and the control, particularly at Bar Olengo and Sagam sites. The Bondo site consistently recorded the highest number of leaves across treatments, while Bar Olengo had the lowest.

Table 6: Mean number of maize leaves during the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. NS = Not significant; no significant differences were detected among treatments within each site and season ($P > 0.05$).

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	12.5	10.25	8.75	10.65	10.3	9.8
FK2	11.5	11.25	8.75	11.15	9.57	9.67
FK3	11.75	10.5	10.5	10.9	10.72	11.2
FK4	12.25	10.25	9.75	11.4	9.9	9.97
FK5	12.5	10.5	10.5	11.47	11.8	10.85
Control	12.25	10.5	9.25	8.97	10.25	9.5
Mean	12.13	10.54	9.58	10.77	10.43	10.16
LSD(0.05)	1.52 (NS)	1.16 (NS)	1.79 (NS)	2.63 (NS)	1.89 (NS)	1.71 (NS)
CV (%)	3.38	3.49	8.35	8.7	7.36	6.8

Maize Yield Components

Stover Weight

Stover weight showed no significant differences between FOS-treated and control plots, nor among the five strains, across most sites and seasons ($P > 0.05$; Table 7). The only exception was a near-significant trend at Sagam during the long rain season ($P = 0.051$), where FK5 (290.2 g) and FK1 (276.8 g) produced the highest stover weights, while the control produced the lowest (150.9 g). Sagam site consistently recorded the highest stover weights, with means of 238.4 g and 268.4 g during the long and short rain seasons, respectively. In contrast, Bondo and Bar Olengo sites had substantially lower stover weights, with means ranging from 105.8 to 155.6 g. Although FK3 and FK5 numerically outperformed other strains across most sites, these differences were not statistically significant.

Table 7: Mean stover weight (g) at the end of the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. NS = Not significant; no significant differences were detected among treatments within each site and season ($P > 0.05$).

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	86.8	276.8	150.7	110	280.2	147
FK2	122.7	254.3	84.7	96.2	246.6	124.4

FK3	157.1	225.8	104.3	136.9	291.4	175.4
FK4	94.5	232.6	94.7	121.2	272.9	162.7
FK5	128.5	290.2	116	152.6	299.1	201.7
Control	116.7	150.9	84.7	122.7	220.1	122.7
Mean	117.7	238.4	105.8	123.3	268.4	155.6
LSD(0.05)	14.6 (NS)	38.9 (NS)	43.1 (NS)	21.1 (NS)	31.2 (NS)	28.2 (NS)
CV (%)	21.43	20.76	23.66	16.07	11.09	19.68

Cob Weight

Cob weight showed significant differences only at Sagam site during the short rain season ($P = 0.008$; Table 8). At this site, FK3 (197.5 g) and FK5 (196.3 g) produced significantly heavier cobs compared to other strains and the control (138.7 g). FK1 (175.1 g) and FK2 (174.5 g) showed intermediate cob weights, while FK4 (184.3 g) was also among the higher-performing treatments.

Across all other site-season combinations, cob weight did not differ significantly among treatments. However, a consistent trend was observed where FK3 and FK5 numerically outperformed other strains and the control. The control plots generally produced the lowest cob weights, except at Bondo during the long rain season where the control (138.5 g) was numerically higher than all FOS treatments.

Sagam site recorded the highest cob weights overall (mean: 172.0 g and 177.7 g during long and short rains, respectively), followed by Bondo (125.4 g and 142.6 g) and Bar Olengo (113.4 g and 147.8 g).

Table 8: Mean cob weight (g) at the end of the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. Values followed by different letters within a column are significantly different at $P \leq 0.05$. NS = Not significant.

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	125.7	157.4	101.4	151.7	175.1 a	142.5
FK2	123.1	160.2	94.8	148.2	174.5 a	146.8
FK3	128.7	172.8	132.3	132.3	197.5 b	165.8
FK4	116	186	114.2	149.2	184.3 ab	135.5
FK5	120.3	199.9	140.7	152.3	196.3 b	158.9
Control	138.5	155.7	97.5	121.9	138.7 c	137.5
Mean	125.4	172	113.4	142.6	177.7	147.8
LSD(0.05)	8.8 (NS)	17.7 (NS)	12.2 (NS)	7.5 (NS)	6.5	19.7 (NS)
CV (%)	6.2	10.4	16.9	8.7	12.1	8.2

Grain Yield

Grain yield exhibited a pattern similar to cob weight, with significant differences observed only at Sagam site during the short rain season ($P = 0.008$; Table 9). At this site, FK3 (1.93 t ha⁻¹) and FK5 (1.92 t ha⁻¹) produced significantly higher grain yields compared to the control (1.36 t ha⁻¹). FK1 (1.71 t ha⁻¹), FK2 (1.71 t ha⁻¹), and FK4 (1.80 t ha⁻¹) showed intermediate yields that were not significantly different from either the top performers or the control.

Across all other site-season combinations, grain yield did not differ significantly among treatments. However, the same trend persisted where FK3 and FK5 numerically outperformed other treatments. Sagam site consistently yielded highest (mean: 1.68 t ha⁻¹ and 1.74 t ha⁻¹ during long and short rains, respectively), while Bar Olengo had the lowest yields (1.10 t ha⁻¹ and 1.44 t ha⁻¹). The control plots generally produced the lowest yields, except at Bondo during the long rain season where the control (1.22 t ha⁻¹) was comparable to or higher than some FOS treatments.

Table 9: Mean maize grain yield (t ha⁻¹) at the end of the growing seasons at Bar Olengo, Bondo, and Sagam sites in 2013. Values followed by different letters within a column are significantly different at $P \leq 0.05$. NS = Not significant.

Treatment	Long Rain Season			Short Rain Season		
	Bondo	Sagam	Bar Olengo	Bondo	Sagam	Bar Olengo
FK1	1.23	1.54	0.99	1.48	1.71 a	1.39
FK2	1.2	1.57	0.93	1.45	1.71 a	1.43
FK3	1.26	1.69	1.29	1.29	1.93 b	1.62
FK4	1.13	1.82	1.12	1.46	1.80 ab	1.32
FK5	1.27	1.95	1.37	1.49	1.92 b	1.55
Control	1.22	1.52	0.95	1.19	1.36 c	1.34
Mean	1.22	1.68	1.1	1.39	1.74	1.44
LSD(0.05)	0.07 (NS)	0.17 (NS)	0.12 (NS)	0.07 (NS)	0.06	0.19 (NS)
CV (%)	4.04	10.38	16.93	8.77	12.1	8.2

Discussion

The results of this study confirm that locally isolated strains of *Fusarium oxysporum* f. sp. *strigae* (FOS) are effective bio-control agents against *Striga hermonthica* under field conditions in western Kenya as confirmed by Oula et al. (2020). All five tested strains significantly reduced *Striga* emergence and achieved substantial infection rates compared to the untreated control. Among the strains, FK3 and FK5 consistently demonstrated the highest efficacy, with infection rates reaching up to 77.4% at the Sagam site during the short rain season.

These findings are consistent with previous studies that have reported the potential of *F. oxysporum* for biological control of *Striga* in various parts of Africa (Abbasher et al., 1998; Ciotola et al., 1995; Marley et al., 1999; Yonli et al., 2005). The high infection rates observed for FK3 and FK5 are particularly noteworthy and comparable to or exceeding those reported for the well-known foreign isolate *Foxy* 2, which showed limited efficacy when tested in western Kenya (Avedi et al., 2014). This underscores the importance of using locally adapted strains, which are presumably better suited to the specific edaphic and climatic conditions of the target region.

The superior performance of FK3 (isolated from Siaya Agricultural Training Centre) and FK5 (isolated from KALRO-CIMMYT Kibos) suggests that these strains possess genetic traits that confer enhanced pathogenicity under the prevailing field conditions. Molecular characterization of the five strains confirmed they belong to a single clade of *F. oxysporum* (Appendix 4), yet their field performance varied, indicating that subtle genotypic or phenotypic differences may influence their biocontrol efficacy. This variability highlights the need for careful strain selection when developing mycoherbicide products for specific agro-ecological zones.

Despite the significant and often substantial reductions in *Striga* emergence and high infection rates achieved by the FOS strains, these benefits did not consistently translate into improved maize growth or yield. Comprehensive review of major knowledge gaps and challenges of smallholders in *Striga* management has highlighted major potentials of microbial-based approach with respect to the mechanisms of host-*Striga*-microbe interactions in *Striga*-infested soil (Olowe et al., 2023). In our study, across most site-season combinations, there were no significant differences in plant height, number of leaves, stover weight, cob weight, or grain yield between FOS-treated and control plots. The only exception was the Sagam site during the short rain season, where FK3 and FK5 produced significantly higher cob weights and grain yields compared to the control. This apparent disconnect between successful biocontrol and agronomic benefit is a critical finding that has important implications for the practical application of FOS as a *Striga* management tool. Several factors may explain this phenomenon.

The most prominent factor explaining the limited yield response is the poor soil fertility and high acidity prevalent at two of the three study sites (Du et al., 2024). Bar Olengo and Bondo sites had highly acidic soils with pH values of 4.0 and 4.1, respectively, well below the optimal pH range of 5.5–6.5 for maize production (Woomer et al., 2004; Golla et al., 2026). These acidic conditions are associated with several constraints that severely limit crop productivity, including aluminum and manganese toxicity, phosphorus fixation, and reduced availability of essential nutrients such as nitrogen, calcium, and magnesium (Kiplangat et al., 2013; Njui & Musandu, 1999; Warke and Wakgari, 2024). Under such conditions, even when *Striga* pressure is reduced, maize plants remain physiologically stressed and unable to capitalize on the reduced competition. The low soil pH likely impaired root development and nutrient uptake, leading to the generally poor growth observed across all treatments at these sites (mean plant heights as low as 57 cm and grain yields as low as 0.93 t ha⁻¹). This interpretation is supported by the significantly better performance observed at Sagam site, which had near-neutral pH (6.4), higher organic matter (1.49%), and greater cation exchange capacity (95.3 meq/100g), creating more favorable conditions for maize growth.

The soil analysis revealed that total nitrogen and organic carbon were also consistently lower at Bar Olengo and Bondo compared to Sagam. Nitrogen deficiency is particularly critical for maize, as it is the primary nutrient limiting growth and yield in many smallholder farming systems in sub-Saharan Africa (Okalebo et al., 2005). The low nitrogen availability at these sites likely constrained the ability of maize to respond to reduced *Striga* competition by producing additional biomass.

Rainfall variability also appears to have played a significant role in modulating the response to FOS treatment (Legeay et al., 2024). The short rain season at Sagam, which coincided with the only significant yield improvements observed, may have had more favorable rainfall distribution than the long rain season. This is consistent with observations that *Striga* parasitism is often more severe under drought stress, but conversely, the benefits of *Striga* control are more apparent when other growth conditions are favorable (Yonli et al., 2005; Zahran, 2008; Legeay et al., 2024). Erratic rainfall during the study period, particularly in the long rain season, likely contributed to the low overall yields and masked the potential benefits of *Striga* control. Even at Sagam, where yields were highest, they remained well below the regional potential, suggesting that moisture stress was a limiting factor.

Another factor that may explain the limited yield response is the timing of *Striga* parasitism relative to biocontrol activity (Rouamba et al., 2024). Much of the damage caused by *Striga* occurs before the parasite emerges above ground, as the developing *Striga* plant extracts water, nutrients, and photosynthates from the host root system (Gressel et al., 2004). By the time *Striga* emerges and becomes visible, significant damage has already been inflicted on the host plant. While FOS infection effectively suppressed emerged *Striga* and prevented seed production, it may not have been able to prevent the pre-emergence damage that already occurred. This temporal limitation suggests that future research should explore strategies to enhance the early-season activity of FOS, such as through improved seed-coating formulations or soil inoculation techniques that ensure rapid colonization of the rhizosphere and early infection of *Striga* attachments.

The high *Striga* seed bank in the soil at all three sites, evidenced by the high *Striga* emergence in control plots, may also contribute to the limited yield improvement (Aliyu et al., 2023). Even with effective FOS infection, a single season of biocontrol may not be sufficient to reduce the seed bank to a level where maize can fully recover. The presence of a large seed bank means that even with reduced emergence in the current season, the soil remains infested and will continue to pose a threat in subsequent seasons.

This highlights the need for integrated *Striga* management strategies that combine biocontrol with other approaches, such as crop rotation, trap crops, or soil fertility enhancement, to achieve long-term sustainable reduction of the *Striga* seed bank (Khan et al., 2008; Oswald, 2005).

Other unmeasured soil factors may also have influenced the response to FOS treatment. The presence of other soil-borne pathogens, nematodes, or beneficial microorganisms could have either enhanced or suppressed the activity of the introduced FOS strains (Hossain et al., 2025). Similarly, interactions between FOS and the native soil microbial community may have varied among sites, contributing to the observed differences in performance.

The findings of this study have important implications for the practical application of FOS-based biocontrol in smallholder farming systems. While FK3 and FK5 show considerable promise as biological control agents, their effectiveness in improving maize yield depends critically on addressing the underlying abiotic constraints that limit maize productivity.

In highly acidic soils typical of many parts of western Kenya (Woomer et al., 2004), *Striga* biocontrol alone is insufficient to achieve yield gains. The benefits of reduced *Striga* pressure are largely overshadowed by the physiological constraints imposed by soil acidity and nutrient deficiency. This suggests that FOS-based biocontrol should be implemented as part of an integrated soil fertility management strategy that includes liming, appropriate fertilizer application, and improved crop husbandry practices.

The superior performance of FK3 and FK5 at the more favorable Sagam site demonstrates that the potential yield benefits of *Striga* biocontrol can be realized when other growth conditions are adequate. This provides a strong incentive for promoting these strains among farmers who are already practicing or willing to adopt soil fertility management practices.

The findings of this study are consistent with the growing body of evidence that biological control alone may not be sufficient to achieve significant yield improvements in *Striga*-infested fields. Similar observations have been reported for other biocontrol agents, including *Foxy* 2 in Kenya (Avedi et al., 2014) and various *Fusarium* isolates in West Africa (Yonli et al., 2005). The common theme emerging from these studies is that biocontrol must be integrated with other management practices to be effective in improving crop productivity.

The significant reduction in *Striga* emergence observed in this study (up to 90% reduction compared to control) is among the highest reported for field trials in the region. This validates the potential of local FOS strains and suggests that strain selection is a critical determinant of biocontrol success.

Conclusion

This study evaluated the efficacy of five locally isolated *Fusarium oxysporum* f. sp. *strigae* (FOS) strains in controlling *Striga hermonthica* and their impact on the growth and yield of local maize ('Rachar') under field conditions in Siaya County, western Kenya. All five FOS strains significantly reduced *Striga* emergence compared to the untreated control across most sites and seasons, with reductions of up to 90% in some treatments. FK3 and FK5 demonstrated the highest pathogenicity, achieving *Striga* infection rates of up to 77.4% at the Sagam site during the short rain season. These strains are therefore recommended as the most promising candidates for development as biocontrol agents in the region. Despite effective *Striga* suppression, significant yield improvements were not consistently observed. FK3 and FK5 produced significantly higher cob weight and grain yield only at the Sagam site during the short rain season. Across most site-season combinations, there were no significant differences in maize growth or yield parameters between FOS-treated and control plots. The lack of consistent yield improvement is attributed to overriding abiotic constraints, particularly soil acidity (pH < 5.5) and low nutrient availability, which limited maize growth and masked the potential benefits of

reduced *Striga* pressure. The highly acidic soils at Bar Olengo and Bondo sites appeared to be the primary factor limiting crop response to biocontrol. Climatic variability and rainfall patterns also contributed to the limited yield response, with the only significant yield improvements occurring during the short rain season at the most favorable site (Sagam).

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Conflict of interest

The author declares no conflict of interest.

Ethical approval

The study protocols and procedures obtained were ethically reviewed and approved by Maseno University Ethical Review Committee. Informed consent was obtained from farmers who surrendered their land for research.

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