

**EFFECTIVENESS OF IMAZAPYR-RESISTANT AND SELECTED STRIGA-  
TOLERANT MAIZE (*Zea mays* L.) VARIETIES ON *Striga hermonthica* CONTROL  
AND YIELD OF MAIZE IN WESTERN KENYA**

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for the Master of Science Degree in Agronomy of Egerton University**

**EGERTON UNIVERSITY  
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## DECLARATION & RECOMMENDATION

### Declaration

This Thesis is my original research work and has not been presented in this University or any other institution for the award of a degree or diploma

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## **DEDICATION**

This Thesis is dedicated to my beloved wife Tabitha Robi, my sons: Alexis, Albert, Allan, and my daughter AshelyAngel for their endurance, patience, encouragement, and consistent prayers during my long absence while pursuing Master of Science degree in Agronomy at Egerton University.

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## ABSTRACT

Witch weed (*Striga hermonthica*) is a hemi-parasitic weed that causes severe maize yield losses globally and in western Kenya. A study was conducted to determine the effectiveness of herbicide coated Imazapyr Resistant (IR) hybrids, selected Striga-tolerant and Local maize varieties on *Striga* management and yield of maize in western Kenya. The study also determined the cost-benefit analysis of IR maize compared to Local landraces in western Kenya. The study was conducted in two *Striga*-infested sites, Rangwe (Homa Bay County) and Kenya Agricultural and Livestock Research Organization (KALRO), Alupe (Busia County) during the 2018/2019 cropping seasons. The varieties evaluated comprised of two IR coated hybrids (H528IR, FRC425IR), two *Striga* tolerant open pollinated varieties (KSTP94, GAF4), five commercial susceptible hybrids (DK8031, H513, DUMA43, DH04, HARAKA 101) and one local landrace. The experiment was laid in a randomized complete block design (RCBD) with three replications for two seasons. Data was collected on days to 1<sup>st</sup> *Striga* shoot appearance, *Striga* shoot emergence counts, *Striga* damage severity rating, *Striga* plants flowering at maize physiological maturity, maize plant height (cm), grain yield (t ha<sup>-1</sup>), maize yield components (kernels per cob, 1000-seed weight (g), and grain yield loss. Data collected were subjected to analysis of variance using Statistical Analysis System software (version 9.0) and treatment means separated using Tukey's HSD test at  $P \leq 0.05$ . Results indicated significant differences ( $P \leq 0.05$ ) of varieties in response to *Striga* infestation. *Striga* count, *Striga* plant rating and significantly reduced ( $P \leq 0.05$ ) in the IR treated hybrids as compared to the susceptible genotypes. IR maize varieties (H528IR, FRC425IR) delayed the emergence of *Striga* shoots by 20 days compared to the commercial susceptible varieties. Additionally, IR coated genotypes reduced *striga* shoot emergence by 79.5%, reduced *Striga* damage severity by 68.1% compared to susceptible varieties in both sites. In conclusion finding from this study showed that IR hybrids has potential to manage *Striga* and improve maize yield by 57% from 1.152 t ha<sup>-1</sup> (Local) to 2.37 t ha<sup>-1</sup> (H528IR) in western Kenya. Further, the coated hybrids performed well economical with a MRR of 3.3, enabling farmers to earn an extra income of Ksh29, 950 by adopting IR technology. This study recommends the adoption of Imazapyr coated varieties in *Striga* prone areas of western Kenya in order to improve grain yield that will ultimately contribute to improved food and nutrition security, household incomes and poverty alleviation in western Kenya.

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## LIST OF ABBREVIATIONS AND ACRONYMS

AATF	Africa Agricultural Technology Foundation
AHAS	Acetohydroxyacid synthase /Acetolactate synthase (ALS)
ANOVA	Analysis of Variance
BCR	Benefit Cost Ratio
CIMMYT	International Maize and Wheat Improvement Centre
DAI	Days after inoculation
EMS	Ethyl methanesulfonate
GM	Gross Margin
HR	Hypersensitive reaction
ICIPE	International Centre of Insect Physiology and Ecology
ICRISAT	International Crop Research Institute of Semi-Arid Tropics
IITA	International Institute of Tropical Agriculture
IR	Imazapyr Resistant maize
KALRO	Kenya Agricultural & Livestock Research Organization
KES	Kenya shilling
KSTP	Kakamega Striga Tolerant Population
MOA	Ministry of Agriculture
MRR	Marginal rate of Return
SAS	Statistical Analysis System
SSA	Sub-Saharan Africa
PB	Partial Budget
US\$	United State Dollars
WAP	Weeks after planting

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of the study

Maize is a major staple food crop grown across many agro-ecological zones and production systems due to its higher demand, wider adaptability, technical advances, yield increases and expansion in area under production. It is the most important cereal crop in the world in terms of acreage and production followed closely by rice and wheat. The global area under maize amounts to 197 M ha, including substantive areas in Sub-Saharan Africa (SSA), Asia and Latin America (FAOSTAT, 2021). The global production of maize was 1162 million metric tonnes (MT) in 2020 (Knoema, 2020), where USA and China accounted for 38% and 23%, respectively (Jaidka *et al.*, 2019). Within the SSA, Nigeria, Tanzania, and South Africa are the largest producers with Tanzania producing 4 million MT leading in Eastern Africa region (FAO, 2018). In Kenya production is estimated at 3.5 million metric tons (FAO, 2022). In 2021, a total of 93,288 hectares (Ha) of land was planted with maize in Kenya, giving total production of 48 million bags that meet 75% of consumption projected at 60 million bags (AFA report, 2021).

Maize is primarily grown in most parts of the world primarily for food, biofuels, extraction of starch, oil, and other industrial substances in several countries (Tajamul *et al.*, 2016). In SSA, Latin America, and a few countries in Asia, maize contributes to over 20% of food calories (Shiferaw *et al.*, 2011). In Kenya, maize is the most important stable cereal crop followed by wheat and rice providing food for over 90% of the population with daily dietary energy uptake of 42% (Shelleemiah & Patrick, 2013). The crop accounts for nearly 40% of cultivated area and contributes about 2.4% of Kenya's GDP (FAO, 2016). Maize takes a center stage in production occupying an estimated 1.6 million hectares annually. Production is mainly by smallholder farmers who accounts for over 70% production (Shelleemiah & Patrick, 2013), providing large proportion of calorie needs to most consumers in both urban and rural areas (Nyoro, 1992). Most population mainly depends on maize directly for food, source of employment and income (Kainyu. 2015; Tsedeke *et al.*, 2015). Maize seed contains 11% protein content compared to rice and wheat (Chowdhury & Hassan, 2013).

In spite of importance of maize's in food security and economy, the average yield still remains below 1.2 tons per hectare ( $t\ ha^{-1}$ ) in Kenya compared to other countries; Spain ( $11.4\ t\ ha^{-1}$ ), Germany ( $10.7\ t\ ha^{-1}$ ), USA ( $10.7\ t\ ha^{-1}$ ), Italy ( $10.6\ t\ ha^{-1}$ ), Canada ( $9.4\ t\ ha^{-1}$ ), Egypt ( $7.8\ t\ ha^{-1}$ ), Argentina ( $6.8\ t\ ha^{-1}$ ) and South Africa ( $5.3\ t\ ha^{-1}$ ) (FAOSTAT, 2014; Ghani *et*

*et al.*, 2017). Recently Ethiopia and Tanzania exceeded their initial yields, currently their yields are 3.2 t ha<sup>-1</sup> and 2.5 t ha<sup>-1</sup> respectively (Abate *et al.*, 2015; Nassary *et al.*, 2020). Globally decline in maize yield has been reported mainly due to weed infestation, decline in soil fertility and changes in climatic conditions (Danda *et al.*, 2015). Despite existence of high yielding varieties, good agronomic practices (Illa *et al.*, 2010) and well established national maize breeding program supported heavily by International Maize and Wheat improvement Centre (CIMMYT) and International Institute of Tropical Agriculture (IITA) yields are still low. These has been attributed mostly to pest and disease infestations, birds damage, low soil fertility, and low use of certified farm inputs, especially nitrogenous fertilizer (Ramachandiran & Pazhanivelan, 2016) and biotic factors, where Striga causes huge losses.

In Africa, Striga causes yield losses estimated at US \$ 7 billion annually (Mbogo *et al.*, 2016) and in SSA; Rodenburg *et al.* (2016) estimated total yield losses of 20%-95% in sorghum and millet. Other African countries such as Ethiopia and Sudan, yield losses of between 65%-100% has been reported (Yousif, 2017). In western Kenya, averagely 246,000 Ha under cereal production is severely infested (De Groote *et al.*, 2008). This affected land is estimated to cause yield loss of 400,000 tonnes (AATF, 2020) valued at \$80 million (Atera *et al.*, 2013; Midega *et al.*, 2016). Counties along the Lake Victoria basin, such as Kisumu, Homa Bay, Migori, Busia, Kakamega, Vihiga, and Bungoma are mostly affected by purple witchweed *Striga hermonthica*, (Delile) Benth. These zones are characterized by declining soil nutrients levels especially phosphorous and nitrogen, low soil moisture and cereal mono-cropping system (Jamil *et al.*, 2012). Despite the huge losses associated to Striga, effective control of Striga has remained elusive due to striga prolific nature of seed production that remains viable for up to 20 years (Merkeb *et al.*, 2016).

Several years of research has resulted in identifying some range of control technologies including novel IR coated technology in maize, tolerant sorghum and millet genotypes, crop rotation and intercropping (Oswald *et al.*, 2002), application of organic manure and use of inorganic fertilizers (Mumera & Below, 1993). To meet the increasing demand of food for rapidly growing population, adoption of Imazapyr-resistant maize (IRM) has shown potential in increasing supply of maize through progressive eradication of Striga (Kanampiu *et al.*, 2006). The technology comprises of two main elements: imazapyr and herbicide-resistant maize seed. As the maize germinates, it absorbs some of the herbicide used for coating and as the germinated Striga attaches to the maize root, it is killed before it

causes damage to the maize plant, herbicide that is not absorbed by the maize plant diffuses into the soil and kills Striga seeds that have not germinated (AATF, 2006; CIMMYT, 2004).

The herbicide used is derived from a naturally occurring gene in maize originally identified by the Badische Anilin- & Soda Fabrik (BASF) and made available to CIMMYT (AATF, 2006). These technologies have showed success in reducing yield losses, however, none of this individual technology has on its own, provided adequate Striga management across the wide range of socioeconomic and biophysical environments. Use of the cultural approaches such as hand pulling, intercropping and crop rotation requires several seasons of repeated use to attain yield benefits (Ransom, 2000). Most of Striga infested fields have high accumulation of Striga seeds due to several years of neglect by farmers (Ekeleme *et al.*, 2014). Thus, there is an urgent need for effective control of this parasite to enhance maize production and productivity.

Cognizant of the above limitations, International Centre for Maize and Wheat Improvement in collaboration with the Weizmann Institute of Science and a chemical company BASF Switzerland developed a novel strategy that involves use of Imazapyr coated IR maize hybrids (Mignouna *et al.*, 2011). The coated herbicide inhibits the biosynthesis of branched-chained amino acids (Leucine, Valine, and Isoleucine), which interferes with production of amino acids that are essential for growth and functioning of the plant system (Chikoye *et al.*, 2011). Use of herbicide coated seed has been reported to reduce yield losses associated with Striga and depletes soil Striga seed bank (Ransom *et al.*, 2012). To use phytotoxic herbicides to control Striga and prevent crop injury, a gene conferring resistance to imadazolinone herbicide was incorporated into a tropically adapted maize germplasm (Menkir *et al.*, 2010) that already had natural resistance to *S. hermonthica* at the International Institute of Tropical Agriculture.

Combining herbicide resistance and agronomic performance of IR-maize minimizes the risk of Striga damage and severe yield loss (Menkir *et al.*, 2010). Imazapyr and pyriithiobac applied as soil drenches or coated on seeds results to an effective early season control of the parasite (Chikoye *et al.*, 2011). Despite the effectiveness of the IR technology, information on its effectiveness and its economic benefits compared to use of tolerant local landraces is limited in Striga prone areas of western Kenya. This study was therefore, conducted to evaluate the effectiveness and economic benefits of IR coated and selected local Striga tolerant maize varieties in the management of Striga in maize producing Counties of western Kenya.

## 1.2 Statement of the problem

Witch weed (*Striga hermontica*) also known as purple witchweed is a parasitic weed that destroys cereal crops mainly maize, sorghum, upland rice, and millet in sub-Saharan Africa. In Kenya it is widespread in Kisumu, Homa Bay, Migori, Busia, Kakamega, Vihiga, and Bungoma counties causing approximated yield loss of between 20-95%. The invasiveness of the weed is evident in its rapid spread to new geographical regions that were initially reported to be free from *Striga*. Its extensive spread has been triggered by; continuous mono-cropping, use of contaminated seed and tillage tools, extensive grazing of animals, declining soil fertility (P and N) and the warm climatic condition in the region. Small-scale farmers are the most affected due to scarce resources limiting their accessibility to newly improved tolerant varieties and herbicides. This has led to over-reliance on recycling locally available susceptible seed. Coupled to *Striga* prolific seed production and longevity (up to 20yrs) without losing viability, early parasitism makes it difficult to be controlled. Total host grain yield loss is reported in field with combined high infestation levels and use of susceptible varieties. This has led to many farmers abandoning highly infested fields that are no longer productive causing increased food insecurity and poverty in the western Kenya. Although considerable research on *Striga* has been carried out and a wide range of technologies developed, *Striga* problem has persisted and increased in magnitude in western Kenya. Research trials on use of Imazapyr Resistant (IR) technology conducted by KALRO in conjunction with CIMMYT led to release of FRC425IR by Fresco Seed Company and H528IR by Kenya seed companies that was expected to be a breakthrough. The coated with Imazapyr herbicide can prevent the attachment of the parasite early in the season since the herbicide will kill the germinating *striga* seeds. Unfortunately, these varieties have not been widely adopted by farmers due to limits in information on their effectiveness and their availability. Furthermore, information on the level of tolerance over local cultivars grown by farmers over generations in western Kenya is still limited. This study therefore was aimed at determining the effectiveness of herbicide coated Imazapyr Resistant (IR) hybrids, selected *Striga*-tolerant and local maize varieties on *Striga* management and yield of maize in western Kenya.

## **1.3 Objectives**

### **1.3.1 Broad objective**

To contribute to improved food and nutritional security through adoption of imazapyr resistant (IR) and selected *Striga* tolerant varieties for effective *Striga hermonthica* management and enhanced yields in small-holder maize farming systems in Kenya.

### **1.3.2 Specific objectives**

- i. To determine the effectiveness of IR and selected *Striga*-tolerant maize varieties on management of *Striga hermonthica* and effects on grain yield in western Kenya.
- ii. To determine the economic benefits of using IR Maize technology against local landraces on maize production among small scale farmers in western Kenya.

## **1.4 Hypotheses**

This study was guided by the following hypotheses;

- i. IR and selected *Striga*-tolerant maize varieties have no effect on management of *Striga hermonthica* and effects on grain yield in western Kenya.
- ii. Use of IR maize technology and selected *Striga*-tolerant maize varieties has no economic advantage over the local landraces on maize production among small scale farmers in western Kenya.

## **1.5 Justification of the study**

Maize is an important staple food crop in the marginalized western Kenya region where it is the main security food crop and a rich alternative source of carbohydrates, protein, fat, and dietary fiber. Despite this, the area under maize production is still low and farmers suffer high yield losses attributed to *Striga* infestation. In western Kenya, over 246,000 ha under cereal production, mainly maize is severely infested (De Groote *et al.*, 2008). This affected land is estimated to cause yield loss of 400,000 tonnes (AATF, 2020) valued \$80 million (Atera *et al.*, 2013; Midega *et al.*, 2016). Yield losses in this region has been heightened by frequent drought and nutrient deficient soils, making it even more detrimental to all farmers especially smallholder farmers (Ejeta & Gressel, 2007). In addition, subsistence small-holder farmers have limited information on the effectiveness, availability, and the yield advantage of improved *Striga* tolerant maize genotypes. As result, most farmers in this region continue to use their local varieties which are highly susceptible to *Striga hermonthica*, further increasing the level of *Striga* infestation. In response to this, most

farmers have abandoned cultivation of maize due to associated high yield losses occurring under such farm conditions (Atera *et al.*, 2013). The novel IR technology under research trials have indicated better yields in striga infested fields compared to susceptible genotypes (Badu-Apraku & Akinwale, 2015). Continuous use of Imazapyr coated varieties does not only reduce the number of seeds added to the soil but also increase grain yield and in return improve the income, food, and nutritional security in western Kenya. This study is anchored on the Agricultural Sector Transformation and Growth Strategy (ASTGS) 2019-2029 policy anchor 1 that endeavors to achieve food and nutrition security, improve farmer and local community incomes, lowering the cost of food, and increasing employment. The effectiveness of IR maize varieties on management of *Striga hermonthica* and effects on grain yield in western Kenya and the economic benefits of using this technology against local landraces on maize production among small scale farmers in western Kenya were evaluated and findings presented in this study.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Importance of Maize

Global maize production has surged in the past few decades, propelled by rising demand, technological advances, yield increases and area expansion becoming the leading global staple cereal in terms of annual production exceeding 1 billion metric tons (García-Lara & Serna-Saldivar, 2019). Maize is the leading cereal in terms of production volume followed by paddy rice (*Oryza sativa*) and wheat (*Triticum aestivum*) (Huma *et al.*, 2019) and is set to become the most widely grown and traded commodity. It is a versatile and multi-purpose crop, primarily used as an animal feed globally, as food crop, especially in sub-Saharan Africa and Latin America, besides other non-food uses (Erestein *et al.*, 2022). Maize grains have proximate composition of moisture content (9.4 - 11.5%), total ash (1.4 - 1.7%), crude fat (5.1 - 7.2%), crude protein (9.7 - 15.3%), crude fiber (1.6 - 3.5%), carbohydrate (62.1 - 70.0%) and Energy (365.9 to 385.8 kal/100g) (Demere, 2018). Maize is also a good source of minerals, vitamins, fiber, and oil present in maize bran. Maize starch is famous in pharmaceutical industries and in cosmetics production. Further, maize grain is used in making alcohol while the stem is used for paper manufacturing. Smallholder farmers engage with maize farming, because of its highly nutritional value and affordable source of vitamins and minerals (Huma *et al.*, 2019).

#### 2.2 Origin and distribution of maize

Central America and Mexico, which consist of a diversity of maize crop, is the primary center of origin of the current maize. Studies revealed that maize is the most important and leading cereal crops in the world after rice and wheat (FAOSTAT, 2014). USA has the largest area under maize followed by Brazil, China, Mexico, and India. Maize was introduced in coastal Kenya in the 15<sup>th</sup> century by the Portuguese traders (Kingori *et al.*, 2016) which further spread and is currently produced in almost all regions of the country. In Kenya, Rift Valley it is the major producing area accounting for 50% of the total production, followed by Nyanza (14%), and central (6%) regions (Chemiat & Makone, 2015).

#### 2.3 Botany and physiology of maize

Maize is a monoecious, annual grass that grows to a height of about 4m subject to variety (Muiru, 2008). Maize plant has adventitious roots that develops from the lower nodes

below the soil surface, these roots are usually limited to the upper 75cm of the soil. Maize stems are simple and solid with well-defined nodes and internodes ranging from 8-21 (George & Karin, 2004). The male and female inflorescences are separate but on the same plant. The ear is a modified female inflorescence, which usually develops from the axil of the largest leaves that is about halfway the stem. The ear is covered with 8-13 modified leaves known as the husk; the tassel on top of the plant is the male part that produces pollen (George & Karin, 2004). Flower initiation usually occurs at 20-30 days after germination. The period from planting to harvesting varies from 70-200 days (Muiru, 2008). Tiny pollen grains are carried by wind to the silks, either of the same plant or a different plant, where they grow down inside the silk to fertilize an egg that will become a kernel (George & Karin, 2004).

#### **2.4 Agro-ecological zones of maize production**

Maize is a widely adaptable crop growing in a wide range of agro-ecological zones ranging from sea level to about 3000 m above sea level (ASL) and grows throughout the year in many parts of the country. The crop requires an average daily temperature of 20°C-30°C for adequate growth and development. During flowering, high temperature and low humidity damages the foliage, scorches the pollens, interferes with pollination, and hinders grain formation. It requires rainfall of between 600 - 900 mm during the growing season. It is highly sensitive to water stagnation especially during early period of growth (Jaidka *et al.*, 2019).

#### **2.5 Constraints to maize production**

Maize yields in most parts of Africa including Kenya has remained below 1.2 t ha<sup>-1</sup> (Knoema, 2020) compared to 1.9 t ha<sup>-1</sup> in other SSA countries (Nigatu *et al.*, 2019) and 10.7 t/ha in USA (Ghani *et al.*, 2017). These low yields are attributed to both biotic and abiotic constraints. Frequent drought, declining soil fertility and over-reliance on rain fed production in the region continues to increase vulnerability in maize production (Tsedeke *et al.*, 2015). In Kenya low maize yields is compounded by heavy weed infestation especially striga in western Kenya, grass and broad leaved in the highlands, declining soil fertility, Pests diseases (stem borers, armyworms) associated to climate change (Danda *et al.*, 2015) and Social economic factors such as price, input availability (Badu-Apraku *et al.*, 2015; De Groote *et al.*, 2020).

About two-thirds of the 73 million hectares devoted to cereal production in the continent is situated in ecological zones where *Striga* is already present. In Africa, only five *Striga* species are of economic importance with *Striga hermonthica* known to cause the most damage to sub-Saharan cereal production, followed by *Striga asiatica*, *Striga gesnerioides* and to a far lesser extent, *Striga aspera* and *Striga forbesi* (Kuria, 2017). *Striga hermonthica* and *Striga asiatica* are the most prevalent species in the SSA affecting 50 million hectares of land, depriving 300 million people of their livelihoods (Showemimo, 2010). The estimated total global loss associated with *Striga* menace stands at US\$7 billion (Ejeta, 2007; Mbogo *et al.*, 2016). *Striga asiatica* is mainly found in semi-arid areas of tropical and subtropical Africa, Asia, China, and Australia (Shayanowako *et al.*, 2018) whereas *S. hermonthica* dominates most cereal growing regions of SSA (Unachukwu *et al.*, 2017). An estimated area of over 21 million ha is infested by *S. hermonthica* in SSA (Qurashi *et al.*, 2017). *Striga hermonthica* is the most dominant species in western Kenya (Illa *et al.*, 2010).

## **2.6 Origin, distribution, and biology of *Striga***

*Striga* spp. is hemi-parasitic plants that parasitize the root systems of their hosts as shown in Figure 1. The genus *Striga*, family Orobanchaceae, comprises of 41 species found in the African continent and parts of Asia. *Striga* weed is believed to have originated from the Nubian Mountains in Sudan and Ethiopia, the same region of origin for sorghum (Ejeta, 2007). The genus belongs to the dicotyledonous family Orobanchaceae that has genetically diverse members ranging from 30 to 35 species (Kirigia, 2015). It has since spread to most countries within the Sub Saharan Africa region (Koua, 2011). Current change in climatic condition experienced in most parts of the world may in future contribute to further extension in geographical area under *Striga* (Teka, 2014).

Purple witch weed is widely distributed in diverse agro-ecologies that experiences an annual rainfall of 250 to 1500 mm and temperatures of between 27°C to 40°C respectively (Jain *et al.*, 2018). The amount of rainfall received in an area determines the levels of *Striga* infestation, where regions receiving low amounts of rainfall experiences high levels of infestation compared to those experiencing high rainfall (Jain *et al.*, 2018). *Striga* species are among the most specialized root parasitic plant that combine the life cycle of holo-parasitism at the seedling stage and hemi parasitism in the subsequent growing period (Badu-Apraku & Fakorede, 2017). In a single growing season, the weed produces several dust-like seeds that

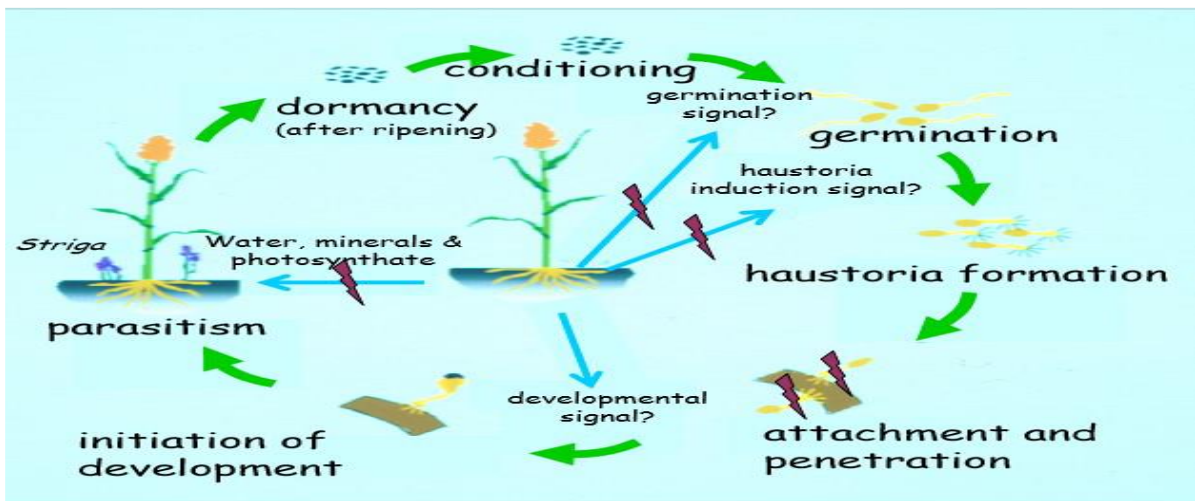
are easily dispersible that stays longer in the soil (Anyonga *et al.*, 2011; Dafaallah *et al.*, 2015).



**Figure 2.1** Maize crop heavily infested with *Striga hermonthica* in western Kenya.

### 2.6.1 Life cycle of *Striga hermonthica*.

The life cycle of the parasite is divided into non-parasitic and a parasitic mode as shown the Figure 2 below.



**Figure 2.2** Life cycle of the *Striga* presenting elaborate association between the parasite, its hosts, and the environment.

Source: Jamil, 2012

### 2.6.2 Nonparasitic phase

The non-parasitic phase starts when *Striga* seed perceives an appropriate germination stimulant and ends with the attachment of *Striga* radicles onto host roots (Cui *et al.*, 2018). *Striga* will respond to germination stimulants after undergoing pre-incubation period of moist and temperatures of 30 to 35° C (Cardoso *et al.*, 2011; Zwanenburg *et al.*, 2016). This process usually occurs underground ordinarily taking between 4-7 days (Matusova *et al.*, 2005).

### 2.6.3 Parasitic phase

Germination of *Striga* seed is associated to the presence of a nearby host, since its seeds endosperm is so tiny that it can only sustain growth or life only for the first 3-7 days, otherwise it will exhaust its energy reserves and die (Thomson, 2017; Yoneyama *et al.*, 2010). The parasitic phase begins upon the radicle contacting host root, developing into a specialized organ, the haustorium which attaches the *Striga* seedlings to the host roots for diverging host growth resources (Yoshida *et al.*, 2016). In addition to chemical signals, a thermotropic response is required for the *Striga* seedling to develop morphologically normal haustorium (Spallek *et al.*, 2013). The developed haustorium penetrates the root cortex into the stele aided by intrusive cells at its tip and forms a direct link between the parasite and root host xylem systems (Kokla & Melnyk, 2018). The linkage is established within a few days after attachment (Yoshida *et al.*, 2016). The parasite tubercles grow underground for approximately 3-6 weeks, during which it's fully dependent on the host for all the substances it requires for growth and development (Runo & Kuria, 2018). After emergence, the parasite forms a stem and leaves with chlorophyll and becomes a hemiparasite that synthesizes assimilates, although remains partially dependent on the host for water, minerals and some assimilate.

About one month after emergence, the parasite flowers, and upon pollination, produces large number of minute (0.20-0.50 mm long) seeds weighing approximately 3.7-12.4 µg each, (Abdalroof, 2016). The estimated numbers of produced seeds per reproductive period varies from 50,000 - 500,000 depending on species and growing conditions (Rodenburg *et al.*, 2016). Produced seeds are dispersed by cattle, wind, floods, contaminated farm implements and crop seeds (Gebreslasie *et al.*, 2016). The seeds produced are capable of remaining viable a period of up to 20 years in the soil (Larsson, 2012). Upon infection, *Striga* damages its host in several ways which including allelopathy, hormonal imbalance, reduction

of host's photosynthetic efficiency, and withdrawal of hosts growth requirements (Bawa *et al.*, 2015). The parasite causes stunted growth, early host discoloration, wilting of the host long before the striga weed appears (Gebreslasie *et al.*, 2016). Striga damage is intensified in areas where soil fertility has deteriorated, shortened fallow periods and where farmers have rapidly expanded to marginal areas without use of additional external inputs (Chikoye *et al.*, 2011).

## **2.7 Methods of Striga control**

Controlling Striga and other root parasites is difficult because of their early parasitism, doing most of its damage before emerging from the ground (Chikoye *et al.*, 2011). Several cultural, mechanical, chemical, and biological control measures are available to regulate the parasite population. However, most of these techniques do not provide complete *Striga* suppression and it is usually necessary to integrate these methods.

### **2.7.1 Cultural and agronomic practices**

Trap cropping and sowing of false host such as cowpea, groundnut, sesame, and cotton to stimulate suicidal germination and improving soil fertility is documented to be effective against Striga (Atera *et al.*, 2013). Combining trap crops and nitrogenous fertilizers have been reported to significantly decrease Striga seed bank (Tadesse, 2018). Additionally, use of cover cropping, mulching suppresses Striga through induction of suicidal germination, and improvement of soil fertility (Pickett *et al.*, 2010; Randrianjafizanaka *et al.*, 2018). Adoption of push-pull technology in controlling Striga in maize field has been found to be very effective (Amudavi *et al.*, 2008). Intercropping maize with legumes such as *Desmodium* spp not only increases maize yield but also fixes nitrogen and improves soil fertility, as well as reducing soil erosion (Khan *et al.*, 2007). The maize - *Desmodium* intercrop is practiced among smallholder farmers, where the *Desmodium* will remain in the field permanently and harvested to feed livestock, or even sold to generate some revenue. The nutritional content of the *Desmodium* forage resulted in a rise in the number of exotics, high-milk-yielding breed of cattle, which helped to enhance the nutritional status and increase in income of the farming population (Khan *et al.*, 2008).

Some intercrops produce allelochemicals, such as C-glycosylflavonoids, isoflavanones, isoschaftoside, phenolics, 3, 4-dihydroxybenzoic acid, which inhibit Striga germination, growth, or development (Hailu *et al.*, 2018). Further, Kanampiu *et al.* (2018),

illustrated that intercropping legumes with herbicide-resistant maize varieties is more effective against *Striga*. Practising fallowing and crop rotation has been reported to improve soil fertility, reduces production of strigol, and induces crop yield increase and lower *Striga* infestation (Ayongwa *et al.*, 2010; Rubiales & Fernández-Aparicio., 2012). Rotating cereals with non-host legume crop considerably reduces *Striga* seed bank in infested fields, leading to decreased infestation and significantly enhance yield, compared with continuous cereal cultivation (Franke *et al.*, 2018). Hand pulling is the cheapest traditional control method (Goldwasser & Rodenburg, 2013) though needs to be done before the weed flowers (Ayongwa *et al.*, 2010; Sibhatu, 2016), is laborious, time-consuming, and less effective on the standing crop (Mahuku *et al.*, 2017).

Additional, addition of nitrogenous fertilizers not only help in reducing strogolactone production but also inhibits germination of the parasite (Nambafu *et al.*, 2013; Sakadizo *et al.*, 2021). Further, previous results showed that addition of 60kg N ha<sup>-1</sup> significantly reduced the number of emerged *Striga* shoots that emerged m<sup>-2</sup> in maize (Dugje *et al.*, 2008). Other studies also indicate that use of ammonium source of nitrogen for top dressing significantly reduced the number of *Striga* shoot emergence (Below & Mumera, 1993; Patrick & Imuetinyan, 1996). Despite these, use of inorganic fertilizer is limiting since they are expensive for most smallholder farmers. In addition, rotating maize with *Hypis* spp. has showed reduced incidences of *Striga hermonthica* (Othira *et al.*, 2008). However, with reduced land sizes, crop rotation is becoming less feasible because of the increasing demand for land to produce cereals and where rotations are made, it hardly surpasses the three years required for rotation to be effective in controlling *Striga* (Parker & Riches, 1993).

### **2.7.2 Biological control**

This is a deliberate use of living organisms to suppress, reduce, or eradicate pest population. It comprises of herbivorous insects, microorganisms (especially fungi), and smother plants. Studies carried using fungus *Fusarium oxysporum* showed effective inhibition of *Striga* germination and reducing seed bank in infested soils (Nzioki *et al.*, 2016; Othira *et al.*, 2012; Rebeka *et al.*, 2013). Some *F. oxysporum* strains produce high amounts of the amino acids L-leucine and L-tyrosin which are toxic to *Striga*; in addition, methionine released by *F. oxysporum* strains is converted by soil microbes into ethylene that causes suicidal germination of *Striga* seeds (Nzioki *et al.*, 2016). Results also indicate that Seed coating with *F. oxysporum* (FOXY2) effectively reduced *Striga* emergence under field

conditions (Rebeka *et al.*, 2013). Arbuscular mycorrhizal (AM) is known to help plants in absorption of water, phosphorous and micronutrients from the soil via extra wide network of radical fungal hyphae thereby reducing strigolactones exudation by the host into the soil (Lendzemo *et al.*, 2007). The use of soil microbes is now considered as a promising, cost effective, and environmentally safe approach for combating Striga (Samejima & Sugimoto, 2018; Watson, 2013), however, it has not been widely used as a routine means of managing the Striga problem in African smallholder farms. This is because such products are not commonly available for use in subsistence farming and requires technical knowledge and expertise in fungal isolation and preservation (Teka, 2014).

### **2.7.3 Chemical control methods**

Plant uses photo hormones in relaying information amongst each other. These chemicals including; ethylene, ethephon, and strigol analogues produced naturally by plants have been harnessed and used by plants to induce suicidal germination of Striga seeds (Logan & Stewart, 1991). Evidences indicate that production of strigol acetones by monocotyledonous plant species could be reduced if sufficient mineral nutrients (nitrogen and phosphorous) are available for plant uptake thus reducing stimulation of Striga germination (Jamil, 2012). Use of pre-emergence herbicides, such as atrazine and metalachlor (dual gold), have also been reported to reduce incidence and damages caused by Striga (Kabambe *et al.*, 2008). Kanampiu *et al.* (2002) reported that use of low doses of imazapyr (30 g per hectare), significantly reduced the number of emerged Striga plants, provided good early season control and increased the yield of maize by 3 to 4-fold in heavily infested fields (Kanampiu *et al.*, 2004). This herbicide, imazapyr, is environmentally friendly and dissipates easily from the soil (AATF, 2011). Despite the effectiveness of chemicals in managing striga there use has also not been widely adopted since they are associated with great environmental degradation, non-selectiveness in their mode of action, and most often expensive to acquire by the subsistence farmers (Dugje *et al.*, 2008)

### **2.7.4 Use of biotechnology and mutation Breeding**

Use of varieties associated with Imidazolinone-tolerance that involves single nucleotide substitution of a foreign gene into elite varieties resulted to mutant 1 and mutant 2 which were then commercialized as IR maize (Siyuan *et al.*, 2005). Imidazolinone herbicides control weeds by inhibiting the enzyme acetohydroxyacid synthase (AHAS) that is a critical

for the biosynthesis of branched chain amino acids (valine, leucine, and isoleucine) that are essential in plants growth (Siyuan *et al.*, 2005). Imazapyr Resistant (IR) maize is tolerant to all AHAS-inhibiting herbicides that prevent maize injury caused by the interaction between AHAS-inhibiting herbicides (Makumbi *et al.*, 2017). Upon absorption of the imazapyr, synthesis of branched amino acid is affected thereby affecting protein synthesis, which eventually hinders growth and development of Striga. The un-absorbed herbicide dissolves in soil moisture forming a film that diffuses into the soil rhizosphere killing germinating Striga seed (Ndwiga *et al.*, 2013).

## **2.8 Host resistance responses to *Striga* infection**

Resistance is the ability of the host or non-host, to sustain parasite attack that prevents formation and growth of the parasite (Timko & Scholes, 2013). Utilization of resistant varieties is generally considered the most economical, practical, and suitable long-term approach for controlling Striga (Mandumbu *et al.*, 2019). Host resistance is either through pre-attachment or post-attachment resistance. Studies on *S. hermonthica* infestation using Rhizotron technology indicated presence of post-attachment resistance in KSTP94, that is demonstrated by lower number of Striga attachments and biomass in comparison to the susceptible maize inbred line CML144 (Mutinda *et al.*, 2018). The ability of cultivars, such as KSTP94, to tolerate Striga infestation at pre- and post-attachment stages makes them very suitable genetic source for resistance breeding traits (Jamil *et al.*, 2021). Further, use of genetic engineering tools in modifying strigolactones profile of host plants has led to improved host resistance (Wakabayshi *et al.*, 2020). Studies have indicated several responses to Striga attachment such as mechanical barriers, hypersensitive response (HR) and incompatible response, secretion of phytotoxic compounds (phenolics and phytoalexins) that form physical barriers at the parasite infection points (Scholes & Timko, 2013). Some accession of wild sorghum accumulates phenolic compounds at the host-parasite interface covering protection from parasite attack (Maiti *et al.*, 1984; Mohamed *et al.*, 2003; Olivier *et al.*, 1991). Similarly, Gurney *et al.* (2003) reported presence of a compound released by a resistant wild relative of maize, (*Tripsacum dactyloides*), that inhibits parasite haustorial formation.

Integrating different management approaches to manage Striga remains the most effective way of dealing with the parasite (Sibhatu, 2016). Mrema *et al.* (2020) reported that combining host resistance with fungal inoculated seeds substantively reduced effects of

Striga. Similarly, Kamara *et al.* (2020) reported high efficacy when herbicide coated seeds was combined with host resistance. Additionally, combination of cereal-legume rotations with application of synthetic germination stimulants depleted Striga seed bank in the infested soils (Hailu *et al.*, 2018). Several technologies have been adopted in farmers' fields in western Kenya; however, the parasite remains a major challenge to cereal crop production. A study was therefore, conducted to evaluate the effectiveness IR and selected Striga-tolerant maize varieties on Striga management and yield of maize. The study further aimed at determining the economic advantage of using IR varieties against use of local maize landraces.

## **2.9 Economic analysis of IR technology**

Elimination of weed should be done using least expensive but effective available technology. Any weed control measures should be used only when its results are expected to be more beneficial economically than without using any control measure (Moody, 1993). Scientists across the world have developed many improved technologies that are aimed at increasing farm productivity and income with the intention of improving farmers' yields (Mignouna *et al.*, 2015). Farmers ordinarily adopt technologies that have potential of higher economic benefit and lowest risk when compared to the present ones (Rana *et al.*, 2016). For easy adoption of new technology, agricultural scientists should be able to prove that new technologies will have an economic benefit over the existing technologies (Simtowe *et al.*, 2011). On the other hand, before switch from a known investment to the unknown, farmers consider many factors, such as agro-climatic and production requirements, including labour, farmland, skill, finance, and other necessary production implements. Additionally, farmers also consider the suitability of the new technology in terms of their socioeconomic values and production goals. It is also of interest for farmers to know whether the extra cost incurred will result into better returns (Parvan, 2012).

The simplest and most straight forward method of comparing the economic benefit of new agricultural technology verses use of existing technology is the use of partial budget (PB) analysis (Badu-Apraku *et al.*, 2012). Partial budget is a farm management technique that is intended to help researchers, agriculturist and farmers in making informed decisions. Partial budget analysis compares and quantifies the impact of the proposed technology with the existing ones. Partial budget analyses present results in ratios such as, Marginal Rate of Return (MRR), Benefit Cost Ration (BCR) and the gross margin analysis. These ratios guide

scientists involved in agricultural practices and extension to identify weaknesses associated with the new technology, such as high cost of production and low income. Further partial budget analysis is used to help researchers identify technology with the highest profit thus guiding farmers in adopting the novel technology or not (Badu- Apraku *et al.*, 2012). In the present study, partial budgeting was used to compare the effect of IR maize coated varieties against local landraces used by farmers in western Kenya.

In this evaluation, cost of cultivation was calculated by adding all the costs involved in each operation (seedbed preparation, seed and sowing, fertilizer, irrigation, weed control, plant protection, harvesting and postharvest operations, land rent. Total cost (TC) consists of variable costs and fixed costs. Total cost is the total opportunity cost of each factor of production as part of its fixed or variable costs. Variable cost (VC) changes according to the quantity of a good or service produced. It includes inputs like labour and raw materials. Variable costs are also the sum of marginal costs over all the units produced (referred to as normal costs). Fixed costs (FC) are incurred independent of the quality of goods or services produced. Additionally, the economic decision that a firm makes depends on the cost of the alternative chosen and the benefit that the best alternative would have provided if chosen.

### **2.9.1 Cost-Benefit computations of Maize productivity**

Maize is the most important cereal crop used both as staple food and cash crop to a number of people. Maize productivity continues to remain very low despite the increasing demand (Omondi *et al.*, 2014). Population increase, reduction of land sizes due to subdivision, limited resources, emergence of weeds (especially *Striga hermontica*), pests and diseases have posted a challenge in maize production in western Kenya. Much of the *Striga*-infested area of western Kenya has ultra-high levels of *Striga* seed in the soil after several years of monocropping with host crops, declining soil fertility, and using *Striga* contaminated crop seed for planting (Kanampiu *et al.*, 2018). The ability of a single *Striga* flower stalk to produce hundreds of thousands of tiny, dust-like seeds means that a minor infestation can lead to devastating levels of damage in only a few seasons. Dormant *Striga* seeds continue to germinate for many years as only a portion of the seeds breaks dormancy when stimulated by the exudates of a receptive crop growing in the locality. Farmers in western Kenya are still facing the problem of *Striga*, a major constraint to cereal production threatening food security of thousands of poor farming households. Some *Striga* species also attack tropical legumes hence further augmenting protein malnutrition of vulnerable younger children. Imazapyr

resistant maize (IRM) technology is being promoted as a response to the increasing Striga problem.

Several control measures such as; crop rotation, intercropping, hand weeding, use of inorganic fertilizer has been used in vain. Use of high yielding varieties, use of low external inputs farming practices will be the solution to address these challenges (Jeavons, 2012). Despite farmers knowing that new maize varieties generally yield more than open pollinated varieties (OPVs), they assume that the hybrids will perform well only when high external inputs are used (Macharia *et al.*, 2010). Many subsistence farmers in *Striga*-infested areas purchase hybrid maize when the cost-benefit ratio renders hybrids superior to saved open pollinated varieties. These practices (seed treatment, whorl pesticide applications, seed purchase) demonstrate that economically viable technologies would be accepted, if they give control of the parasite prior to crop damage (Kanampiu *et al.*, 2007). IR maize seed retails at US\$2 per kg (or US\$40-50/ha), similar to other improved varieties. Higher yields and ability to reduce Striga seeds in the soil are some of the benefits that make IR maize more attractive to farmers than their own seed (CIMMYT, 2002). To develop effective policies to enhance adoption of new agricultural technologies such as IRM, policy makers need information on the viability and profitability of these technologies that can be targeted to facilitate poverty reduction. The objective of this study was to compare the agronomic and economic performance of a local landrace with that of IR coated maize (FRC425) for improved and sustained maize production in western Kenya. The hypothesis was that there is a significant profitability difference between IRM and other maize varieties in the Striga-prone areas which implies that farmers need to consider profitability of different technologies before their use. The economic analysis of IRM technology involved the gross margin (GM) analysis, the Marginal rate of Return (MRR) and Benefit-Cost Ratio (BCR).

Total variable costs for IRM production were labour costs on land preparation, cultivation, sowing, weeding, transport and inputs application, harvesting costs and costs of inputs: seeds, fertilizers, pesticides and other field operation during the 2008 long rains season. Valuation of rural family labour has been an area of economic debate (Fox *et al.*, 2005; Kunze, 2000; Senkondo *et al.*, 2004). In this study, family labour was retained as man-days and was not valued in monetary terms. Man-day is the work one person would normally do in one working day of eight hours to carry out specific activity (Oduor, 2002). Parameters used along with gross margin to express the profitability of IRM crop enterprise under Striga infestation included productivity (tons per hectare), returns to land (gross margin per hectare)

and returns to labour (gross margin per man-day). Gross margins (returns) were computed by subtracting the variable costs from the gross revenue. In western Kenya, IRM supposes to improve maize productivity while reducing *Striga* biomass and seed bank in the soil. Therefore, the major effect of IRM is expected from an increase in productivity through a reduction of *Striga* parasitism.

Final results were computed by subtracting the total cost of cultivation from the returns. This value gives the actual profit obtained by the farmer. In this type of calculation, only the variable costs are considered. The net returns per shilling invested also known as benefit cost ratio was obtained by dividing net returns with the treatment wise cost of cultivation.

$$\text{Net returns per shilling invested (BCR)} = \frac{\text{Net benefits}}{\text{cost of cultivation}}$$

This ratio provided an estimate of the benefit derived and expenditure incurred by the farmer in adopting IR maize technology.

In determining the returns, the economic data was subjected to analysis using the partial budget analysis method (CIMMYT, 1988).

Marginal rate of return (MRR) was calculated as:

$$\text{MRR (\%)} = \frac{\text{DNI}}{\text{DTC}} \times 100$$

Where, MRR is marginal rate of returns, DNI is the difference in net income compared with control and DTC refers to difference in total cost of the IR and the control variety. The local landrace mostly preferred by farmers was used as the control.

**CHAPTER THREE**  
**EFFECTIVENESS OF IMAZAPYR COATED HYBRIDS AND SELECTED STRIGA-TOLERANT VARIETIES ON *S. hermonthica* L. CONTROL AND YIELD OF MAIZE IN WESTERN KENYA.**

**Abstract**

Witchweed (*Striga hermonthica*) an obligate root hemi-parasite is a massive biological constraint that hinders maize (*Zea mays* L.) production in western Kenya particularly when susceptible varieties are used. The parasite impairs host plant's normal growth by developing and attaching its haustoria to the host xylem drawing water and nutrients, resulting in a stunted growth, reduction of biomass and poor grain filling. Use maize genotypes coated with small doses of Imazapyr resistant (IR) herbicide and tolerant local accessions offers hope for management of *S. hermonthica* and increased maize production among small-scale farmers in Western Kenya. A field study was conducted to evaluate the effectiveness of IR hybrids and selected Striga-tolerant varieties on *S. hermonthica* management and yield of maize during the two successive cropping seasons of (2018 and 2019) at the KALRO-Alupe Research Station, in Busia under (artificial inoculation) and farmer's field in Rangwe (natural infestation) in Homa Bay Counties. The varieties were evaluated in randomized complete block design (RCBD) with three replications. Test genotypes comprised of two IR (H528IR, FRC425IR), two Striga tolerant (KSTP94, GAF4), five susceptible commercial hybrids (DK8031, H513, DUMA43, DH04, Haraka 101) and one two local landraces. All Striga and crop data collected was 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 by 56 and 69% compared to the local landraces and commercial susceptible 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. The study supported the hypothesis that different maize genotypes respond differently ( $P < 0.05$ ) to *Striga hermonthica* infection. The IRM maize genotypes under investigation in this study recorded high yields (2.50-2.64 t ha<sup>-1</sup>), supported fewer Striga shoots (numbers), had lower Striga damage ratings scale of 2.2-2.5 and were broadly adapted to the growing condition in western Kenya. In conclusion the susceptible checks had lower mean yields, (0.54-1.45 t ha<sup>-1</sup>). Breeding programs focused on developing resistant cultivars may adopt use of FRC425 and H528 parents as they have potential sources of Striga weed tolerance genes.

### 3.1 Introduction

Witch weed (*Striga* spp.) is a massive root hemi-parasite of significant economic importance in much of Africa and parts of Asia where it deters production of maize (*Zea mays* L.) and other cereal crops. In Africa, only five *Striga* species are of economic importance with *Striga hermonthica* known to cause the most significant damage to sub-Saharan cereal production, followed by *Striga asiatica*, *Striga gesnerioides* and to a far lesser extent, *Striga aspera* and *Striga forbesi* Benth (Kuria, 2017; Parker, 2009). *Striga asiatica* is mainly found in semi-arid areas of tropical and subtropical Africa, Asia, China, and Australia (Shayanowako *et al.*, 2018). The weed causes yield losses estimated at US\$7 billion annually affecting the livelihood of about 300 million people in Sub Saharan Africa (SSA) (Ejeta & Gressel, 2007; Kariuki, 2015).

In Kenya, it is estimated that over 246,000 ha of land are infested with *Striga* causing crop losses amounting to 400,000 tons worth US\$ 80 million per year (AATF, 2020). *Striga hermonthica* is a predominant species that poses a serious threat to maize production that sometimes leads to total crop loss (Odongo *et al.*, 1998). It is widespread and most damaging to many other cereal crops such as finger millet (*Eleusine coracana*), rice (*Oryza sativa* L.), and sorghum (*Sorghum bicolor* L. Moench). Under extreme infestation, a single host plant can support several parasitic plants, each capable of producing tens of thousands of seeds (Teka, 2014). These seeds persistently remain in the soil for long periods.

Beyond the burden of losing nutrients and water to the parasitic weed, the host plants suffer from a characteristic condition resembling the symptoms of severe drought, including leaf scorching and increased root to shoot ratios (Watling & Press, 2001). It causes crop damage through hormonal distresses particularly in ABA, inducing harmful phytotoxic chemicals that alter host plant–water relations and reduces photosynthesis through competition for water, nutrients, and light (Frost *et al.*, 1997; Gurney *et al.*, 1999; Taryor *et al.*, 1996). *Striga hermonthica* has heavily infested western Kenya, a region where maize is the major staple food crop, resulting to low yields of less than 1 t ha<sup>-1</sup> against a potential yield of 5 t ha<sup>-1</sup> (Illa *et al.*, 2010). Depleted soil fertility, degraded land and soil moisture deficit has worsened the situation (Kanampiu *et al.*, 2012; Natcher *et al.*, 2016). In addition, rapid expansion of cereal production into marginal areas with minimal use of external inputs has intensified the effects of *Striga* parasitism (De-Groote *et al.*, 2005). Additionally, farmers in these areas practice poor farming practices such as monocropping with little or inadequate use of fertilizer.

Management of *Striga* is complicated by its nature of prodigious seeds production that only germinate when they perceive strigolactones produced by suitable host (Jamil *et al.*, 2012). In the absence of host roots' stimulants, the seed persistently remain dormant in the soil for up to 20 years (Dalley *et al.*, 2006). Its early parasitism results to substantive yield losses of up to 75% just before emerging from the ground (Chikoye *et al.*, 2011). Several management methods have been suggested including; use of *Striga*-tolerant or resistant maize cultivars (Menkir *et al.*, 2016; Menkir *et al.*, 2019), application of nitrogenous fertilizer particularly on infertile and degenerated soils (Jamil *et al.*, 2012; Kamara *et al.*, 2020), legume-maize rotation (Franke *et al.*, 2006; Kamara *et al.*, 2004), herbicide seed coating (Kanampiu *et al.*, 2001; Kamara *et al.*, 2020). Maize breeders at the International Institute of Tropical Agriculture (IITA) have bred varieties that have polygenic resistance to *S. hermonthica* (Menkir *et al.*, 2019; Teka 2014). As a result of using Imazapyr resistant varieties, there has been significant increases in grain yield, coupled with reductions in parasite-induced damage symptoms, and number of emerged parasites have been reported (Badu-Apraku *et al.*, 2008; Menkir *et al.*, 2019). Utilization of some extra-early and late maize cultivars that combine tolerance to *Striga* with drought tolerance has shown progress towards combating *Striga* (Badu-Apraku *et al.*, 2008; Midega *et al.*, 2016; Menkir *et al.*, 2019).

In addition, bio-control options such as inoculation with *Fusarium* isolates, arbuscular mycorrhizal (AM) fungi have been widely deployed with minimal success (Abdullah *et al.*, 2015; Lenzemo *et al.*, 2006; Zahran *et al.*, 2008). In the short-run, improved crop varieties with tolerance to *Striga* remain the most feasible technology for the smallholder farmers, as it is most practicable and sustainable (Mutinda *et al.*, 2018). Additionally, tolerant varieties have the ability to manage *Striga* parasitism at early growing period thereby depleting *Striga* seed bank and mostly compatible with the existing farming systems (Kanampiu *et al.*, 2002). Integrating various management options with improved agronomic practices has generally enhanced the adeptness of management of *Striga* in many African countries (Ejeta & Gressel, 2007).

Previous study in western Kenya on using seed coated with small doses of imazapyr inhibits synthesis of branched amino acids (Valine, Leucine, isoleucine) by the parasitic weed thereby reducing losses (Kanampiu *et al.*, 2009). 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 damage (Siyuan *et al.*, 2005). 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. The unabsorbed herbicide disperses into the surrounding soil killing dormant, germinated and none attached seeds (Kanampiu, 2007).

In order to prevent development of resistance to Imazapyr and protect this advanced technology, 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 (Menkir *et al.*, 2010). However, limited research generated information on the field efficacy of IRM technology on *Striga* management and maize productivity is available. In addition, information on the level of tolerance and associated yield advantage of local cultivars or accessions which have been grown by farmers over generations in Western Kenya is limited. This study therefore evaluated an integrated *Striga* management package combining Imazapyr Resistant (IR) technology with host plant resistance of local cultivars under field conditions in Alupe and Rangwe of Busia and Homa Bay counties respectively.

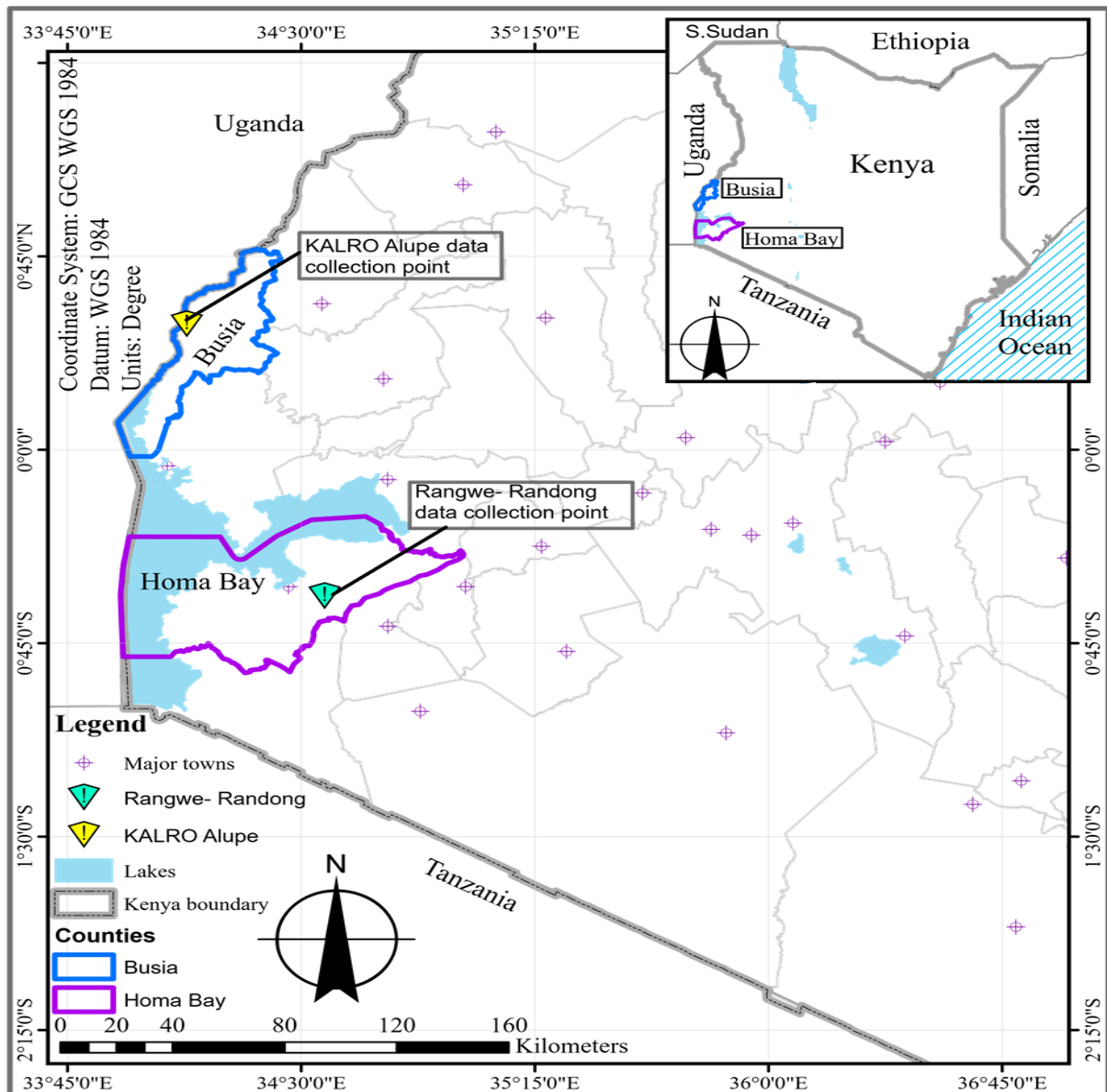
### **3.2 Materials and methods**

#### **3.2.1 Description of the Experimental Sites**

The study was conducted at KALRO Alupe Research Station (0°30'N, 34°07'E, altitude 1157 meters above sea level (masl) in Busia county and Rangwe (0°37'S, 34°37'E, altitude 1700 masl) Homa Bay County (Fig 3.1). These two sites were purposely selected based on previous history of high *Striga* infestation incidences. To minimize natural field *Striga* heterogeneity, the fields used in this study were carefully selected for homogeneity based on their *Striga* infestation history. These sites cover agriculturally important lower (Alupe) and upper (Radong in Rangwe) midland agro-ecological zones with a bi-modal rainfall pattern, experiencing wet seasons from March to June (long rains season) and September to December (short rains season) with an annual rainfall range of 930 mm to 1550 mm.

The daily mean temperature is about 24°C in Alupe and 22.5°C in Rangwe. The soils are predominantly Ferralsols with sandy-clay texture in Alupe and Nitisols in Rangwe (Jaetzold *et al.*, 2006). Rangwe represents wetter zones while Alupe represents the drier zone based on rainfall amounts

**Map of the study area showing Homa Bay and Busia counties in Kenya**



**Figure 3.1 Map of study sites**

### 3.2.2 Experimental Materials

Ten intermediate maturing (110–120 days) genotypes that exhibit differences in levels of tolerance to *Striga* were evaluated under *Striga*-infested conditions. These consisted of two IR varieties (H528, FRC425), two open pollinated cultivars (GAF4, KSTP94), one local landrace and five commercial susceptible varieties (DK8031, DUMA43, Haraka 101, DH04, and H513) (Table 3.1). Local landrace used was considered tolerant to *S. hermonthica* as it produces good yield despite emergence of many *Striga* shoots (Midega *et al.*, 2016).

**Table 3.1 List of Maize genotypes evaluated in natural and artificial *Striga hermonthica* infestation during 2018/2019 Long and short rains.**

No	Genotype	Source	Year of release	Trait
1	FRC 425IR	Fresco Seed	2013	Tolerant
2	H528IR	Kenya Seed	2009	Tolerant
3	H513	Kenya seed	1995	Susceptible
4	HARAKA 101	Western seed	2015	Susceptible
5	Local	Farmers	Landrace	Tolerant
6	DK8031	Monsanto	2015	Susceptible
7	DUMA43	SEEDCO	2009	Susceptible
8	DH04	Kenya seed	2001	Susceptible
9	KSTP 94	KALRO	2008	Tolerant
10	GAF 4	KALRO	Pre-Release Stage	Tolerant

### 3.2.3 Experimental Design

The experiment was conducted during the 2018-2019 cropping seasons in Busia and Homabay counties, Kenya. Fields were ploughed using disc ploughs and manually harrowed using jembes. The experiment was laid on a Randomized Complete Block Design (RCBD) with three replications. Each experimental plot consisted of five rows, each 5 m long with rows spacing at 0.75 m, and an intra-row spacing of 0.25 m between plants. At KALRO Alupe, the experimental plots were artificially inoculated with one teaspoonful of preconditioned *S. hermonthica* seeds per hole. The striga-seed mix was prepared at a ratio of 5 kg sand to one tea spoonful (2.5 g) of preconditioned on the eve of planting (Nzioki *et al.*, 2016). At planting a basal application of DAP to provide 40 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and 18 kg N ha<sup>-1</sup> was done. Two maize seeds were planted per hill and later thinned to one plant per stand at 2 weeks after planting. Thinning was done to achieve a final plant population of 53,333 plants ha<sup>-1</sup>. Topdressing with CAN was done in two splits at 14 days after planting (DAP) and 28 DAP giving 60 kg N ha<sup>-1</sup> (Odhiambo & Ariga, 2001). Hand weeding was done to remove all weed flora except *Striga* at the 4<sup>th</sup> and 8<sup>th</sup> weeks after planting. Scouting and spraying against fall armyworm was done at first appearance of infestation and subsequently at intervals of two weeks using Match (insecticide) at the rate of 60ml/100litres of water ha<sup>-1</sup>.

### 3.3 Data Collection

Data on days to 1<sup>st</sup> striga shoot emergence, emerged Striga counts and Striga - host damage ratings were recorded in the net plots (three central rows) of each experimental unit at the 10<sup>th</sup> and 12<sup>th</sup> weeks after crop emergence (Badu-Apraku *et al.*, 2012). Striga damage rating was visually scored at the 12<sup>th</sup> WAP using a scale of 1 to 9 where; 1 indicates no visible symptoms and 9 indicate all leaves completely scorched resulting in premature death (Kim, 1994). At maturity, data on plant height (cm), and grain yield (t/ha) was collected. Plant height was measured in centimeters as the distances from ground level to the point where the tassel starts to branch at 12<sup>th</sup> WAP. Grain yield was determined by sun drying the harvested ears from each plot and weighed using a top pan weighing balance. The percentage grain moisture was determined using a DRAMINSKI -TwistGrain moisture tester.

To determine grain yield, maize cobs from the net plots were harvested, sun-dried to 13% moisture content, threshed, weighed, and converted into t/ ha using the formula described by Abera *et al.* (2020) as follows.

$$\text{Grain Yield (kg ha}^{-1}\text{)} = \frac{(\text{FW} * 10000 \text{ M}^2 \text{ ha}^{-1}) * (100 - \text{AMC})}{(\text{HarvestArea} * 1000 \text{kg t}^{-1}) * (100 - \text{SMC})} * 0.81$$

Where, FW= field weight (kg), AMC = actual grain moisture content at harvest and SMC = recommended storage moisture content.

Yield component which included the number of ears per plant was recorded by counting all the ears harvested in the net plots and divided by the total number of plants in the net plot. The number of rows in a cob was taken as the average number of rows of a cob in 5 cobs sampled from the net plot harvest. The number of kernels in an ear was computed by multiplying the average number of rows by the average number of kernels per 5 sampled ears. 1000-seed weight (g) was determined from a bulk of shelled seed and weighed using sensitive balance from each plot at after adjusting to 12.5 % moisture content. The grain yield loss was determined based on the number of emerged Striga number m<sup>-2</sup> using a method described by Mesa-Garcia & Garcia-Torres, (1984) as follows:

$$\mathbf{L = 100 \times 0.124 \times SN}$$

Where *L* = percent yield loss and *SN* = emerged Striga number per plant.

### 3.4 Data Analysis

All data collected were subjected to analysis of variance (ANOVA) using Statistical Analysis System (SAS) software package (version 9.0) and tested for significance at 5% level and means separated using Tukey's HSD (SAS, 2014).

The combined across season analysis was done in SAS using the model below:

$$Y_{ij} = \mu + L_i + H_j + \epsilon_{ij}$$

Where,

$Y_{ij}$  is the observed yield at each location:

$\mu$  is the overall mean for grain yield,

$L_i$  is the effect of the  $i^{\text{th}}$  Location,

$H_j$  is the effect of the  $j^{\text{th}}$  Treatment,

$\epsilon_{ij}$  is the Residual effect.

To meet the assumption of analysis of variance, the actual field Striga counts were transformed using the square root ( $x+0.5$ ) formula as described by Illa *et al.* (2010), where  $X$  refers to the original data obtained for this parameter. The data were analyzed separately for each location using mixed-model procedure through the PROC GLM command of SAS. Correlation analysis was conducted, and the Pearson's correlation coefficients were used to determine correlation between yield, Striga emergence counts, flowered shoots count, Striga damage rating.

### 3.5 Results

ANOVA analysis on the evaluation of effectiveness Imazapyr coated hybrids and selected Striga-tolerant varieties on *S. hermonthica* showed significant differences between treatments, sites and seasons ( $P < 0.05$ ) (Table 3.2). Analysis indicated significant differences ( $P < 0.05$ ) on striga infestation between Rangwe and Alupe within the two seasons of September 2018 and March 2019 (Table 3.2). Evaluation of maize genotypes at Alupe recorded a higher mean post emerged shoot count (av. 33.47  $\text{m}^{-2}$ ) in Alupe compared to (av. 7.01  $\text{m}^{-2}$ ) in Rangwe (Table 3.3). The observed difference in *Striga* infestation levels between the two sites could have resulted probably due to a higher pre-existing soil seed bank at Alupe trial site. In addition, there were more striga shoot flowering at the 12 WAP (av. 5.36  $\text{m}^{-2}$ ) compared to (av. 3.92  $\text{m}^{-2}$ ) (Table 3.3). In addition, analysis indicated no significant

differences ( $P < 0.05$ ) on Striga damage rating score amongst the genotypes tested in both sites. Further, higher shoots reached flowering (av.  $5.36 \text{ m}^{-2}$ ) in Alupe compared to (av.  $3.92 \text{ m}^{-2}$ ) in Rangwe. Additional lower yield (ave.  $1.32 \text{ t ha}^{-1}$ ) was observed in rangwe compared to (av.  $1.47 \text{ t ha}^{-1}$ ) in Alupe. Consequently, higher percentage yield loss (av. 24.47%) compared to (5.14%) in Rangwe (Table 3.4)

**Table 3.2. Analysis of Variance on measured Striga and growth data observed in short and long rains seasons of 2018/2019.**

SV	df	DAE	SC10	SC12	SPF12	HT12	GY	SW
<b>Rangwe</b>								
Season	1	5.4	23.83**	20.03**	0.03**	395.2**	1.47**	7971.67*
Variety	9	344.93**	31.1**	47.89**	15.67**	110206.1**	3.13**	34081.67**
Season*Variety	9	17.77NS	2.27**	4.29**	0.27**	1803.1	0.1**	1511.27**
Error	38	18.29	3.08	3.18	1.07	20266.3	0.009	1254.12
<b>Alupe</b>								
Season	1	3.7	2950.9**	4466.0**	37.94**	1585.9**	2.63**	21808.4**
Variety	9	333.5**	974.4**	1932.21**	51.9**	1746.9**	2.04**	21995.7**
Season*Variety	9	13.2NS	167.6**	2312.4**	8.7**	447.23**	0.19NS	10747.6**
Error	38	17.02	23.3	46.41	2.2	387.79	0.13	4097.43

Key: SV- source of variation, Df=degree of freedom, DAE-days to 1<sup>st</sup> Striga shoot emergence, SC- Striga shoot count at the 10<sup>th</sup> and 12<sup>th</sup> WAS, SPF12- Striga plant shoots that had flowed at the 12<sup>th</sup> week, HT- plant height an at the 12<sup>th</sup> week, GY- grain yield, SW-1000 seed weight

### **3.6 Evaluation of maize genotypes for their response to striga under natural striga infestation in Rangwe during short and long rains season of 2018/2019**

Results showed significant differences ( $P < 0.05$ ) on genotypes in their responses to striga parameters measured (Table 3.2) except on days to 1<sup>st</sup> striga emergence. Results from this study revealed that season had significant effects ( $P < 0.05$ ) on post emergence Striga count at 10<sup>th</sup> WAP (Table 3.2). Season 1 compared to mean average shoot emergence count of 3.4 shoots  $m^{-2}$  in season 2 as shown in Appendix 2 at the 8<sup>th</sup> WAP. Further ANOVA results revealed significant differences ( $P < 0.05$ ) in Season X Genotypes interaction on Striga damage rating scores and Striga shoots that had flowed at 12 weeks after planting. Higher mean average yield of 1.47 t  $ha^{-1}$  was reported in Season 2 compared yields of 1.16 t  $ha^{-1}$  in Season 1 (Appendix 2).

#### **3.6.1 Days to 1<sup>st</sup> Striga emergence and post emergence Striga counts.**

Results indicated no significant seasonal differences on genotype in relation to days to 1<sup>st</sup> shoot emergence, however there was significant differences ( $P < 0.05$ ) on genotypes responses in days to 1<sup>st</sup> shoot emergence (Table 3.3). Imazapyr resistant genotypes used experienced the longest days to 1<sup>st</sup> striga shoot emergence (av. 50.33 days) compared to (av. 32.67 days) in both Striga tolerant open pollinated genotypes and local landraces (Table 3.3). Further, results indicated shorter duration (av. 32.67 days) on DK8031 highly susceptible commercial genotypes (Table 3.3). Further, results indicated significant differences ( $P < 0.05$ ) amongst the genotypes tested (Table 3.2). The lowest numbers of emerged Striga shoots were observed on IR maize genotypes (H528IR and F425IR) (av. 2.27  $m^{-2}$ ) in comparison to local landraces (av. 5.47  $m^{-2}$ ), while the highest number of emerged shoots (av. 11.09  $m^{-2}$ ) was observed in susceptible (DK8031) genotype (Table 3.3).

#### **3.6.2 Striga damage rating and Striga plant shoot flowering.**

The host Striga damage ratings and striga shoots flowering presented Table 3.3 differed significantly ( $P < 0.05$ ). Results showed lower severity score (av. 2.3) in IR genotypes (H528IR and FRC425IR) compared to a mean score of (av. 4.0) on local landraces and the highest damage rating score of (av. 7.2) on highly commercial susceptible (DK8031) genotypes (Table 3.3). Further, results revealed highest observed average number of Striga shoots (av. 7.03  $m^{-2}$ ) growing to maturity at the 12<sup>th</sup> WAP (Table 3.3) on the highly susceptible commercial (DK8031) compared to (av. 2.89  $m^{-2}$ ) on local landraces. In contrast the lowest shoot (av. 1.27  $m^{-2}$ ) was recorded on IR (FRC425 and H528) genotypes (Table 3.3).

### **3.6.3 Growth, Yield and Yield components of maize in Rangwe.**

Results from the present study indicated significant ( $P < 0.05$ ) differences amongst the genotypes tested (Table 3.2) on plant height, grain yield and 1000-seed weight (Table 3.4). The tallest maize plants were recorded in the Local landrace (252.11 cm) whereas the shortest plants were recorded in the susceptible genotype, Haraka 101 (av. 138.00 cm) while plant height of IR (av. 240.00cm) genotypes (Table 3.4). In addition, the lowest average grain yield (av. 0.54 t ha<sup>-1</sup>) was recorded in DH04 (a highly susceptible) while the highest average grain yield (av. 2.50 t ha<sup>-1</sup>) compared to IR (H528IR and FRC425IR) genotypes and (av. 1.18 t ha<sup>-1</sup>), as indicated in (Fig 3.3). Further, results indicated higher 1000-seed weight (av. 263.33 g) in local landrace compared to (av. 195.0g) for IR (FRC425IR and H528IR) genotypes and the lowest seed weight (av. 130.0g) in the highly susceptible commercial (DK8031) genotypes (Table 3.4).

### **3.6.4 Percentage yield loss.**

Results presented on (Table 3.4) showed significant ( $P < 0.05$ ) differences on yield loss in response to *Striga* infestation. The least percentage loss (av. 1.66%) was recorded in IR (H528IR and FRC425IR) compared to (av. 3.99%) on local landrace and the highest percentage yield loss (av. 8.09 %) was recorded in the susceptible hybrid DK8031 (Table 3.4). Increase in % yield loss was noted with the increase in number of post emerged *Striga* count.

**Table 3.3 Striga data for both artificial inoculated site (Alupe) and Natural invested site (Rangwe) for season 2018/2019**

Variety	Rangwe				ALUPE			
	DAE	SC10	SPF12	STR	DAE	SC10	SPF12	STR
FRC425IR	54.83 <sup>a</sup>	2.49 <sup>c</sup>	1.27 <sup>ed</sup>	2.50 <sup>ed</sup>	50.33 <sup>a</sup>	3.78 <sup>d</sup>	1.41 <sup>c</sup>	2.20 <sup>d</sup>
H528IR	50.33 <sup>a</sup>	2.27 <sup>c</sup>	2.15 <sup>e</sup>	2.30 <sup>e</sup>	51.67 <sup>a</sup>	3.07 <sup>d</sup>	1.18 <sup>c</sup>	2.40 <sup>d</sup>
H513	37.50 <sup>b</sup>	8.89 <sup>ab</sup>	4.80 <sup>bc</sup>	5.80 <sup>ab</sup>	34.83 <sup>b</sup>	52.56 <sup>ab</sup>	5.48 <sup>b</sup>	5.50 <sup>ab</sup>
KSTP94	37.16 <sup>b</sup>	7.73 <sup>ab</sup>	3.57 <sup>bcd</sup>	4.00 <sup>cd</sup>	36.67 <sup>b</sup>	40.33 <sup>bc</sup>	4.48 <sup>b</sup>	3.00 <sup>ab</sup>
Duma43	37.00 <sup>b</sup>	8.74 <sup>ab</sup>	4.90 <sup>b</sup>	5.50 <sup>bc</sup>	34.64 <sup>b</sup>	32.72 <sup>c</sup>	5.44 <sup>b</sup>	4.60 <sup>bc</sup>
Local	36.00 <sup>b</sup>	5.47 <sup>bc</sup>	2.89 <sup>ced</sup>	4.00 <sup>cd</sup>	37.00 <sup>b</sup>	34.72 <sup>c</sup>	6.11 <sup>b</sup>	5.00 <sup>ed</sup>
HRK101	35.33 <sup>b</sup>	8.53 <sup>ab</sup>	4.36 <sup>bc</sup>	4.70 <sup>bc</sup>	34.50 <sup>b</sup>	37.05 <sup>c</sup>	6.95 <sup>b</sup>	5.70 <sup>bc</sup>
GAF4	32.68 <sup>b</sup>	7.73 <sup>ab</sup>	4.05 <sup>bcd</sup>	4.60 <sup>bc</sup>	33.67 <sup>b</sup>	36.24 <sup>c</sup>	5.64 <sup>b</sup>	4.70 <sup>cd</sup>
DH04	32.68 <sup>b</sup>	7.13 <sup>abc</sup>	4.10 <sup>cbd</sup>	5.70 <sup>ab</sup>	29.33 <sup>b</sup>	35.47 <sup>c</sup>	5.14 <sup>b</sup>	7.20 <sup>cd</sup>
DK8031	32.67 <sup>b</sup>	11.09 <sup>a</sup>	7.08 <sup>a</sup>	7.20 <sup>a</sup>	32.17 <sup>b</sup>	58.78 <sup>a</sup>	11.76 <sup>a</sup>	8.20 <sup>a</sup>
Mean	38.62	7.01	3.92	4.63	37.48	33.47	5.36	4.85
HSD (0.05)	8.29	3.48	2.08	1.54	7.99	13.32	2.93	1.54
Cv %	11.04	25.44	26.36	17.18	11	20.32	28.24	17.18

Key: Means followed by the same letter(s) along the columns are not significantly different at  $p < 0.05$ : LSD,

DAE= days to Striga emergence,

SC10= Striga emergence count at 10 weeks after planting (WAP),

SF12= shoots flowered at 12 WAP

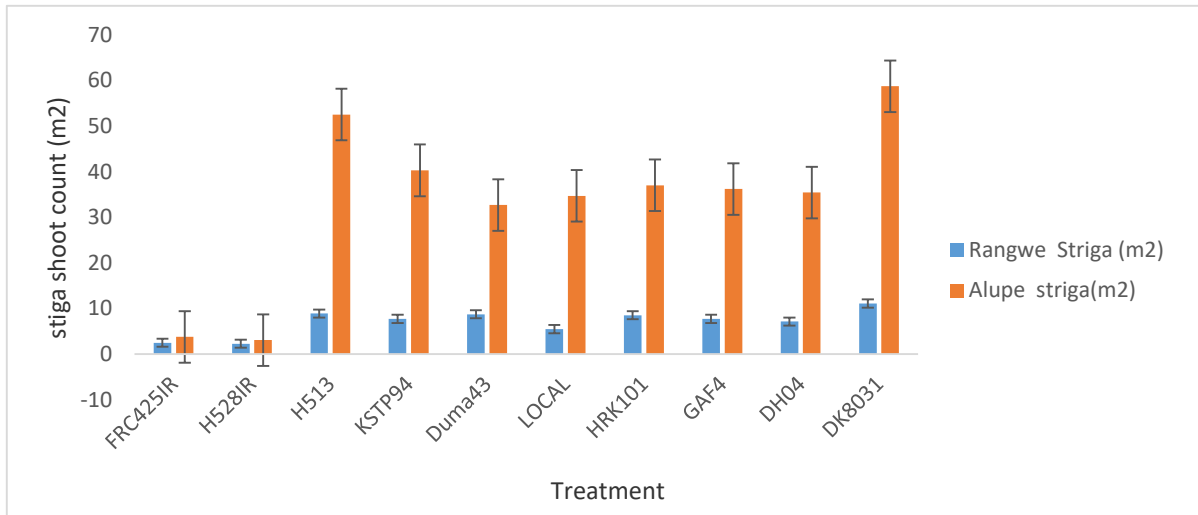
STR= Striga damage rating, SPF12= count of Striga plant shoot flowered at 10 WAP

### **3.7 Evaluation of maize genotypes for their response to striga under artificial infestation condition in Alupe during short and long rains season of 2018/2019**

Results showed significant ( $P < 0.05$ ) season and season by genotype interaction effects on response to striga infestation amongst the genotypes tested (Table 3.2). The differences were observed on; days to 1<sup>st</sup> Striga shoot emergence, Striga shoot count at 10 WAP, plant height at 12 WAP, and 1000-seed weight. Results indicated more days to 1<sup>st</sup> striga shoot emergence in season 2 (av. 37.83 days) compared to season 1 (av. 24.3 days). Additionally, average Striga emergence count of 27.76 m<sup>-2</sup> was recorded in season 1 compared to av. 13.28 m<sup>-2</sup> counts in season 2. Consequently, these resulted to taller maize plants in season 2 (av. plant height of 174.97 cm) compared to season 1 (av. 90 cm). Further, results showed no significant grain yield differences across the seasons with Season 2 recording 1.26 t ha<sup>-1</sup> while Season 1 recorded mean grain yield of 1.18 t ha<sup>-1</sup>. Additionally, average 1000-seed weight of 233.24 g was recorded in Season 2 compared to mean of 173.3 g in Season 1 (Appendix 1).

#### **3.7.1 Days to 1<sup>st</sup> striga emergence and Post emergence striga counts.**

The number of days showed significant ( $P < 0.05$ ) (Table 3.2) differences among the maize genotypes tested (Table 3.4). Results indicated longest days (av. 51.67 days) to 1<sup>st</sup> shoot emergence in IR (FRC425 and H528IR) genotypes compared to (av. 37.0 days) on local landrace, while the shortest duration (ave. 29.33 days) highly susceptible commercial (DH04) genotype (Table 3.3). The numbers of post-emerged *Striga* shoots differed significantly ( $P < 0.05$ ) among the maize genotypes evaluated at the KALRO Alupe (Table 3.4). DK8031, a highly susceptible commercial genotypes, supported the highest number of emerged striga shoots (av. 58.78 shoots m<sup>-2</sup>) compared to (av. 34.72 m<sup>-2</sup>) and the lowest number observed on IR (FRC425 and H528IR (av. 3.07 shoots m<sup>-2</sup>) (Figure 3.2).



**Figure 3.2 Effects of IR and selected maize genotypes on the emerged Striga shoot counts m<sup>-2</sup> in Rangwe and Alupe during the 2018/2019 cropping seasons.**

### 3.7.2 Striga damage rating

The differences in the severity of *Striga* attack in the maize genotypes presented in Table 3.3 revealed significant differences ( $P < 0.05$ ) in their responses to striga damage. IR (FRC425IR and H528) genotypes recorded the lowest striga damage rating score (av. 2.20) compared to (av. 5.0) on local landrace, whereas the highest (av. 8.2) Striga damage rating score was observed on the susceptible variety DK8031 (Table 3.3).

### 3.7.3 Number of flowering Striga plants

The number of striga plants that had flowered at 12 WAP differed significantly ( $P < 0.05$ ) across the experimental sites and seasons (Tables 3.3 and Fig.3.2). The highest average number of striga plants (av. 11.76 plants m<sup>-2</sup>) that flowered at harvest was observed on the susceptible maize variety (DK8031) compared to (av. 6.11 m<sup>-2</sup>) on Local landraces, while the least number of striga plants (av. 1.18 plants m<sup>-2</sup>) was recorded on IR (H528 and FRC425IR) coated genotypes (Table 3.3).

### 3.7.4 Maize plant height

Results showed significant ( $P < 0.05$ ) maize plant height differences amongst the maize genotypes tested (Table 3.4). The tallest maize genotypes under artificial Striga infestation were KSTP94 (av. 202.23 cm), compared to (av. 181.27 cm) on local landraces, whereas the

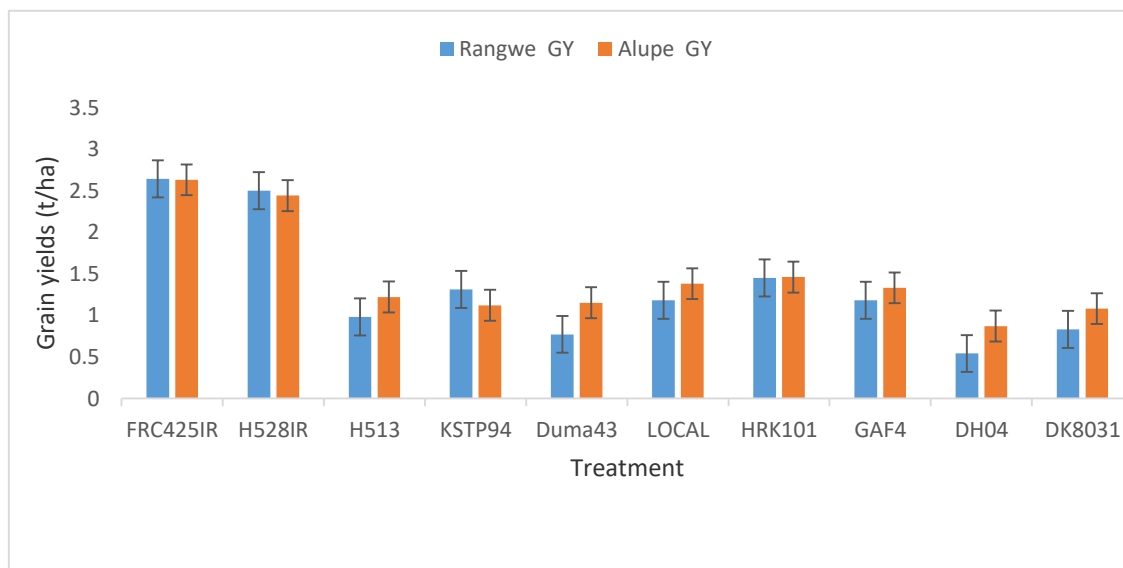
shortest (av.138.58 cm) maize genotypes on the highly susceptible genotypes DK8031 (Table 3.4).

### **3.7.5 Maize Grain yield and seed weight**

Results on grain yield revealed significant differences ( $P < 0.05$ ) amongst the maize genotypes tested under artificial striga inoculation at the Alupe site (Table 3.4). The IR coated maize genotypes recorded the highest grain yields (av. 2.50 t ha<sup>-1</sup>) compared to (av. 1.18 t ha<sup>-1</sup>) recorded on Local landraces, while the lowest grain yield (av. 0.54 t ha<sup>-1</sup>) was recorded on the highly susceptible (DH04) commercial genotype (Table 3.4). Further, results indicated significant differences ( $P < 0.05$ ) of 1000-seed weight significant ( $P < 0.05$ ) differences amongst the maize genotypes evaluated (Table 3.4). The highest 1000-seed weight (av. 232.17g) was recorded on IR (H528IR and FRC425IR) coated genotypes compared to (av.208.03 g), while the lowest 1000-seed weight (93.20 g) was recorded on the highly susceptible (DK8031) commercial genotype (Table 3.4).

### **3.7.6 Percentage yield loss**

The percentage yield loss due to striga infestation showed significant ( $P < 0.05$ ) differences amongst the maize genotypes tested (Table 3.4). Percentage yield loss increased with increase in number of Striga plants per unit area and striga damage rating. The highest grain loss was observed in susceptible genotypes, DK8031 (av.42.87%) compared to (av. 25.33%) on local landraces, while the lowest percentage yield loss (av. 2.52%) was observed on IR (H528IR and FRC425IR) coated genotypes (Table 3.4).



**Figure 3.3 Grain yield of IR and selected maize genotypes under Striga infestation in Rangwe and Alupe during the 2018/2019 cropping seasons.**

**Table 3.4 Plant height, Yield, and yield components of IR maize and selected Striga tolerant varieties grown under Natural and artificial *S. hermonthica* infestation for 2018 and 2019 cropping seasons.**

Variety	Rangwe				Alupe			
	HT12	GY	1000KWT	Yield loss (%)	HT12	GY	1000KWT	Yield loss (%)
FRC425IR	240.40 <sup>a</sup>	2.64 <sup>a</sup>	195.00 <sup>a</sup>	1.82 <sup>c</sup>	162.79 <sup>cb</sup>	2.63 <sup>a</sup>	232.17 <sup>ab</sup>	2.76 <sup>d</sup>
H528IR	247.50 <sup>a</sup>	2.50 <sup>a</sup>	178.33 <sup>a</sup>	1.66 <sup>c</sup>	170.30 <sup>cb</sup>	2.44 <sup>a</sup>	272.90 <sup>a</sup>	2.52 <sup>d</sup>
H513	161.56 <sup>b</sup>	0.98 <sup>bcd</sup>	168.33 <sup>c</sup>	6.49 <sup>ab</sup>	168.49 <sup>abc</sup>	1.22 <sup>b</sup>	200.77 <sup>ab</sup>	38.63 <sup>ab</sup>
KSTP94	173.50 <sup>b</sup>	1.31 <sup>bc</sup>	200.00 <sup>a</sup>	5.64 <sup>ab</sup>	202.23 <sup>a</sup>	1.12 <sup>b</sup>	230.27 <sup>ab</sup>	29.42 <sup>bc</sup>
Duma43	146.94 <sup>b</sup>	0.77 <sup>ced</sup>	198.33 <sup>a</sup>	6.38 <sup>ab</sup>	178.80 <sup>ab</sup>	1.15 <sup>b</sup>	208.03 <sup>ab</sup>	23.87 <sup>c</sup>
Local	252.11 <sup>a</sup>	1.18 <sup>bcd</sup>	263.33 <sup>ab</sup>	3.99 <sup>bc</sup>	181.27 <sup>ab</sup>	1.38 <sup>b</sup>	248.33 <sup>ab</sup>	25.33 <sup>c</sup>
HRK101	138.89 <sup>b</sup>	1.45 <sup>b</sup>	211.67 <sup>abc</sup>	6.23 <sup>ab</sup>	153.67 <sup>cb</sup>	1.46 <sup>b</sup>	227.53 <sup>ab</sup>	27.03 <sup>c</sup>
GAF4	151.00 <sup>b</sup>	1.18 <sup>bcd</sup>	178.33 <sup>ab</sup>	5.64 <sup>ab</sup>	176.87 <sup>ab</sup>	1.33 <sup>b</sup>	222.00 <sup>ab</sup>	26.43 <sup>c</sup>
DH04	154.95 <sup>b</sup>	0.54 <sup>e</sup>	186.67 <sup>abc</sup>	5.20 <sup>b</sup>	165.33 <sup>abc</sup>	0.87 <sup>b</sup>	177.23 <sup>b</sup>	25.87 <sup>c</sup>
DK8031	159.95 <sup>b</sup>	0.83 <sup>e</sup>	130.00 <sup>bc</sup>	8.09 <sup>a</sup>	138.58 <sup>c</sup>	1.08 <sup>b</sup>	93.20 <sup>c</sup>	42.87 <sup>a</sup>
Mean	182.68	1.32	191	5.14	169.83	1.47	211.24	24.47
HSD (0.05)	12.64	0.59	124.09	2.52	38.17	0.69	78.06	9.63
Cv %	22.4	23.16	25.37	25.44	11.59	24.14	19.06	20.33

Key: Means followed by the same letter(s) along the columns are not significantly different at

$p < 0.05$ : LSD

HT12= maize plant height (cm) at 12 WAP, GY= grain yield ( $t\ ha^{-1}$ ), 1000KWT= 1000 seed weight (g).

### 3.7.7 Correlation between Striga emergence, Striga damage ratings, yield components and yield of maize genotypes evaluated at Rangwe and KALRO ALUPE sites.

Correlation analysis conducted on data collected in the present study indicated a positive ( $r = 0.9158$ ) relationship between the number of post emergence *Striga* counts at 10<sup>th</sup> WAP and the number of shoots that grew to weed maturity. Further, analysis showed a negative relationship ( $r = 0.61439$ ) to plant height, grain yields and 1000-seed weight ( $r = 0.86048$ ), ( $r = 0.59997$ ) respectively (Table 3.5).

Additionally, correlation analysis indicated a positive relationship between striga shoots flowered at 12<sup>th</sup> WAP ( $r = 0.8963$ ), to striga damage score ( $r=0.8903$ ) and a negative relationship ( $r = 0.7282$ ), grain yields, and 100seed weight ( $r = 0.7239$ ). In addition, analysis revealed a positive relationship between plant height and grain yields ( $r = 0.6246$ ), 1000-seed weight ( $r = 0.6722$ ), while it was revealed that striga damage rating score had a negative correlation to grain yields ( $r = 0.8238$ ) and 100-seed weight ( $r = 0.7792$ ) (Table 3.5)

**Table 3.5 Correlation Coefficient (r) between Striga counts, Striga Flowered, Plant height Striga damage score on Grain yield under Striga-infestation during the 2018/2019 cropping seasons.**

	SC10	SPF12	PH	STR	GY	KNWT
SC10	1	0.89637	-0.6808**	0.88078	-0.86048**	-0.58741**
SPF12	0.89637	1	-0.7282**	0.89026	-0.74318**	-0.72394**
PH	-0.6808**	-0.7282**	1	-0.76086	0.62462	0.67229
STR	0.88078	0.89026	-0.76086**	1	-0.82382**	-0.77926**
GY	-0.86048**	-0.74318**	0.62462	-0.82382**	1	0.41541
KNWT	-0.58741**	-0.72394**	0.67229	-0.77926**	0.41541	1

Key; SC8 -SC10, Striga counts at 8 and 10 weeks after planting,

SPF12- Striga Plant shoots that had flowered at 12<sup>th</sup> week,

STR Striga damage rating at the 10<sup>th</sup> week,

PH- Plant Shoots and

\*\* Correlation is significant at 0.01 level

### 3.8 Discussion

The findings of this study showed that *Striga* infestation differed significantly between Rangwe and Alupe sites and within the two seasons of September 2018 and March 2019. The observed differences in the two sites were possibly linked to the pre-existing soil *Striga* seed bank at Alupe. These sites were purposively selected based on the striga history. Gasura *et al.* (2019) demonstrated striga infestation strongly and positively correlate with the level of soil seed bank. The observed difference in *Striga* infestation levels between the two sites could have resulted probably due to a higher pre-existing soil *Striga* seed bank at Alupe. This is because field *Striga* infestation levels have been found to correlate with soil *Striga* seed bank strongly and positively (Gasura *et al.*, 2019). The significant total genotype  $\times$  environment (G  $\times$  E) variance that contains interaction effects between the genotypes, specific climatic and edaphic factors such as soil organic content, soil microorganisms, rainfall, and temperature that differed between the two sites probably contributed to the observed differences in the two sites.

These results finding conforms with the findings of Hausmann *et al.* (2001) who investigated genotype  $\times$  environment interaction patterns for *Striga* resistance in sorghum in Kenya and Mali and reported sites' differences in levels of *Striga* infestations caused by genotypic response to climatic conditions. The significant seasonal differences in terms of effects of striga parameters measured indicated that striga performance is influenced by climatic conditions, more striga shoots emergence, higher striga damage rating and more striga reached flowering was recorded in short rains compared to long rains in both sites. Further, these resulted into lower yield in short rains seasons compared to long rains. The reported variation in the genotypes field levels of striga infestation at Rangwe and Alupe was possibly due to genotypic differences in the amount of secreted strigolactones in response to significant differences in genotype  $\times$  environment variance. Similar finding was reported by Waters *et al.* (2017).

The loss in grain yield contributed by either the host genotype levels of tolerance, severity of infestation and low levels of soil fertility. Bawa *et al.* (2015) showed that tolerant varieties suffer lower yield reduction and often produce 2 - 2.5 times the yield of susceptible varieties, especially under high infestation. In addition, grain yield loss is associated to the diversion of photosynthates, mineral salts and water from the host to the parasite. Mutinda *et al.* (2018) indicated that tolerant genotypes possess post attachment mechanism such as lignified root cortex, hypersensitivity response, incompatibility response, and insensitivity to

*Striga* toxins that maintained absorption of water and nutrients from the soil and rate of photosynthesis in host crop despite high striga infestation.

The maize genotypes tested responded differently to *Striga* infestation regarding plant height, maize grain yields and the 1000-seed weights in both sites. The differences in their performance under *Striga* infestation showed existences of genetic variation among the genotypes and possible differences in their response to *Striga*. The differences in their levels of tolerance or susceptibility of the genotypes used contributed to their difference in yield components and the overall yields under striga infestation. Imazapyr coated genotypes (FRC425 and H528IR) outperformed the rest of the genotypes used. This is associated to the effects of the herbicide which reduced the effects of early *Striga* parasitism, compared to susceptible genotypes. Herbicide coating led to significant improved yields of 2.4-2.6 t ha<sup>-1</sup> recorded in IR maize varieties compared to 0.54-1.46 t ha<sup>-1</sup> recorded in the susceptible varieties. Previous study by Chikoye *et al.* (2011) and Kanampiu *et al.* (2007) that evaluated effects of herbicide coating and reported enhanced yields. Findings of this study are also consistent with the results of earlier study that showed high negative correlation between grain yield and host plant *Striga* damage rating and *Striga* emergence count (Kim, 1994).

Imazapyr coated (FR425IR and H528IR) maize hybrids prolonged the number of days to 1<sup>st</sup> *Striga* emergence by 17-21 days in both locations. In similar studies, Kanampiu *et al.* (2002) while evaluating effects of herbicide coating at Kenya agricultural research reported prolonged days by 41%. Further it was revealed that the unabsorbed imazapyr herbicide by the germinating maize seed disperses into the nearby soil destroying germinating *Striga* seeds. Mohamed *et al.* (2020) also reported prolonged days to striga shoot emergence by herbicide coating. Additionally, the observed higher grain yields in IR (H528, FRC425) compared to susceptible varieties in all locations under study suggests that low grain yield can be associated with *Striga* damage score and number of emerged *Striga* shoots. Coating of maize with imazapyr resulted in adequate protection against *Striga* damage and early season competition for growth factors leading to an increase in grain yield.

Aside from parasitism, *Striga* impairs photosynthetic efficiency (Stewart *et al.*, 1991) and exerts phytotoxic effects (Ransom *et al.*, 1996) on its host contributing to low yield observed in susceptible varieties used. Several studies have also shown higher grain yield in plots treated with herbicide coated maize seed (Chikoye *et al.*, 2011; Kanampiu *et al.*, 2018; Makumbi *et al.*, 2015). Additionally, the higher grain yield loss in commercial susceptible varieties compared to IR coated varieties was associated to higher *Striga* densities and high

Striga damage scores. Similar results were reported by Atera *et al.* (2013), who showed that Striga weed interferes with the host crop causing yield loss of up to 100%. Lower Striga counts recorded in plots with IR seed, confirmed that Imazapyr herbicide is effective in reducing the number of shoots attached on the treated hybrids. Several studies have demonstrated the effectiveness of IR maize hybrids treated with Imazapyr in controlling Striga (Chikoye *et al.*, 2011; Kanampiu *et al.*, 2018, Menkir *et al.*, 2010). Few numbers of Striga shoots counts recorded in plots treated with IR at 10<sup>th</sup> and 12<sup>th</sup> WAP was attributed to reduced concentration of the herbicide. Kanampiu *et al.* (2018) and Chikoye *et al.* (2019) indicated that the herbicide gradually dissipated and probably get leached down the soil profile, reducing its concentration in the maize root zone. However, maize grain yield was not affected since Striga was controlled early in the season.

Accordingly, a combination of herbicide seed treatment and host plant resistance would serve as an effective integrated approach that would drastically reduce the parasite soil seed bank and prevent production of new seeds. In addition, intercropping of cereals with legumes such as *Desmodium* spp. (Push–Pull) which reduces Striga shoot emergence by improving soil fertility, organic matter, and soil moisture content (Midega *et al.*, 2016; Mutuku *et al.*, 2019) could be adopted to mitigate Striga weed. Further, host plant resistance (HPR), is a biological strategy that gives resistance to parasitic weed infection and is an important characteristic that should be integrated in seed provided to subsistence farmers to help manage Striga (Beyene *et al.*, 2013). According to Karaya *et al.* (2014), host plant resistance prevents the hemi-parasite Striga from attaching to the crop. Adoption of the host plant host resistance by smallholder farmers in the SSA region will benefit from a more effective, long-term, and cost-effective control method (Karaya *et al.*, 2014). Addition of HPR to the crop genome possesses the potential to increase production and will lower reliance on agrochemicals as well as losses caused by parasite infection. The HPR method is a more practical control method that can be used on a modest scale (Beyene *et al.*, 2013). In cereal crops, tolerance is the sole genetic Striga resistance reserve (Spallek *et al.*, 2013).

Results from the present study indicated that open pollinated (KSTP94 and GAF4) and the Local landrace, sustained less Striga damage and supported fewer Striga shoots. Local maize accession reported improved yields compared to susceptible varieties used in this study. This was attributed to the possibility of them releasing low strigolactones that hindered Striga seed germination. Similar findings were reported by Yohannes *et al.* (2016) who observed low Striga germination due to production of low germination stimulant in local

sorghum accession that inhibited *Striga* seed germination. The performance of several open pollinated varieties tested in diverse environments revealed outstanding grain yield performance. Similarly, Makumbi *et al.* (2015) reported that use of open pollinated varieties reduced soil seed bank and increased grain yield. In a similar study, Kanampiu *et al.* (2018) also reported effective control of *Striga* weed when OPVs was used.

Low yields observed in plots planted with susceptible commercial varieties are attributed to early parasitism and higher parasite density. Previous studies also reported similar observation (Chikoye *et al.*, 2011; Kanampiu *et al.*, 2018; Makumbi *et al.*, 2015; Mbogo *et al.*, 2016;). Despite, fewer parasites densities observed in Rangwe, there was low grain yield. This is possibly linked to other factors such as low inherent soil fertility. Badu-Apraku *et al.* (2007) linked such results to low soil fertility. Further, competition for soil moisture, nutrients and light between weeds and maize also greatly reduces grain yield (Dalley *et al.*, 2006).

The observed differences in plant height amongst the maize genotypes used in both sites could be associated to the diverse genetic differences. Plant height of IR maize genotypes was consistently taller than the commercial susceptible varieties across season and location. Susceptible maize genotypes had reduced growth leading to short plants which is associated with heavy parasite densities particularly on DK8031. Related studies indicate that herbicide seed coating reduced the effects of *Striga* on plant height (Chikoye *et al.*, 2019; Odongo & Abayo, 1998; Saeed *et al.*, 2001; Soliman & Gharib, 2011). In addition, there was low 1000-seed weight in commercial susceptible varieties compared to coated varieties. This was attributed to high infestation of the parasite resulting to maize-weed competition for growth factors. Previous studies on the same reported reduction in the maximum 1000 seed weight when weed density increased (Karimmojeni *et al.*, 2021). Similarly, Akamolafe *et al.* (2018) noted that sorghum growth and yield was significantly affected by *Striga* infestation leading to reduction of 1000-seed weight by 30-50%. A similar study revealed that yield loss in an infested locality depends on the differences in *Striga* weed infestation, soil fertility level and level of maize genotype resistance to *Striga* damage (Akaogu *et al.*, 2013).

Correlation analysis studies in the yield components and yield of maize genotypes computed on emerged *Striga* counts, *striga* plants flowered and *Striga* damage ratings with plant height and grain yield indicated a highly negative relationship. The non-linear relationship between *Striga* counts, SDR, yield components and yield indicate that parasitic effect in its host is associated to increased withdrawal of hosts' nutrient with the additional

numbers of *Striga* plants supported by the host plant. Comparable results were previously reported by Mbogo *et al.* (2016).

### **3.9 Conclusion and recommendation**

Continuous use of *Striga* susceptible commercial and local landraces by farmers in every season in the *Striga* prone fields in western Kenya aggravates *Striga* infestations. Findings from the present study indicated that Alupe was more affected with *striga* weed infestation. The use of IR treated maize varieties could reduce *Striga* infestations and, therefore, increase maize grain yields that will increase farmers' income and food security. The findings from this study demonstrated that both productivity and increased yield can be obtained from the use of IR coated (FRC425 and H528) varieties. Adoption of IR coated varieties improved the yields of maize in *striga* prone areas of western Kenya by 57% from 1.152 t ha<sup>-1</sup> (Local) to 2.37 t ha<sup>-1</sup> (H528IR) in western Kenya. Further, the coated hybrids performed well economical with a benefit cost ration of 4.3, enabling farmers to earn an extra income of Kes29, 950. IR coated maize genotypes (FRC425IR and H528IR) that have been released for commercial production targeting *Striga* endemic areas of western Kenya and, therefore, recommended for vigorously adoption and commercialization in western Kenya.

## CHAPTER FOUR

### ECONOMIC BENEFIT ANALYSIS OF IR MAIZE TECHNOLOGY OVER LOCAL LANDRACES IN MAIZE PRODUCTION IN WESTERN KENYA

#### Abstract

Witchweed, (*Striga hermonthica* (Del.) Benth) is a major threat to the realization of yield potentials of cereal crops especially maize. This study was designed to determine the economic benefits of IR coated varieties against hybrids and local landraces in western Kenya. The experiment was laid in a randomized complete design with three replications in each site. Data on the prices of fertilizer, seed was collected from the agroshops around the study site. Labour cost was taken as the price that ICRISAT pays for mandays at the station. In addition, the overall yields of IR and local landrace was measured on the on-station and on-farm experiments conducted in Alupe and Rangwe during the consecutive 2018 and 2019 cropping seasons. Data collected was analysed using SAS analysis tool (Version 9) and the treatment means were further subjected to T-test to determine their differences. Gross margins and cost to benefit ratios were also used in data analysis. Yield results further, indicated that the IR (FR425) had the highest yield of 2.4376 t ha<sup>-2</sup> compared to local landraces yields of 1.152 t ha<sup>-2</sup>. In contrast most hybrids varieties H513, DK8031, Duma43 and DH04 recorded <1 t/ha. Additionally, results indicated higher gross margin of FRC425IR of 1.2 compared to 0.7 on Local landrace. Additionally, there was higher benefit cost ratio of 4.3 and net marginal rate of 3.3. Evaluation of the use of IRM indicated that the technology is profitable and viable. The highest gross margin of Kes 12,400 was realized in the IR (FRC425) compared to a net loss of Kes 17, 550 on local landrace. This result indicates that the use of IR technology in maize production would increase farmer income and food security.

#### 4.1 Introduction

Maize productivity for majority of smallholder farmers in sub-Saharan Africa (SSA) is highly constrained by Striga parasite mainly the *Striga hermonthica* Benth. (Orobanchaceae) (Joel *et al.*, 2007) which causes severe losses to staple crops (Scholes & Press, 2008). Striga weed causes an estimated yield loss of 35- 80% in rice (Rodenburg *et al.*, 2016), 50-100% in sorghum (Abunyewa & Padi, 2003), and 21-74% in maize (De Groot, 2007). The invasiveness of Striga, long persistence and economic impacts is mainly due to its unique biology which is associated with production of large amounts of

microscopic seeds (Joel *et al.*, 2013), that results to high weed density within a short period of time (Gressel & Joel, 2013). These seeds have the ability of remaining in the soil for long periods, up to 20 years, causing vast economic damages (Parker, 2013).

Continued intensification of cereal-based systems in the region in response to the rising demographic pressures has led to an increase in the area under *Striga* infestation (Oswald, 2005). Despite the development of high-yielding varieties and improved cultivation methods, Kenya is still unable to meet its domestic demand of maize grains. The deficit in production is bridged through imports from the neighboring countries (Jayne *et al.*, 2001). In western Kenya the average maize productivity has stagnated at 1.2-1.6 t ha<sup>-1</sup> (Shen, 2016; Vanlauwe *et al.*, 2008). This situation is triggered by a number of constraints including *Striga* weed infestation (De Groote & Okuro, 2004) and low levels of phosphorous and nitrogen (Jamil *et al.*, 2012). This not only affects quality but also adversely reduces yields. Typical yield losses range from 5 to 70% depending on the degree of infestation and susceptibility of the cultivar (Lagoke *et al.*, 1991). Severe infestation of sorghum by *S. hermonthica* has been reported to cause 30-50 % land being abandoned (Werkissa, 2022).

Several integrated control initiatives have been promoted by farmers in different regions of SSA to control *Striga* (Baiyegunhi *et al.*, 2019). Integrated management incorporates technologies such as use of herbicide-resistant cultivars (Kanampiu *et al.*, 2003), intercropping with legumes (Khan *et al.*, 2007) and use of improved fallows system. Despite the use of herbicide technology for management of *Striga* in high-intensive agriculture, levels of herbicide use in SSA remain at very low levels, due to limited access to capital (Grabowski & Jayne, 2016). Farmers in the affected regions prefer using local recycled seeds possibly due to inadequate capital, lack of knowledge on the availability of IR treated seed and high cost of seed (Lyimo *et al.*, 2014). Further, recommended potential control measures from research have not been adopted, especially in the maize, sorghum and millet based cropping systems. This may be due to; poor understanding of the biology of *Striga* and long-term effects of control options, low efficacy of individual control options in reducing *Striga* to tolerable levels, lack of adaptability of control options to the local farming systems, and high cost-benefit ratio of control options compared to existing farmer practice (Oswald, 2005).

The use of small doses of herbicide imazapyr and pyrithiobac for seed coatings have been shown to provide an early control of *Striga* (Kanampiu *et al.*, 2009). The herbicide has been reported to inhibit production of branched amino acid that is responsible for normal

plant growth (Chikoye *et al.*, 2011). Upon absorption by Striga weed, the weed is eradicated and the un-absorbed herbicide combines with water and moves within the soil killing Striga seed in the soil (Kanampiu *et al.*, 2002). Additionally, the herbicide is reported to reduce losses associated with Striga, depletes the seed bank and ultimately reduces the amount of new seeds added to the soil the following season (Ransom *et al.*, 2012). Limited comparative study on the economic benefit of IR technology over the use of commercial hybrids and local landraces has been reported in Kenya. This study was therefore conducted to determine the cost–benefit ratio (CBR) and marginal rate of return (MRR) of Imazapyr-resistant (IR) maize technology against commercial hybrids and local varieties in control of Striga in western Kenya.

## **4.2 Materials and methods**

### **4.2.1 Experimental Design and Treatments**

Experimental treatments were arranged in a randomized complete blocked design with three replicates KALRO ALUPE and Rangwe. Each experimental plot consisted of 5 m by 5 m. Planting was done at spacing of 0.75 m X 0.25 m. During planting 2 seeds was planted per hill and later thinned to 1 plant per hill at 2 Weeks after planting. At KALRO Alupe, the experimental plots were artificially inoculated with one teaspoon full of preconditioned *S. hermonthica* seeds per hole. Basal fertilizer was applied in the form of di-ammonium phosphate (DAP) (18:46:0) during planting and topdressing with calcium ammonium nitrate (CAN) (26:0:0). Topdressing with CAN was done in two splits, with 1<sup>st</sup> split applied 2 weeks after planting and the 2<sup>nd</sup> done at 4 weeks after planting (WAP) giving 60 kg N ha<sup>-1</sup> (Odhambo and Ariga, 2001). Hand weeding was done twice while removing all other weeds except Striga. Local landrace was used as the control in evaluating the economic analysis against IR.

### **4.2.2 Data collection-check information I added**

At harvest, all ears harvested from each plot were dried, shelled. Percentage grain moisture was determined using a DRAMINSKI -TwistGrain moisture tester. Grain yield was adjusted to 12.5% using ear weight and grain moisture, assuming a shelling percentage of 80% according to Kanampiu *et al.* (2018). Grain yield was determined from the net harvestable area and using the following formula.

$$\text{Grain Yield (kg ha}^{-1}\text{)} = \frac{(\text{FW} * 10000 \text{ M}^2 \text{ ha}^{-1}) * (100 - \text{AMC})}{(\text{HarvestArea} * 1000 \text{kg t}^{-1}) * (100 - \text{SMC})} * 0.81$$

Where, FW= field weight (kg), AMC = actual grain moisture content at harvest and SMC = recommended storage moisture content. On-station grain yield obtained was adjusted to 10% as described by Muchiri *et al.* (2017) to match yields obtained by farmers before subjecting them to partial budgeting analysis.

### 4.3 Statistical Analysis

Benefit-Cost analysis was done to assess the economic value of treatments. The partial budget analysis as described by (CIMMYT, 1998) was carried out to assess the costs and benefits associated with IR maize technology compared to use of local landrace in maize production under Striga infested fields. Gross margin (GM) analysis was also done using farm budgeting techniques by Microsoft Excel spreadsheets. Parameters used in determining the performance of maize variety under Striga infestation included, yield in kilogram per hectare and returns to investment in inputs, which was expressed as GM per hectare. In order to compute associated revenues of variety yields was multiplied by 2019 season average market prices (mean of prices immediately after harvest and at the onset of the new season). The GM was the difference between the gross farm revenue earned and the incurred total variable cost. The GM analysis was used to justify whether the selected variety was financially and technically viable to address the need of the targeted farmers (Mignouna *et al.*, 2011). In order to determine GM, all the varieties subjected to the same seed quantities, fertilizer rates and agronomic practices. The only difference was the cost of the technology, which was the price of IR seed. This study only focused on the Cost-Benefit ratio and the MRR associated with maize production under Striga infestation. All harvested yield at the end of the season priced at the prevailing market price. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested (Table 4.1).

### **4.3.1 Statistical analysis model.**

**Combined Analysis of variance was done in SAS using the model shown below:**

$$Y_{ij} = \mu + L_i + H_j + \epsilon_{ij}$$

Where,

$Y_{ij}$  is the observed yield at each location:

$\mu$  is the overall mean for grain yield;

$L_i$  is the effect of the

$i^{\text{th}}$  location;

$H_j$  is the effect of the  $j^{\text{th}}$  treatment;

$\epsilon_{ij}$  is the residual effect.

### **4.3.2 Economic analysis**

Economic analysis of maize from different treatments was determined using gross margin and cost-benefit analyses. Cost and benefit estimates were based on revenues and costs incurred in production of maize using the different treatments. Total revenue represented the value of maize harvested from each plot based on prevailing prices at the time of the study. The price of 2 kg of ‘Locallandrace’ at the Busia Municipal Market and ‘FRC425IR’ from FRESCO Seed Company Ltd. were KES 100 and KES 425 respectively, in the month of September 2019. Variable costs accrued from purchase of seeds and labor involved in land preparation, planting, weeding, harvesting, drying and shelling were determined based on the prevailing market prices (Table 4.1). Benefit/cost ratio was determined by dividing the revenue by variable costs from each treatment, while gross margin was obtained from revenue less variable cost accrued in each treatment

### **4.3.3 Benefit-Cost analysis (CBA)**

Partial budget analysis as described by (CIMMYT, 1998) was carried out to assess the costs and benefits associated with IR maize technology compared to use of local landrace in maize production under Striga infested fields. Gross margin (GM) analysis was also done using farm budgeting techniques by Microsoft Excel spreadsheets. Parameters used in determining the performance of maize variety under Striga infestation included yield in kilogram per hectare and returns to investment in inputs, which was expressed as GM per hectare. To compute associated revenues of variety yields was multiplied by 2019 season average market prices (mean of prices immediately after harvest and at the onset of the new season). The GM was the difference between the gross farm revenue earned and the incurred

total variable cost. The GM analysis was done to determine if the selected variety was economically viable (is it worth investing in this varieties) by targeted farmers (Mignouna *et al.*, 2011). To determine GM, all the varieties subjected to the same seed quantities, fertilizer rates and agronomic practices. The only difference was the cost of the technology, which was the price of IR seed. This study only focused on the Cost-Benefit ratio and the MRR associated with maize production under Striga infestation. All harvested yield at the end of the season priced at the prevailing market price. Economic analysis was done using the prevailing market prices for inputs at planting and for outputs at the time the crop was harvested (Table 4.1).

## 4.4 Results

### 4.4.1 Input and Labour prices

Fertilizer, seed, and pesticides prices were obtained from local agro-shops in the markets found within the Striga infested areas of western Kenya. The input prices: KES4000 for 50kg bag of DAP, KES1600 for 50kg bag of CAN, price for 2kg packet of IR seed (H528IR) KES 450, price of 2 packet seed FRC425IR was KES 500, and price of 1 kg local seed was assumed to be KES 100. Labour cost was KES 300 price paid by KARLO Alupe to casual labour per person (MD) and the price of a bag of 90 kilogram of maize was Kes 3000 (Table 4.1).

**Table 4.1 Average input and output prices.**

Type	Unit	Quantity	Unit Price (KES)
Grain	Kg	90	3000
DAP	Kg	125	80
DAP	Kg	125	32
IR Seed	Kg	25	225
Local Seed	Kg	25	100
Labour	Man Day		300

### 4.4.2 Grain yields

Results from this study indicated significant differences between the yields from the IR varieties and the local landrace used. The highest maize yields were obtained from IR coated maize FRC425IR (2.37 t/ha) and lowest on local landraces 1.152 (Table 4.2). A

paired T-test computed on grain yield showed significant ( $P < 0.05$ ) differences among the maize genotypes. The observed higher grain yields observed on FRC425IR compared to Local landraces indicates the ability of the IR variety to tolerate the effects of Striga weed hence giving higher farm output.

**Table 4.2. Paired T-test between FRC425IR and Local landrace**

Variety	yields (t/ha)	Difference	Observ	df	mean	stddev	stderror	Tvalue
IR	2.37	1.27***	12	11	1.59	0.51	0.15	8.5
Local	1.152							

*Note \*\*\* denote statistical significance at 1% level.*

#### 4.4.3 Partial budget analysis.

Partial budget analysis was carried out based on the yield data and inputs prices collected. Partial Budget evaluation indicated that changing from using local landrace to use of IR maize technology was a profitable venture for the affected smallholder farmers in the Striga hot spot areas (Table 4.3). The process involved tallying up all costs of required for both varieties FRC425IR and Local and then subtracting that amount from the total benefits from the change. The total revenue was obtained by multiplying average unit market prices with the mean output of the various genotypes tested per hectare (Table 4.3).

**Table 4.3 Partial budget analysis.**

Variable	Seed Type	
	Local seed	IR
Adjusted grain yield (bags/ha)	13	26
Average price per 90 Kg bag	3000	3000
<b>Gross output per hectare (Kes)</b>	<b>39,000</b>	<b>78,000</b>
<b>Total Variable Cost</b>	56,550	65,600
<b>Net benefits</b>		
Gross benefit	-17, 550	12,400

#### 4.4.4 Computation of BCR and MRR

Total cost incurred in producing IR maize was Kes 65,600, against a gross income of Kes 78 000, giving a net return of Kes 12, 400. Similarly, the total cost incurred in producing Local landraces was Kes 56,550 against a gross income of Kes 39,000 (giving net negative

returns of Kes 17,550). The total Net change realized in changing from local landrace to IR variety was Kes 29,950 and the total gross change in total variable cost was Kes 9, 050 (Table 4.3).

**Therefore,**

$$\text{MRR} = \frac{\text{Change in Net benefits}}{\text{Change in total variable cost}} = \frac{\text{Kes } 29,950}{\text{Kes } 9,050} = 3.3$$

$$\text{BCR} = \frac{\text{Change in Gross benefit}}{\text{Gross change in total variable cost}} = \frac{\text{Kes } 39,000}{\text{Kes } 9,050} = 4.3$$

#### **4.4.5 Determination of gross margins**

Gross margin was obtained from revenue less variable cost accrued in each treatment. Results indicates that it costs more to produce IR maize compare producing local landrace, however the gross margin and the benefit cost ration was higher on using IR coated maize. Generally, comparisons between FRC425IR and the local variety showed no significant differences in cost of land preparation, cost of fertilizer, and cost of labour (Table 4.4). Therefore, they were treated as non-experimental variable and hence the two varieties were subjected to the same conditions to determine the gross margin. Further, there was significant differences with respect to the cost of seed, which further reflected in differences in the cost of bags and transportation (Table 4.4).

**Table 4.4 Gross margin analysis between FRC425IR and Local landraces in Western Kenya**

<b>Variety</b>	<b>Input costs</b>	<b>Local</b>	<b>FRC425IR</b>
Yields	bags@ha	13	26
Price	kes@bag	3,000	3,000
Revenue	Kes	39000	78000
Cost of seed	25kgs	2500	6250
Cost of DAP	Kes80@125kg	10,000	10,000
Cost of CAN	Kes32@125	4,000	4,000
Cost of Insecticide	kes2000@1lit	2,000	2,000
Cost of Landprep	kes5625@2	11,250	11,250
	kes300@85MD (local),		
Cost of Labour	kes300@98MD (IR seed)	25,500	29,300
Cost of bags	kes50@bag	650	1,400
Transport cost	Kes@bag	650	1,400
<b>TVC</b>		<b>56550</b>	<b>65600</b>
<b>GM</b>		<b>-17550</b>	<b>12400</b>
<b>BCR</b>		<b>0.7</b>	<b>1.2</b>

#### **4.5 Discussion**

The observed yield difference between IR herbicide coated maize genotypes compared to local landrace indicated that coating of IR-maize seeds with imazapyr herbicide suppressed the development of Striga, especially in the early stages. Similar studies reported higher grain yield in plots that received treated maize genotypes (Chikoye *et al.*, 2011; Makumbi *et al.*, 2015; Kanampiu *et al.*, 2018;). Further, results from this study revealed that the grain yield of FRC425IR maize genotype doubled the overall yields. Similar findings were reported by Omondi *et al.* (2014). Despite farmer's preference in using local landraces in the area, results further showed that their use results into negative returns to the farmer. Mignouna *et al.* (2013) reported similar findings in a study on the adoption of IR Maize in Nyanza and western Kenya. In addition, it has been reported that IR coated maize hybrids are more drought tolerant compared to susceptible maize genotypes (Ejeta, 2007).

Furthermore, economic analysis in the present study demonstrated higher gross margin, higher benefit cost ratio derived from using IR maize. This was attributed to the

ability of IR coated maize in suppressing the damages caused by the parasite. Higher yields and higher profit were reported in earlier studies (De-Groote *et al.*, 2007; Garba *et al.*, 2017; Woome *et al.*, 2008) and who reported. Further findings in the current study clearly showed improved gross margin and higher Benefit cost ratio therefore changing from local landraces into IR maize technology will be economically worth for farmers challenged with striga. Similar findings showed that IR coated genotype treated with low dose of herbicide was able to increase yields more than four-fold with an additional cost of less than US\$4 per hectare (cost of herbicide added to other existing seed treatments). The added cost was equivalent to about 25-50 kg/ha maize yield depending on market prices, suggesting potential benefit: cost ratios of greater than 25:1 even under the least favorable circumstances (Kanampiu & Freiesen, 2004).

However, the low gross margin observed in this study was associated with low market prices of maize grain compared to high input prices at the time of study. In addition, the low economic benefit derived from the use of local landraces in farmers' fields was principally attributable to competition for nutrients by heavy Striga infestation. Present study indicates a higher BCR, thus the change is economically worth. This conforms with Minouna *et al.* (2015) who suggested that a change in investment is possible if the BCR is greater than 1. Despite this, small holder farmers in western Kenya continue to use local landraces due to the unavailability of IR coated genotypes and high associated costs. Wambugu *et al.* (2012) also reported that 80% of farmers in western Kenya use local landraces seed due to financial constraints. It therefore means that cost of technology is a major consideration in the choice of varieties by farmers alongside other factors. Despite higher cost of IR seed, the extra revenue generated can pay for the cost.

#### **4.6 Conclusion and recommendations**

The findings of this study showed that the use IR technology (FRC425IR and H528IR) in maize production in striga prone areas is economically viable. Findings showed a MRR and BCR of 3.3 and 4.3 respectively. Hence, there is need for smallholder farmers to adopt the technology to manage striga weed, improve farm household income and alleviate poverty among maize farming households. Despite the effectiveness of the technology, there is scarcity in the availability of the coated seeds in the striga prone areas. A collaborative initiative between seed companies, research institutions and extension service providers is recommended for dissemination of the technology.

## CHAPTER FIVE

### GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 General Discussion

The present study evaluated the response of maize genotypes in terms of plant height, yield components, grain yield and grain yield loss under field Striga infestation at Alupe and Rangwe. Site comparison of Striga infestation levels revealed Alupe to be highly infested with Striga than Rangwe in the both seasons of 2018/2019 probably due to a higher pre-existing soil Striga seed bank and artificially seeds inoculation in Alupe. Additional factors such as significant GxE interactions that varied between the sites (Alupe) and Rangwe (Short rains of Sept 2018 and Long rains of March 2019) could have also been influenced by the different Striga infestation levels between the seasons and sites. Imazapyr coated genotypes (H528IR, FRC425IR) had constantly high grain yields in field evaluation in both sites and seasons, whereas DH04, DK8031 had very low yields under high Striga infestation. The difference in numbers of Striga plants supported by the maize genotypes could have resulted due to the genotypes' differences in the amount of secreted strigolactones as reflected in the respective genotypes' numbers of post emergence shoot counts.

#### 5.2 Conclusions

Findings from this study it was concluded that:

- i. Use of IR and Striga tolerant maize significantly delayed striga emergence, suppressed Striga infestation and increased yield and yield components by 57% from 1.152 t/ha (Local) to 2.37 t ha<sup>-1</sup> (H528IR) in striga endemic areas of western Kenya. Use of IR treated maize varieties will therefore reduce Striga infestations increase maize grain yields hence increased farmers' income and food security.
- ii. Use of IR coated maize technology in maize production is economically viable with Marginal Rate of Returns and BCR of 3 and 4.3:1, respectively compared to local maize.

#### 5.3 Recommendations

The following recommendations were found from this study:

- i. Small-holder farmers in western Kenya are encouraged to adopt use of IR varieties (FRC425IR and H528IR) in maize production in the infested fields to reduce the

Striga weed density and increase maize grain yields. This will help in improving farmer's income and ensuring food security in the western Kenya.

- ii. Continuous promotion on use of IR technologies is recommended to create sufficient market for seed companies to produce enough IR for farmers use in striga hotspots. This will help farmers in improving farmer's income and alleviate poverty among the smallholder farmers in western Kenya.

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## APPENDICES

### Appendix A: Analysis of variance for effectiveness of IR and selected striga tolerant varieties on growth and yield of maize in Alupe 2018 and 2019 seasons.

#### Dependent Variable: DAE

Source variation	DF	F Value	Pr > F
Season	1	323.13	<.0001
REP	2	0.06	0.9418
VAR	9	151.00	<.0001
Season*VAR	9	56.48	<.0001

#### Dependent Variable: Plant height at 12 weeks

Source	DF	F Value	Pr > F
Season	1	56.98	<.0001
Rep	2	3.26	0.0494
Var	9	33.66	<.0001
Season*Var	9	21.24	<.0001

#### Dependent Variable: Grain yield

Source	DF	F Value	Pr > F
Season	1	1.15	0.2910
REP	2	0.34	0.7166
VAR	9	37.10	<.0001
Season*VAR	9	14.41	<.0001

#### Dependent Variable: 1000-seed weight

Source	DF	F Value	Pr > F
Season	1	15.43	0.0003
REP	2	2.16	0.1290
VAR	9	14.49	<.0001
Season*VAR	9	13.14	<.0001

**Appendix B. Analysis of variance for effectiveness of IR and selected striga tolerant varieties on growth and yield of maize in Rangwe for 2018 and 2019 seasons**

**Dependent Variable: DAE**

**Dependent Variable: Striga shoot Count at week 8**

Source	DF	F Value	Pr > F
REP	2	1.12	0.3378
Season	1	7.74	0.0083
TRT	9	10.11	<.0001
Season*TRT	9	0.74	0.6726

**Dependent Variable: Striga shoot count at week 10**

Source	DF	F Value	Pr > F
REP	2	3.67	0.0348
Season	1	6.30	0.0165
TRT	9	15.06	<.0001
Season*TRT	9	1.35	0.2470

**Dependent Variable: Striga Plant flowered at week 12**

Source	DF	F Value	Pr > F
REP	2	3.25	0.0499
Season	1	0.03	0.8653
TRT	9	14.61	<.0001
Season*TRT	9	0.26	0.9824

**Dependent Variable: Plant height at week 12**

Source	DF	F Value	Pr > F
REP	2	7.69	0.0016

Season	1	0.74	0.3947
TRT	9	22.96	<.0001
Season*TRT	9	0.38	0.9395

**Dependent Variable: Striga Damage Rating**

Source	DF	F Value	Pr > F
REP	2	0.97	0.3874
Season	1	1.68	0.2025
TRT	9	21.36	<.0001
Season*TRT	9	0.63	0.7636

**Dependent Variable: yield**

Source	DF	F Value	Pr > F
REP	2	5.54	0.0077
Season	1	15.75	0.0003
TRT	9	33.48	<.0001
Season*TRT	9	1.13	0.3669

**Dependent Variable: rows**

Source	DF	F Value	Pr > F
REP	2	1.44	0.2502
Season	1	5.12	0.0294
TRT	9	4.28	0.0007
Season*TRT	9	1.83	0.0937

**Dependent Variable: 1000-seed weight**

Source	DF	F Value	Pr > F
REP	2	0.24	0.7848
Season	1	0.95	0.3369
TRT	9	5.87	<.0001
Season*TRT	9	0.97	0.4756

# 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

Appendix D. Research permit

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