RESPONSE OF SELECTED SORGHUM (*Sorghum bicolor* (L.) Moench) GENOTYPES TO *Striga hermonthica* (Del.) Benth IN WESTERN KENYA

BY

DAUGLAS CLAOUDIOUS OCHIEL

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MASENO UNIVERSITY

DECLARATION

This thesis is my original work and it has not been previously presented in this or any other university. All sources of information have been specifically acknowledged through references.

Dauglas.Claoudious.Ochiel

MSc/AF/00080/2016

Signature……. Date…….

Supervisors:

This thesis has been submitted for examination with our approval as university supervisors

Prof. Mathews Dida

Department of Applied Plant Science

School of Agriculture and Food Security

Maseno University

Signature……. Date…….

Prof. Ayiecho Olweny

Department of Applied Plant Science

School of Agriculture and Food Security

Maseno University

Signature……. Date…….

Dr. Evans Ouma

Department of Agronomy and Environment Sciences

School of Agriculture, Natural Resources and Environmental Science

Rongo University

Signature……. Date…….

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DEDICATION

This thesis has been dedicated to my beloved parents Mr. and Mrs. Ochiel and my son Adrian John Ochiel

ABSTRACT

Sorghum (*Sorghum bicolor* (L.) Moench) is an important staple food crop in western Kenya, but its yields are low due to many constraints including; pest and diseases, drought, soil acidity, and parasitic weed *Striga hermonthica*. In recent years, *Striga* has been a major cause of yield reduction in western Kenya owing to declining soil fertility and susceptibility of existing cultivars. Several control options such as chemical, biological and cultural methods have been utilized but only with little success realized. This has created renewed interest in resistance breeding for its proper management. The objectives of this study were to: determine the numbers of induced and maximum distance of germinated *Striga* seeds under laboratory conditions and assess the response in yield components and yield in the selected sorghum genotypes under field *Striga hermonthica* infestation. A total of 21 sorghum genotypes, 7 obtained from each institution; International Crop Research Institute for the Semi-Arid Tropics, Rongo and Maseno Universities were evaluated in Agar Gel (AG) experiment in Maseno botanical laboratory and in an on-farm trial at Kadel and Nyahera under natural *Striga* infestation. The AG experiment and field trials were respectively set up in three replications in a completely randomized design and randomized complete block design. Variance analysis (ANOVA) and mean field *Striga* counts, numbers of induced germinated *Striga* seeds, *Striga* damage ratings, maximum distance of the germinated *Striga* seeds, and yield components and yield were analyzed using a Statistical Analysis System (SAS) software package (release 6.1) tested for significance at 5% level and means separated using L.S.D 5%. Significant differences ($p<0.001$) were realized both in the fields (plant height, dry shoot biomass yield, grain yield, field *Striga* count, and *Striga* damage ratings) and in the AG experiment with respect to maximum germination distance and numbers of induced germinated *Striga* seeds. Among the sorghum genotypes evaluated, T53B, N57, N68, C26, IESV 92036-SH, T30B, and Uyoma 47 white genotypes had stable yields under *Striga* infestation in the two sites whereas Nyadundo1, Nyadundo 2, and Uyoma 8 were susceptible. In the AG experiment, E117B, T30B, Uyoma 8, Uyoma 42 STR, and T53B induced high numbers of germinated *Striga* seeds with maximum germination distances (MGD). In contrast, Uyoma 47 Brown, IESV 92038/2-SH, and IESV 92036-SH sorghum genotypes induced the germination of few *Striga* seeds with low MGD. This study has identified and selected four *Striga* tolerant (T53B, N68, N57, and T 30B) and three resistant (C 26, Uyoma 47 Brown, and IESV 92036-SH) sorghum genotypes which can be utilized in further research programs or adopted to improve sorghum productivity in the highly *Striga* infested regions of western Kenya.

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LIST OF ABBREVIATIONS

AGT: Agar Gel Technique

AM: Arbiscular Mycorrhiza

ANOVA: Analysis of Variance

CIMMYT: International Maize and Wheat Improvement Center

HR: Hypersensitive Response

ICRISAT: International Crop Research Institute for the Semi-Arid Tropics

IITA: International Institute of Tropical Agriculture

IR: Incompatible Response

KALRO: Kenya Agricultural and Livestock Research Organization

LGS: Low Germination Stimulant

LHF: Low Haustoria Initiation Factor

MGD**:** Maximum Germination Distance

PRT: Paper Roll Assay Technique

SAT**:** Semi-Arid Tropics

SLs: Strigolactones

SSA: Sub-Saharan Africa

W.A.C.E: Weeks After Crop Emergence

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CHAPTER ONE

INTRODUCTION

1.1 Background information

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth most important staple food crop after rice, wheat, maize, and barley (Ng'uni *et al*., 2011). The crop can meet the increased food needs of more than 500 million people in regions that still experience periodic food deficits (Kouressy *et al.,* 2008; Wang *et al.,* 2014; Romana *et al.,* 2018). The drought tolerance of sorghum and its ability to withstand more heat and an array of other biotic and abiotic stresses than maize (Hadebe *et al.*, 2017) has made it one of the main security food crop that have wide adaptation in the most marginalized regions of the world (Omamo *et al.,* 2006; Duncan *et al*., 2016). Similarly in Kenya, it is grown mainly in the drought-prone and *Striga* stricken agricultural regions of Eastern, Nyanza, and Coast provinces (Chepng'etich *et al*., 2015).

The overreliance on rain-fed agricultural crop cultivation in Kenya has increased the subsistence cultivation of sorghum. This is due to the low and unreliable rainfall pattern that is endemic in the drought-prone agricultural regions of the country (Fernandez *et al*., 2014). Owing to the resilience of sorghum to major biotic and abiotic constraints such as drought, soil acidity, pest, and diseases. Various agricultural research and development agencies including Kenya Agricultural and Livestock Research Organization (KALRO), United States Agency for International Development (USAID), International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) have undertaken vigorous promotion and advised smallholder farmers to grow sorghum to attain food and nutrition security in the country (Chepng'etich *et al*., 2015). These promotional efforts in Kenya have led to an increase in the cultivation area of sorghum from 122,368 ha in 2005 to 173,172 ha in 2009 contributed majorly by subsistence smallholder farming of the crop

(Chepng'etich *et al*., 2015). The national yield average of sorghum has, however, remained low at 0.8 tons per hectare (Bosire, 2019) despite the increased cultivation area of the crop and research intervention measures such as breeding for better yields and distribution of high-yielding and stress-tolerant sorghum varieties (Weltzien and Christinck, 2017). The low national yield average has been attributed mostly to; pest and disease infestations, damage by birds, low soil fertility, and farm inputs, together with increased cultivation of highly *Striga* susceptible local sorghum varieties (Chimoita *et al.,* 2019). It has been established that due to limited access to improved tolerant/resistant varieties, the majority of farmers, which constitute 87 percent plant saved seeds from the previous harvest, and only 13 percent use certified seeds (Kiambi and Mugo, 2016). It is through continuous cultivation of locally available susceptible sorghum varieties that have, therefore, largely contributed to the endemic high *Striga* infestations and notable farm abandoned in most agricultural regions of western Kenya (Nzioki *et al*., 2016).

Witch weed (*Striga spp*.) is one of the most limiting biotic stress factors to the small-scale farmers in the semi-arid tropics (Belete and Sarmiso, 2015: Gebreslasie *et al*., 2018). There are nine *Striga* species in Kenya and only two species namely *S. hermonthica* (Del.) Benth and *S. asiatica* (L.) Kuntze are of economic importance in the country (Mutuku and Shirasu, 2019). In western Kenya, *S. hermonthica* species is the most predominant species and widespread especially in the densely populated parts of the Lake Victoria basin (Mbogo *et al.,* 2016). It infests and seriously reduces the grain yield of cereal crops that include rice, maize, pearl millet, sorghum, and millet (Mrema *et al.,* 2017).

Upon infection, *Striga* damages its host in several ways which include allelopathy, hormonal imbalance, reduction of host's photosynthetic parameters, and withdrawal of hosts' (photosynthate, water, mineral nutrients, and amino acids). The host-*Striga* related damages all

lead to phenotypic reduced heights, leaf necrosis, and relatively small panicle sizes in the infested host (Parker and Riches, 1993; Fernández-Aparicio *et al*., 2016; Hassan and Elmajeed, 2017; Beyene, 2018). The extent of agronomic damage of *Striga* on its host is determined mainly by the response of the host in terms of resistance, tolerance, or susceptibility to the weed. The genotypes which support the growth of few *Striga* plants and suffer minimal agronomic damage are considered as resistant while those that are tolerant can produce equally good yield even when under severe field *Striga* infestation (Mbuvi *et al.,* 2017). The susceptible genotypes, on the other hand, incur high yield depression due to reduced panicle sizes and often fail to reach the reproductive stage either under severe or low *Striga* infestation (Wang and Bouwmeester, 2018; Dafaallah *et al.*, 2019).

Successful parasitism of *Striga* on its host requires a properly coordinated and synchronized life cycle with that of its host crop (Fujioka *et al.,* 2019). *Striga* life cycle begins with a non-parasitic phase of *Striga* seed conditioning and germination which develops into the parasitic phase of *Striga*-host haustorium establishment and ends with the reproductive stage of setting seeds (Leandre *et al*., 2018). It has been established that a single *Striga asiatica* and *Striga hermonthica* weed can respectively produce as many as 58,000 and 200,000 seeds (Parker and Riches, 1993). The *Striga* seeds can then remain viable in the soil for a period of time which can vary from 6 months to 20 years depending on both the soil and climatic condition (Samejima *et al.,* 2016). In order to germinate, the seeds have to undergo a period of conditioning under moist and warm environmental conditions. It is only after conditioning that the seeds will be able to respond to strigolactone, a germination stimulant secreted by the host plant (Dafaallah *et al.*, 2019).

Host crops such as sorghum and maize secrete strigolactone to attract Arbuscular Mycorrhiza (AM) and form a symbiotic association with their roots for enhanced nutrient uptake (DeCuyper

and Goormachtig, 2017). The same chemical stimulant, however, has a dual physiological function of inducing the germination of conditioned soil *Striga* seeds (Samejima and Sugimoto, 2018). The increased incidences of *Striga* infestation in the most populous western regions of Kenya is a result of increased secretion of the host's strigolactones in response to nutrient-depleted soils (Midega *et al*., 2017; Manyasi *et al*., 2018). The regions in which the agricultural sector is centered mainly on continuous cultivation and sole cropping of major cereal crops purposed to compensate for high yield losses and meet the threshold basic food needs (Kanampiu *et al*., 2018).

The longevity and the viability of the produced many *Striga* seeds together with their synchronized germination with the secreted SLs besides other factors have rendered the control of the weed difficult especially by use of control measures such as chemical, biological, and cultural methods that fail to address the vast *Striga* seed productions (Kountche *et al*., 2019). The use of ethylene, which is a plant hormone, for instance, involves treatment of the soils with a synthetic germination stimulant to induce suicidal *Striga* seed germination using special, sophisticated equipment. Suicidal germination, though is a promising option that has been successfully used in controlling *Striga* in the United States of America (Abbas *et al*., 2018), has not been used as a routine method in controlling *Striga* especially in sub-Saharan Africa where the income of subsistence farmers is usually too low to afford such technology (Abbas *et al*., 2018). Additionally, few studies have tested this strategy under field conditions especially in sub-Saharan Africa (Zwanenburg et al.,2016). Furthermore, the residual and pollution effect of the chemical has also limited its adoption in Kenya and other African countries (Epée, 2017).

Traditionally, the African cropping systems which included crop rotation of infested land with non-susceptible crops or prolonged fallowing and hand weeding of mature *Striga* plants had kept *Striga* at tolerable levels by interrupting further production of *Striga* seeds and eventual decline in

the soil *Striga* seed bank. The practical limitations of these techniques are the more than 3 years required for rotation together with the tedious, and time-consuming nature of hand weeding of *Striga* plants that have rendered these *Striga* control methods impractical (Teka, 2014; Lee and Thierfelder, 2017). Rotation and furrowing also rely on land availability which makes these cultural methods to be largely ineffective with declining land sizes brought about by the increasing human population.

Soil fertilization using inorganic fertilizers as sources of soil nitrogen inputs has also been demonstrated to alleviate the impact of *Striga* on cereal hosts by reducing the amount of *Striga* germination stimulant secreted by the host (Mandumbu et *al.,* 2018). However, the use of fertilizer as a remedy in *Striga* control has not been widely adopted amongst subsistence due to its high associated cost (Lobulu *et al*., 2019). The field impact of the application of fertilizers on plant performance under *Striga*-infested conditions has also been found to be variable. Since it is dependent on soil type, more volatile/soluble forms of nitrogen could be easily lost from the soil, and to a greater degree in those soils with lowered ability to retain nutrients (Teka, 2014). Biological control methods such as application of Fusarium oxysporum in *Striga* management, on the other hand, are less available to farmers due to the required knowledge in fungal isolation, preservation, application, and are best utilized only in the integrated *Striga* management systems (Mrema *et al.,* 2017).

Breeding for *Striga* resistance in cereals could provide a long term solution to the *Striga* problem especially to the resource-poor farmers (Orr, 2003; Mrema *et al*., 2017) since its adoption requires no additional input (Badu-Apraku and Fakorede, 2017). The method (breeding for resistance) also allows for crop improvement for drought tolerance, wide adaptability to a range of climatic and soil conditions, and specific farmers' preferred agronomic traits in addition to high yields (Spallek

et al., 2013). Therefore, to solve the *Striga* problem and enhance the adoption of newly identified resistant/tolerant sorghum genotypes, the current study evaluated resistance/tolerance in the selected elite farmers' preferred sorghum lines.

1.2 Statement of the Problem

Striga hermonthica is a serious biological constraint to sorghum production in sub-Saharan Africa. The weed is invasive evident in its widespread especially in the new geographical regions that were initially reported to be free from *Striga.* Small scale farmers are the most affected due to scarce resources that have reduced their accessibility to newly improved resistant varieties, thus the over-reliance on locally available susceptible saved seed varieties. Besides, most farmers are reluctant to use chemical control methods owing to high costs and the fact that symptoms of *Striga* damage on the host appear before it emerges above the ground surface. *Striga* can reduce host grain yield to almost zero in high field infestation levels and especially if susceptible varieties are used, and as a result, many farmers have abandon highly infested fields that are no longer productive. Although considerable research on *Striga* has been carried out and a wide range of technologies developed, the *Striga* problem has persisted and increased in magnitude in the sorghum growing regions of SSA. Furthermore, breeding for *Striga* resistance in sorghum and variety testing has also produced varieties such as N 13 and SRN-39 which have not been widely adopted by farmers due to their poor agronomic traits. Therefore, to solve the *Striga* problem especially in the subsistence farming of sorghum, increased accessibility of resistant/tolerant genotypes with good agronomic traits should be made possible to farmers.

1.3 Justification

Sorghum is an important staple food crop in Kenya particularly in the marginalized western regions of the country where it is the main security food crop and rich alternative sources of carbohydrates, protein, fat and dietary fiber. Despite this, the area under sorghum production is still low in western Kenya and farmers suffer high yield losses. The yield losses especially in the subsistence farming of the crop have been occasioned by reduced accessibility of improved *Striga* resistant sorghum varieties that can do well in the *Striga* hot spots. Therefore, most farmers in the western Kenya region still rely on their local varieties that are highly susceptible to *Striga hermonthica* hence the increased magnitude of *Striga* infestation in these regions. As a consequence, most farmers have abandoned the cultivation of sorghum/maize due to the high yield losses that they incur under such farm conditions. The breakdown of partial resistance in the currently available sorghum varieties by *Striga* biotypes is also known to be rapid, and if partial resistance is available, the resistant varieties usually have poor agronomic traits. Additionally, given the high genetic diversity of the Sorghum spp., with regard to the amount of strigolactone stimulant secretion, there is a need to quantify strigolactones in most of these cultivated lines with the anticipation that better genotypes with lower amounts of secreted *Striga* germination stimulant can be identified.

1.4 Objectives of the study

1.4.1. General objectives

To minimize *Striga*-related high yield losses in sorghum by developing genotypes that have stable yields under *Striga* infestation.

1.4.2. Specific objectives

1. To assess the response in yield components and yield in the selected sorghum genotypes under *Striga hermonthica* infestation.
2. To determine genotypic variations in the numbers of induced and maximum distance of the germinated *Striga* seeds in the selected sorghum genotypes.

1.5. Hypotheses

1. There are no differences in the response in yield components and yield in the selected sorghum genotypes under *Striga hermonthica* infestation.
2. There are no genotypic variations in the numbers of induced and maximum distance of the germinated *Striga* seeds in the selected sorghum genotypes.

CHAPTER TWO

LITERATURE REVIEW

2.1. Sorghum production and its importance

Sorghum [*Sorghum bicolor* (L.) Moench] is a self-pollinating, diploid (2n = 2x = 20) crop from the family Poaceae. The crop is native to Sub-Saharan Africa with its origin located in East Africa in the region bordering Ethiopia and Sudan (Doggett, 1988). Sorghum is the fifth most important cereal crop in the world grown on about 42 million hectares, and the second in Africa after maize (Ndimba *et al.,* 2017). In Kenya, over 70% of sorghum is produced in the Lake Victoria basin (Ngugi *et al*., 2002) with additional production in Eastern and Coast Provinces, regions that frequently experience maize crop failure (Muui et al., 2013). The crop provide a good source of food and nutrition to the millions of subsistence households. Sorghum grain is one of the best food rich in dietary fiber capable of providing 48% of the body's daily-recommended intake of dietary fiber (Stephen *et al*., 2017). This enables the digestive tract to move food rapidly and prevents cramps, bloats, constipation, stomachaches, excess gas, and diarrhea. Furthermore, excess amounts of fiber in the body also help to scrape off dangerous cholesterol that would otherwise cause conditions like atherosclerosis, heart attack, and stroke (Proietti *et al.,* 2015). Some of the other benefits accrued from taking sorghum include, increased intake of carbohydrates required for bodybuilding, reduced cases of esophageal cancer, and reduced cases of diabetes (Demi, 2014). Sorghum grain is mainly used as food in the consumable forms of porridge, ugali, and traditional dishes in which it is mixed with legumes. The industrial and economic uses of sorghum include beer brewing, baking bread, and manufacturing of; wax, starch, syrup, dextrose agar, and edible oils.

2.2. Constraints of sorghum production

The production of Sorghum in sub-Saharan Africa has been comparatively low due to biotic and abiotic stresses (Teshome *et al.,* 2018). Drought, low soil fertility, and high soil acidity are some the major abiotic stresses capable of causing significant yield losses in sorghum while biotic stresses include diseases and insect pests (Amelework *et al.,* 2016). In regards to diseases, a survey carried out by Ngugi *et al*. (2002) reported oval leaf spot (*Ramulispora sorghicola*), rust (*Puccinia purpurea*), ladder leaf spot (*Cercospora fusimaculans*), zonate leaf spot (*Gloeocercospora sorghi*), gray leaf spot (*Cercospora sorghi*), leaf blight (*Exserohilum turcicum*), and anthracnose (*Colletotrichum sublineolum*) as the most common foliar diseases affecting most regions of western Kenya. Ngugi *et al.* (2002) also observed that the prevalence of these diseases ranged between 95% to 97% in fields for oval leaf spot, 44% to 65% for anthracnose and 73% to 75% for head smut (*Sporisorium reilianum*). Collectively, these diseases have caused significant yield losses, which have varied from one region to the other and the different use of sorghum genotypes.

Sorghum also serves as a host crop to more than150 insect pest species such as shoot fly, sorghum midge and head bugs, insects that inflict serious crop damages from the time of sowing to storage (El-Zik and Frisbie, 2018). Sorghum midge is the most devastating out of the three listed insect pests and is widely distributed in all of the sorghum growing regions of Africa, America, Asia, Australia, and Europe (Castro *et al.*, 2000). It infects and reduces world sorghum grain yield by up to 15% annually (Singh and Sharma, 2002). In western Kenya, midge is the most significant sorghum head pest capable of causing grain yield losses of about 30% (Reddy *et al.,* 2017). According to Hiron *et al*. (2014) other than insect pests and diseases, granivorous birds such as *Quelea quelea* and village weavers (*Ploceus cucullatus*) are also capable of causing high grain yield losses in sorghum. Hiron *et al*. (2014) reported that despite the presence and efforts made by

human ‘bird scarers’ in an attempt to limit sorghum crop damage, almost 60% of the seed was lost before harvest in a 0.12 ha sorghum field protected by two full-time bird scarers.

Drought is also another constraint affecting sorghum cultivation in western Kenya. Agricultural systems in this region still engage in traditional farming systems that rely entirely on a rain-fed agricultural crop production system (Rockström *et al.,* 2003). High sorghum grain yield losses always occur when moisture stress coincides with either flowering or grain filling stage. Other factors known to reduce crop yield include inadequate availability of improved sorghum varieties and most importantly *Striga*.

2.3. The *Striga* weed

Striga is a Latin word that stands for ‘witch’. *Striga* is known as witchweed, presumably because plants diseased by the weed display stunted growth, early discoloration, and an overall drought-like phenotype long before *Striga* weed appears (Gebreslasie *et al*., 2016). *Striga* weed is believed to have originated from the Nuba Mountains in Sudan and Ethiopia, the same region of origin of sorghum (Ejeta, 2007). The genus belongs to the dicotyledonous family Orobanchaceae with genetically diverse members ranging from 30 to 35 species (Kirigia, 2015). Unachukwu *et al*. (2017) collected and characterized *S. hermonthica* plants from Kenya and Nigeria using single nucleotide polymorphisms (SNPs) and established that the *S. hermonthica* populations exhibited a high level of genetic diversity. This shows genetic distinctiveness, an indication that they have had a very limited exchange of genetic material.

Over 80 % of *Striga* species are found in Africa with the rest in Asia (Westwood, *et al.,* 2010; Runo and Kuria, 2018). 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*

Benth. (Parker, 2009; Kuria, 2017). *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,* has affected and dominated most cereal growing regions of SSA (Unachukwu *et al*. (2017). An estimated area of over 21 million ha has been covered by *S hermonthica* in SSA (Qurashi *et al*., 2017).

In Africa, yield losses due to *Striga* are estimated at US $ 7 billion annually (Mbogo *et al*., 2016) and within SSA, Rodenburg *et al*. (2016) estimated total yield losses ranging between 20%-95% in sorghum and millet to occur as a result of *Striga* infestation. In Africa, countries such as Ethiopia and Sudan have reported grain yield losses of between 65%-100% from heavily infested fields (Yousif, 2017). In Kenya, about 80,000 hectares cropped to maize, sorghum, and millet are severely infested causing an estimated grain yield loss that translates into $ 10 million annually (Atera *et al*., 2013; Midega *et al*., 2016). In western Kenya, *S. hermonthica* infestation has affected over 217,000 ha of arable land in many counties including Kisumu, Homa Bay, Migori, Busia, Kakamega, Vihiga, and Bungoma (Ndung, 2003).

2.4. *Striga* biology and life cycle

Striga is an obligate root hemiparasitic parasite. The weed is widely distributed in diverse agro-ecologies experiencing annual rainfall and temperatures of as low as 250 mm and 27°C and as high as 1500 mm and 40°C respectively (Jain *et al*., 2018). The amount of rainfall received in an area determines its levels of *Striga* infestation. The regions which receive low amounts of rainfall are likely to experience high levels of *Striga* infestation compared to those experiencing high rainfall (Jain *et al*., 2018). The *Striga* species are among the most specialized of all the root-parasitic plant parasites that combine the life cycle of holo-parasite at the seedling stage and hemiparasite as a green, chlorophyll-containing emergent plant (Teshome, 2013; Badu-Apraku

and Fakorede, 2017; Delavault *et al*., 2017; Kenyi *et al*., 2017). *Striga* life cycle involves the identification of a suitable host, gain of access into the host's nutrients and water supply through the development of functional haustoria, and finally, maturity and seed set while still attached to its host (Fernández *et al*., 2016). According to Adam (2017), *Striga*'s developmental stages can be grouped into an independent phase that does not require the presence of the host and a dependent phase, which requires the presence of the host.

2.4.1. Independent phase

The independent phase or non-parasitic phase begins with the *Striga* seed perception of an appropriate germination stimulant and ends with the attachment of *Striga* radicles onto host roots (Cui *et al*., 2018). To respond to germination stimulants, *Striga* seeds must undergo a pre-incubation period of moist and suitable temperatures (Zwanenburg *et al*., 2016). After conditioning, *Striga* seed will germinate even in the presence of minute levels of germination stimulant released from the host roots (Loubser, 2016). If during this time no germination stimulant is perceived, then the *Striga* seed will go into secondary dormancy.

2.4.2. Parasitic phase

Germination of *Striga* seed is linked to the presence of a nearby host, because the endosperm of *Striga* seed 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). This requires that they shift from independent to parasitic phase. The transition from independent to dependent phase requires proximity of *Striga* seedlings to host roots. This enables the seedling radical to reach the host root within a few days before exhausting the resources in their tiny seed (Delavault *et al*., 2017). Upon contact with the host root, the radicle develops into a specialized organ, the haustorium. The organ which attaches the germinated *Striga* seedlings to the host roots translocates host resources and

begins the parasitic phase of the *Striga* plant (Fernández *et al*., 2016; Yoshida *et al*., 2016). In addition to chemical signals, a thigmotropic response is required for the *Striga* seedling to develop morphologically normal haustorium (Spallek *et al*., 2013). The produced 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 and Melnyk, 2018). The linkage can be established within a few days after attachment (Yoshida *et al.*, 2016).

Once the parasite seedlings are connected to the host roots, they can grow underground for approximately 3-6 weeks, the duration in which it will be fully dependant on the host for all the substances it requires for growth and development (Těšitel, 2016; Runo and Kuria, 2018). After emergence, the parasite forms stems 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, seed production begins. *Striga* seeds are minute (0.20-0.50 mm long), weighing only approximately 3.7-12.4 µg each, and are produced in very large numbers (Abdalroof, 2016). The estimated numbers of seeds produced per reproductive *Striga* plant can vary from several thousand to over 85,000 depending on species and growing conditions (Rodenburg *et al.*, 2016). The produced seeds can be dispersed by cattle, wind, floods, and the shared use of contaminated farm implements and crop seeds (Gebreslasie *et al.*, 2016).

2.5. *Striga*-host interaction and the effects of *Striga* on host yield components and yield.

Striga-host synchronized developmental stages of seed germination, haustoria initiation, and penetration establish its initial interaction with its host (Hegenauer *et al*., 2017). This mode of infection cuts across all host crops such as maize, rice, cowpeas, and sorghum (Runo and Kuria, 2018). Although it is expected that the weed would photosynthesize most of the sugars it requires for growth once they emerge from the soil, this is, however, not possible due to the reduced *Striga* leaf chlorophyll content which has a low photosynthetic efficiency of about 20-30%, hence its life-long dependency on its host (Těšitel, 2016). *Striga*-host parasitism occurs through indirect disruption of photosynthetic pathways and direct withdrawal of host nutrients (Bawa *et al*., 2015).

The reduction in the host's photosynthetic capacity to less than half of that in healthy plants is the main mode of *Striga* parasitism on its host. It causes a growth loss of about 80-85% in the infested sorghum compared to only 20% loss that results from the actual withdrawal of carbon from the host (Stewart *et al.,* 1991; Matthies, 2017). Investigations indicate that the rate of photorespiration is very high in *S. hermonthica* and as a result, the net gain from its photosynthesis is very little (Delavault *et al.*, 2017; Ramesh *et al*., 2017). This will, therefore, require the weed to obtain almost its entire nutrient resources such as amino acid and water (a key component required for photolysis in photosynthesis) from the host plant. Such resource withdrawal by the parasite leads to characteristic features of stunting, drought-like leaf wilting, chlorotic lesions, leaf rolling, and highly reduced panicle sizes; all indicating growth loss in the *Striga*-infested host (Delavault *et al.,* 2017). Additional impacts of *Striga* on its host include a strong toxic effect and disruption of hormonal balance in *Striga*-sick host plants exhibited by increased levels of abscisic acid and decreased levels of cytokinins and gibberellins (Frost *et al*., 1997).

2.6 *Striga* control mechanisms and their limitations

The selection and identification of resistant crop genotypes is one way of solving the *Striga* problem. However, other control mechanisms are currently in place and applied in *Striga* control. These include cultural, chemical, and biological options. Among these control options, the cultural practices such as hand weeding, crop rotation, trap cropping, and intercropping are the methods that are readily available to subsistence farmers (Dawud, 2017). Hand weeding, for instance, involves the physical removal of mature *Striga* plants before they set seeds. Although this will reduce the amount of *Striga* weed above the ground and subsequently reduce additional soil-*Striga* seed input, it will not significantly reduce yield losses even with early weeding (Lado and Hussaini, 2018). This is because the damage caused to the host crop will have been seriously inflicted even before the emergence of the *Striga* plant above the soil surface (Leandre *et al*., 2018). Hand weeding as a cultural method of *Striga* control is highly labor-intensive since repeated hand-pulling of *Striga* is required per growing season and it can take up to 3-4 years to reduce field *Striga* infestation levels (Parker and Riches, 1993) which also applies to crop rotation, trap-cropping, and intercropping (Teka, 2014).

Biological *Striga* control methods have also been developed to eradicate the *Striga* problem in subsistence farming. These include the use of insects such as *Smicronix spp* and pathogenic fungus *Fusarium oxysporum* as a mycoherbicide (Mrema *et al*., 2017). The use of Fusarium oxysporum in *Striga* management has been reported to be effective (Musyoki *et al.*, 2015; Zarafi *et al*., 2015; Kangethe, *et al.,* 2016; Nzioki *et al*., 2016) though 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 probably because of the required knowledge and expertise involved in fungal isolation and preservation (Teka, 2014). Besides, the

use of *Fusarium oxysporum* for *Striga* management is also ineffective when applied independently of other *Striga* control methods. Berner *et al*. (1996) reported that the use of *F*. *oxysporum* in combination with other cost-effective control methods such as the use of resistant varieties could provide an effective and sustainable control option for subsistence farmers, but when used in the absence of other *Striga* control mechanisms, it is not effective and sometimes affected by environmental conditions. In general, there has been a slow rate in the implementation of biological methods of *Striga* control since such methods of *Striga* control go beyond farmers' common knowledge and need a lot to be learned in terms of ecological requirement, quantitative damage, and host specificity (Zimdahl, 2018).

The use of herbicides has also not been widely adopted. This is because it has been associated with great environmental degradation, non-selectiveness in their mode of action, and most often expensive to acquire by the subsistence farmers (Joel, 2000). Application of Dicamba, for instance, can provide an early-season control but is not cost-effective (Odhiambo and Ransom, 1993) since it fails to provide the persistent, continual control necessary to make it cost-effective (Abayo *et al.*, 1998; Shaw, 2018). The fact that the symptoms of *Striga* damage on the host appear before it emerges above the ground also illustrates how ineffective herbicide control is likely to be. Despite the high potential of some of these control methods, the associated shortcomings of these methods as stated above have made these methods to be inefficient both in reducing the *Striga* problem and in improving crop yield in sustainable ways. Therefore, the use of resistant/tolerant varieties is a feasible way that could solve the *Striga* problem.

2.7 Breeding for *Striga* resistance

Breeding for *Striga* resistance is an area of research that has cut across various host crops such as cowpeas, pearl millet, maize, sorghum, and rice (Mandumbu *et al*., 2017). Many plant scientists have conducted different studies under *Striga* infestation to develop resistant varieties in the listed crops. For example, a mutation in maize for herbicide resistance has been used as a control technology in East Africa (Kanampiu *et al*., 2003). The germplasm used in this technology is resistant to the imidazolinone group of acetolactate synthase. Seed treatment with imidazolinone, an herbicide registered as "*Striga*way" has given effective control of *Striga* in the early stages of parasitic attachment to maize seedlings (Mbogo *et al*., 2016). The International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Center (CIMMYT) have also developed open-pollinated maize varieties (OPV), hybrids, and inbred lines that are resistant to *S. hermonthica* (Shayanowako *et al*.,2018). In Kenya, two *Striga* -resistant maize varieties namely, KSTP94 and GVF 4 have been developed by the Kenya Agricultural Research and Livestock Research Organization (KALRO) (IITA, 2014).

In sorghum, breeding for *Striga* resistance in the crop is reported to have started in South Africa around 1920 (Mohamed, 2002). Saunders (1933) reported one of the first comprehensive studies aimed at selecting sorghum varieties resistant to *Striga* in South Africa. His work led to the identification of cultivar 'Radar' that was reported to be resistant to *Striga asiatica* (Riches *et al*., 1987). Doggett (1953) reported sorghum varieties, Dobbs and P41 to be resistant to *Striga* in East Africa, and in 1991, the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) reported seven sorghum varieties; Framida, IS6961, IS7777, IS7739, IS 14928, IS14825 as resistant to *Striga*. The organization also recommended IS 9830 as the most promising sorghum variety resistant to *Striga hermonthica* in East and West Africa (Bozkurt *et al*., 2015).

In Zimbabwe, the Southern African Development Community SADC/ICRISAT regional sorghum and pearl millet improvement program screened a series of sorghum cultivars and identified SAR29, SAR33, SAR35, SAR37, and SAR16 to be resistant to *Striga* (Robert, 2013). Early research in Sudan also confirmed Dobbs sorghum varieties to be resistant to *Striga* just as Doggett did in 1953, the study also identified additional genotypes such as Framida, Serena, and Najjad sorghum genotypes to be best suited in *Striga* stricken regions of Sudan (Mohamed, 2002).

In Kenya, breeding for *Striga* resistance in sorghum started in 1965, when Dobbs variety was found to be resistant to *Striga* in western Kenya (Kiriro, 1998), and over the years, great progress has been made in improving the resistance of sorghum to *Striga*. In 2017, Mbuvi *et al*. (2017) explored various novel sources of *Striga* resistance from wild sorghum in Kumi, Bukedea, and Alupe and found significantly higher levels of resistance in wild sorghum accessions. The wild accessions also had lower numbers of *Striga* attachments and *Striga* biomass when compared to resistant check N13. Joel *et al.* (2018) carried out genetic diversity and virulence of *S hermonthica* from Kenya and Uganda on selected sorghum varieties and identified sorghum genotypes Asareca W2, Asareca AG3, N13, and the Wild-type to be resistant. The resistant and susceptible genotypes also supported low and high mean numbers of *S. hermonthica* plantlets growing on their roots respectively.

Although great progress has been made particularly in breeding for *Striga* resistance in sorghum, there is the need to carry out further field selection, since field observations and surveys still indicate that some genotypes grown locally by farmers are tolerant to *Striga* and can produce good yield even when under a high *Striga* infestation (Robert, 2013; Kenyi *et al*.,2017; Joel *et al*., 2018). The current research, therefore, screened and identified additional *Striga*-resistant sorghum genotypes in a group of farmers' preferred sorghum genotypes.

2.8 Mechanisms of *Striga* resistance in Host crop

Several possible defense reaction mechanisms in host crops that can operate singly or in various combinations have been suggested (Oswald, 2005). These include production of low germination stimulants and haustoria-inducing factors, presence of mechanical barriers in host roots that results from lignifications of cell walls, or radicular cortex structure (Robert, 2011). Post-attachment hypersensitive reactions, insensitivity to *Striga* "toxin" associated with maintenance of photosynthetic efficiency in host under *Striga* infestation and avoidance mechanism such as deeper root growth habits exhibited by fewer roots in the upper 15-20 cm soil layer (Robert, 2013). Four specific invitro mechanisms of resistance to *Striga* in sorghum and some wild accessions are known (Grenier *et al*., 2001; Mohamed, 2002; Mohamed *et al*., 2003; Rich *et al.*, 2004; Ejeta, 2007). These mechanisms are low production of germination stimulant (LGS), low production of haustoria initiation factor (LHIF), hypersensitive response (HR), and incompatible response (IR).

2.8.1. Germination stimulants

Germination stimulants are chemical stimuli or signaling molecules that initiate the lifecycle of *Striga*. The presence of germination stimulants such as strigolactones (SLs) in root exudates of sorghum is critical for symbiotic colonization by arbuscular mycorrhizal (AM) fungi (Waters *et al*., 2017). This association improves the performance of sorghum under nutrient and water deficit soils (Parker and Riches 1993; Nadeem *et al*., 2014; Brun *et al.*, 2017). Yoneyama *et al*. (2015) established that SLs secretion was promoted by soils' N and P deficiencies. However, the amount of SLs exuded in response to low soil fertility as reflected by low organic matter and low soil biological activity was much greater.

The differences in the amount of secreted SLs signify differences in the levels of resistance in host crops. The genotypes which secrete low amounts of SLs produce insufficient amounts of exudates

required for germination of conditioned *Striga* seeds, consequently resisting the growth of many *Striga* plants in field trials (Gobena *et al*., 2017). Conversely, all highly susceptible sorghum genotypes are high producers of germination stimulants (Mohemed *et al*., 2018). Some of the sorghum genotypes that have been identified to secrete low amounts of *Striga* germination stimulant as a mechanism of resistance to *Striga* are SRN39, Framida, 555, `SRN 6496, IS9830, ICSV1006, and a wild accession of *S. bicolor* subspecies drummondii (Dorothy, 2014).

Different studies have explored the relationship between *Striga* resistance and host plant secretion of germination stimulants (Cardoso *et al*., 2011: Jamil, *et al.,* 2011; Gobena *et al*., 2017). Waters *et al*. (2017) found that sorghum genotypes can differ by as much as a billion folds in the amount of stimulant production and such variation was partly responsible for their differences in field resistance to *Striga*. Mohemed *et al*. (2016) observed that the sorghum genotypes which secreted low amounts of strigolactone had equally low numbers of *Striga* infestation. In a later study, they reported that susceptibility of sorghum genotypes to *Striga* was highly correlated with concentrations of strigolactone; 5-deoxystrigol (Mohemed *et al*., 2018). Yohannes *et al*. (2016) also observed that low *Striga* germination percentage observed in the accession, EG830 had a significant role in its resistance to *Striga.* This finding corroborates those of Siame *et al*. (1993) and Hess *et al*. (1992) who reported that low stimulant production was sufficient to confer field resistance to *Striga* independent of other mechanisms.

The secretion of germination stimulants in host crops is one mechanism that has been explored in various host crops and it has led to the identification and characterization of several germination stimulants. These include dihydro sorgoleone as an active stimulant in root exudates of sorghum and other monocotyledonous hosts, strigolactones, and sesquiterpene lactones (Yoneyama *et al*., 2015). Among these chemicals, SLs are the most potent *Striga* germination inducer in the sorghum

root exudates, since it has the highest stimulant activity to initiate *Striga* seed germination (López-Ráez *et al*., 2017). Mohemed *et al*. (2018) established that irrespective of morphological group, geographical location, climatic adaptation, and field reaction to *Striga*, all sorghum genotypes released strigolactones as a major germination stimulant for *Striga*. Due to their high activity in inducing the germination of *Striga* seeds, Strigolactones are the most explored class of germination stimulants with up to seven natural strigolactones germination stimulants so far isolated and characterized (Tokuma and Patrick, 2016). These are strigol in exudates of millet and maize (Awad *et. al*., 2006), orobanche acetate and orobanchol, isolated from cowpea, red clover, and soya bean (Cardoso *et al.*,2011), sorgolactone and sorghumol isolated from sorghum, and 5 –deoxystrigol which is a strigolactone present in the root exudates of maize, paso millet and sorghum (Adam, 2017).

2.8.2. Signal production for Haustoria initiation

To further the development and differentiation of *Striga* radicle into a specialized structure, haustoria, it will require a second host-derived signal, failure of which the seedling will die after four days (Fernández *et al.*, 2016). Upon receiving the chemical signal, the radicle will differentiate rapidly into haustoria, an organ that establishes attachment of the weed to the host's vascular system (Yoshida *et al.*, 2016). The secretion of the germination signal and haustorial initiation signal are independently inherited. (Ejeta *et al.*, 2000). Therefore, crops that secrete germination stimulants in abundance but fail to produce haustorial initiation signal will not only be resistant to *Striga* but will also deplete the *Striga* soil seed population by promoting suicidal *Striga* seed germination (Tokuma and Patrick, 2016).

2.8.3. Hypersensitive response (HR)

This is a type of resistance that involves localized necrosis of host tissues surrounding the site of attempted parasite attachment. This may be coupled with the release of phytoalexins that can kill the attached *Striga*. Sorghum varieties that exhibit this mechanism of resistance are; Dobbs, Framida, Serena, and wild accessions *S. bicolor subspecies drummondii*, *S.hewisonni*, and *S.b.verticilliflorum* (Mutinda *et al*., 2018).

2.8.4. Incompatible response (IR)

Some *Striga* plants appear to develop normally at first but show signs of stunted growth. This is a response similar to that observed when *Striga* unsuccessfully infests non-host plants, hence the Incompatible response (IR). The IR is similar to HR in that it also discourages the development of *Striga* beyond attachment. However, there is no apparent necrosis in host root tissue surrounding the attachment site in IR-based resistance (Tokuma and Patrick, 2016).

2.9. Evaluation Techniques for Resistance against *Striga*

Evaluation of genotypes for *Striga* resistance requires that the only stressing factor in the field is *Striga* so that the observed differences between genotypes are due to differences in *Striga* resistance only (Kountche *et al*., 2013). Field screening, pot screening, and screening with the help of laboratory assays for the detection of a specific resistant mechanism are effective evaluation methods that can help the breeder to identify genotypes with superior resistance or tolerance against *Striga* weed (Rodenburg *et al.,* 2005).

2.9.1. Laboratory screening

Agar-gel assay and paper roll assay are the commonly used laboratory assays (Hess *et al.,* 1992). The methods allow for observation of early resistance reactions of the host to specific *Striga* developmental stages of seed germination, radicle formation, attachment, penetration, and

haustorium production. The paper roll assay technique (PRT) is used to evaluate post-infection resistance to *Striga* whereas the agar gel technique (AGT) is a simple pre-infection screening method of host genotypes for the production of low *Striga* seed germination stimulant (Mohamed and Riches,2001). A modification of AGT is an extended agar gel technique (EAGT) which involves increasing the assay time for the AGT by 24 hours. The techniques are useful tools for screening sorghum germplasm for *Striga* seed germination stimulant production, haustorial initiation factor production, and hypersensitive reaction. The assays also allow for repeated observations of sorghum-*Striga* associations before and after infection.

2.9.2. Pot screening

Pot screening involves growing the host plant in pots artificially infested with *Striga* seeds. Screening for resistance and tolerance in pots is a useful technique because of the ease in managing and controlling the environment. Furthermore, unlike in the field screening, cross- inoculation studies, i.e. screening of genotypes against a range of *Striga* eco-biotypes is possible (Kuria, 2017).

2.9.3. Field screening

This has been the conventional method in plant breeding for *Striga* resistance. It involves evaluation of germplasm either under artificial or natural field *Striga* infestations. Field screening allows for evaluation of sorghum accessions not only for their reaction to *Striga* infestation but also for other important traits such as grain yield, grain quality, disease under natural field conditions. According to Haussmann *et al.* (2000) and Omanya *et al*. (2004), field screening is still the most reliable technique to produce stable resistance to *Striga*. However, screening under natural field *Striga* infestation is hampered by additional problems of high soil micro-variability, heterogeneity of natural field infestations, and complex interactions between host, parasite, and environmental factors such as drought, soil type, and fertility (Ejeta, 2007; Amusan *et al.*, 2008).

Kim (1991) indicated that improved accuracy in field tests should include one or several of the following; artificial plot infestation with *Striga* seeds, specific plot layout, appropriate experimental design that allows high replication, use of appropriate susceptible and resistant checks, evaluation in adjacent infested and non-infested plots and use of appropriate selection indices such as emerged *Striga* counts and *Striga* vigor ratings.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Evaluation of sorghum genotypes for resistance to *Striga hermonthica* under field conditions

3.1.1. Plant Materials

Twenty-one (21) sorghum genotypes (Table 3.1.1) from Maseno University, Rongo University, and International Centre for Research in Semi-Arid Tropics (ICRISAT) breeding programs were used in the study. The elite genotypes are yet to be released as varieties.

Table 3.1 1: List of sorghum genotypes evaluated under *Striga hermonthica* infestation during the short rains of September 2018 and long rains of March 2019 at Kadel and Nyahera sites

Entry	Genotype	Trait	Source
1	IESV 92022/1-SH	Accessions	ICRISAT
2	N 13	Resistant check	ICRISAT
3	IESV 92042-SH	Accessions	ICRISAT
4	IESV 92036-SH	Accessions	ICRISAT
5	IESV 92038/2-SH	Accessions	ICRISAT
6	T 53B	Elite material	Rongo University
7	T 30B	Elite material	Rongo University
8	Nyadundo 1	Elite material	Rongo University
9	Nyadundo 2	Elite material	Rongo University
10	C 26	Elite material	Rongo University
11	N 57	Elite material	Rongo University
12	MUK 60	Elite material	Rongo University
13	N 68	Elite material	Rongo University
14	E 117B	Elite material	Rongo University
15	Uyoma 47 Brown	Elite material	Maseno University
16	Maseno 49	Elite material	Maseno University
17	Uyoma 42 STR	Elite material	Maseno University
18	Uyoma 8	Elite material	Maseno University
19	Maseno 6	Elite material	Maseno University
20	Uyoma 47 white	Elite material	Maseno University
21	Uyoma 6	Elite material	Maseno University

3.1.2. Experimental site description

Field trials for *Striga* resistance in the listed sorghum genotypes (Table 3.1.1) were conducted at Nyahera in Kisumu County and Kadel in Homabay County, the two sites are both *Striga* hot spots. Nyahera lies at a longitude of 34º 53. 452′E, latitude of 0º 35.977′N and an altitude of 1490 m above the sea level with an average annual rainfall of 1650 mm per annum. The soils are well-drained and classified as ferralic with a pH of 5.9 (Mbogo *et al*., 2016). Kadel is found at a longitude of 34^0 24^0E, latitude 0^0 11'27" S, and an altitude of 1400 m above sea level with an average annual rainfall of 1226 mm (Ogenga *et al*.,2018). The soils are vertisol with a pH of 7.3 and made of very fine loose textured clay soils with low organic matter. The two sites have bimodal type of rainfall where the first peak falls between March and June (Long rains season) and the second peak between September and December (short rains season).

3.1.3. Experimental design and layout

Field trials for *Striga* resistance in the sorghum genotypes were laid out in a randomized complete block design (RCBD) replicated three times with two treatments, *Striga* plots, and *Striga* free plots. Evaluation of genotypes at Nyahera site was carried out under *Striga* infestation in the short rains of September 2018 and both under *Striga* free and *Striga* infestation in the long rains of March 2019. Nyahera is a site that had been used for *Striga* research by various organizations such as Nairobi University and International Maize and Wheat Improvement Center (Mbogo *et al*., 2016), the site, therefore, had already established *Striga* plots and *Striga* free plots. At Kadel, successful evaluation of sorghum genotypes was in the long rains of March 2019 and only in the *Striga* plots, given that the whole site was *Striga* infested. Land preparation was done using a disc plough and harrowed twice before planting. Planting in each plot was made in four-rows measuring 3 m in length with a row spacing of 0.75 m and a plant spacing of 0.2 m. Hand hoe weeding was carried

out before *Striga* emergence and thereafter weeds other than *Striga* were regularly handpicked. In *Striga* free plots, hand hoe weeding was practiced throughout the trial as opposed to hand weeding.

3.1.4. Data collection

In *Striga* infested plots, emerged *Striga* counts and *Striga*- host damage ratings were recorded in the net plots (two central rows) of each experimental unit at intervals of 8, 10, and 12 weeks after crop emergence. *Striga* damage rating was scored using a scale of 1-5 as described by Haussmann *et al.* (2000) where 1 indicated normal plant growth and a high level of tolerance and 5 represented complete collapse or death of highly susceptible sorghum genotypes. At maturity, the data collected in both *Striga* and *Striga* free plots were plant height (cm), plant dry biomass yield (Kg), and grain yield (t/ha); measurements obtained from the net plots of the 63 experimental units used. Sorghum plant height was measured from the soil surface to the tip of the main head just before harvesting. To determine dry shoot biomass yields, 12 sorghum stalks were sun-dried under field conditions and weighed in grams using a top pan weighing balance. The obtained dry shoot biomass yield units in grams were divided by 1000 to convert them into Kg. To determine grain yield, 12 sorghum panicles from the net plots were harvested, sun-dried to 13% moisture content, threshed, weighed, and converted into t/ ha^{-1} using the formula described by Abera *et al. (*2020) as follows;

$$t/ha = (yield\ of\ plot\ in\ t\ \times\ 10000) \div\ plot\ area\ in\ m^2$$

Where *t* is tonnes, *ha* is hectare and m^2 is plot size in meters square

3.1.5. Data analysis

The variance analysis (ANOVA) and mean plant height, dry shoot biomass yield, grain yield, *Striga* count, and *Striga* damage rating were analyzed using a Statistical Analysis System (SAS) software package (release 6.1), tested for significance at 5% level and means separated using 5% least

significant difference (L.S.D). To meet the assumptions of analysis of variance, actual field *Striga* counts were transformed using the formula log (X + 1), where X is the original field *Striga* counts. The following formula by Rodenburg *et al*. (2006) was used to calculate the relative yield loss (differences between genotypes' realized grain yields in *Striga* free plots and *Striga* plots).

$$RYL = [(Yc - Ys) / Yc] \times 100$$

Where RYL is the relative yield loss, Yc is the average yield of *Striga*-free plots of a specific sorghum genotype and Ys is the observed yield of the same sorghum genotype grown under *Striga* infestation.

3.2 Determination of genotypic variation in the numbers of induced and maximum distance of the germinated *Striga* seeds in the selected sorghum genotypes

3.2.1 Plant materials and experimental site description

Striga hermonthica seeds were obtained from the International Maize and Wheat Improvement Center (CIMMYT), Kibos and sorghum genotypes used were those described in Table 3.1.1. The experiment was carried out in Maseno University's botanical laboratory.

3.2.2. Laboratory experiment

3.2.2.1. Surface sterilization and conditioning of sorghum seeds

The sorghum seeds were soaked for five minutes in 10 ml of 1% sodium hypochlorite solution and rinsed three times with distilled water. The seeds were incubated in petri dishes on moist filter papers at 28 °C for 24 hours. Vigorously germinated sorghum seeds were selected based on the length of their radicle and used in the agar gel assay.

3.2.2.2. Surface sterilization and conditioning of *Striga* seeds

Striga seed surface sterilization and conditioning was performed using the procedure described by Mohamed *et al.* (2010). About 0.5 mg of dry *Striga* seeds were placed in a 10 mL of 1% sodium hypochlorite solution for 5 minutes in a 50-mL flask containing 3 drops of Tween 20. Floating seeds and debris were discarded and the remaining seeds were rinsed thoroughly with 200 ml of sterile distilled water. The *Striga* seeds were spread on a glass fiber filter paper (Whatman GFA) in sterile petri dishes wetted with 5 ml of sterile distilled water. The petri dishes were sealed with parafilm and wrapped with aluminum foil and conditioned for 14 days at 29 ^{0}C.

3.2.2.3. The assay; Agar Gel Technique (AGT)

Agar gel assay was performed according to the procedure described by Mohamed *et al*. (2010) in a completely randomized design (CRD) replicated three times. Approximately 1500 *Striga* seeds (4 drops of settled seeds) were pipetted into a sterile 9 cm diameter Petri dish. A 0.7% water agar solution (1.05 g bacto agar in 150 ml H_2O) that had been autoclaved for 15 min and cooled for at least one hour was poured before it solidified into petri dishes containing an even distribution of conditioned *Striga* seeds. The radicle of a pre-germinated sorghum seed was submerged in the center of the solidifying agar gel. The dishes were covered and placed in an incubator at 28°C for five days. The germinated *Striga* seeds were observed and counted through the bottom of the petri dishes using a dissecting microscope and the locations of the furthest germinated *Striga* seeds away from the roots marked. The marked distances were measured in cm using a straight ruler from the root of sorghum to the furthest germinated *Striga* seed.

3.2.3. Data analysis

This was performed as described in section 3.1.5 in which the numbers and distances of the furthest germinated *Striga* seeds were subjected to analysis of Variance (ANOVA) tested for significance at 5% level and means separated using L.S.D 5%.

CHAPTER FOUR

RESULTS

4.1 Evaluation of sorghum genotypes for resistance to *Striga hermonthica* at Nyahera site during the short rains of September 2018.

4.1.1 Emerged *Striga* counts

The results of emerged *Striga* counts are presented in Table 4.1.1. In week 8 after crop emergence, T30B and Uyoma 8 sorghum genotypes gave the highest mean *Striga* counts of 165.7 and 155 while Maseno 49, IESV 92036-SH, and Uyoma 47 Brown recorded the lowest respective mean *Striga* counts of 18, 16.3, and 9.3. At 12 weeks after crop emergence, C26, IESV 92036-SH, and Uyoma 47 Brown sorghum genotypes recorded the lowest respective mean *Striga* counts of 84.7, 88.3, and 50.3 which were significantly different at ($p<0.05$) (Table 4.1.1) with a mean *Striga* count of 110 recorded in the resistant check N 13. E117B, Uyoma 8, and Nyadundo 1 genotypes, however, recorded the highest respective mean *Striga* counts of 347.3, 337.7, and 326.7. Significant difference ($p<0.001$) (Appendix 1) in emerged *Striga* count at 12 weeks after crop emergence was also observed amongst the sorghum genotypes.

4.1.2 *Striga* damage ratings (SDR)

The hosts' *Striga* damage ratings presented in Table 4.1.1 differed significantly ($p<0.001$) (Appendix 1) at 12 weeks after crop emergence. Uyoma 8 and E117B recorded the highest mean SDR score of 4.0 and the second highest mean SDR score of 3.0 was recorded in Nyadundo 1, Nyadundo 2, T30B, and Muk 60 sorghum genotypes. Uyoma 47 Brown (1.0), IESV 92036-SH (1.33), Maseno 49 (1.33), Uyoma 47 white (1.67), and IESV 92038/2-SH (1.67), however, recorded the lowest mean *Striga* damage ratings which were significantly different at ($p<0.05$) (Table 4.1.1) with a mean SDR score of 2.0 recorded in the resistant check N13.

Table 4.1 1: Mean emerged *Striga hermonthica* counts and *Striga* damage ratings of sorghum genotypes evaluated at Nyahera during the short rains of September 2018.

Genotype	Number of emerged *Striga* plants per net plot			SDR (Scale 1-5)		
	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e
E117B	130.33 (2.10)^{a}	250 .0 (2.39)^{a}	347.33 (2.54)^{a}	1.3^{b}	3.0^{a}	4.0^{a}
Uyoma 8	155.0 (2.18)^{a}	241.33(2.38)^{a}	337.67 (2.53)^{a}	1.7^{a}	3.0^{a}	4.0^{a}
Nyadundo 1	152.33 (2.16)^{a}	238.0 (2.36)^{a}	326.67 (2.51)^{a}	1.0^{c}	2.0^{b}	3.0^{b}
N 57	119.33 (2.05)^{a}	206.33 (2.31)^{a}	290.0 (2.46)^{ba}	1.0^{c}	1.3^{cd}	2.33^{cbd}
Nyadundo 2	114.0 (2.04)^{a}	201.67 (2.30)^{ba}	287.67 (2.45)^{ba}	1.0^{c}	1.7^{cb}	3.0^{b}
T53B	134.67 (2.12)^{a}	221.33 (2.32)^{a}	278.0 (2.44)^{ba}	1.0^{c}	1.7^{cb}	2.33^{cbd}
T30B	165.67 (2.16)^{a}	232.0 (2.33)^{a}	277.33 (2.42)^{ba}	1.0^{c}	2.0^{b}	3.0^{b}
N68	82.0 (1.92)^{ba}	177.0 (2.45)^{ba}	251.67 (2.40)^{ba}	1.0^{c}	1.7^{cb}	2.33^{cbd}
Uyoma 6	74.67 (1.88)^{ba}	154.67 (2.18)^{ba}	244.0 (2.38)^{bac}	1.0^{c}	1.3^{cd}	2.0^{ced}
Uyoma 42 STR	96.33 (1.99)^{ba}	176.0 (2.25)^{ba}	234.33 (2.37)^{bdac}	1.0^{c}	2.0^{b}	2.67^{cb}
Maseno 6	83.0 (1.92)^{ba}	134.0 (2.12)^{bac}	199.0 (2.30)^{bdec}	1.0^{c}	2.0^{b}	2.67^{cb}
Muk 60	63.33 (1.80)^{bac}	132.67 (2.11)^{bac}	159.67(2.20) ^{fdec}	1.0^{c}	2.0^{b}	3.0^{b}
Uyoma 47 white	19.33 (1.30)^{fed}	77.33 (1.86)^{edc}	147.0 (2.17) ^{fde}	1.0^{c}	1.0^{d}	1.67^{fed}
IESV92022/1-SH	42.0 (1.63)^{bdc}	102.33 (2.01)^{bdc}	145.0 (2.16) ^{feg}	1.0^{c}	1.7^{cb}	2.0^{ced}
N 13	29.0 (1.45)^{edc}	58.33 (1.71)^{e}	110.0 (2.04) ^{fhg}	1.0^{c}	1.0^{d}	2.0^{ced}
Maseno 49	18.0 (1.24)^{fed}	52.33 (1.70)^{e}	92.0 (1.96) ^{hg}	1.0^{c}	1.0^{d}	1.33^{fe}
IESV 92042-SH	42.0 (1.62)^{bedc}	64.33 (1.80)^{ed}	89.67 (1.96) ^{h}	1.0^{c}	1.3^{cd}	2.0^{ced}
IESV92038/2-SH	19.33 (1.27)^{fed}	52.33 (1.68)^{e}	89.33 (1.95) ^{h}	1.0^{c}	1.0^{d}	1.67^{fed}
IESV 92036-SH	16.33 (0.93)^{f}	54.67 (1.71)^{e}	88.33 (1.91) ^{h}	1.0^{c}	1.0^{d}	1.33^{fe}
C 26	45.67(1.60)^{bedc}	60.67 (1.78)^{ed}	84.67 (1.91) ^{h}	1.0^{c}	1.0^{d}	2.0^{ced}
Uyoma 47 Brown	9.33 (0.91)^{f}	26.0 (1.38)^{f}	50.33 (1.6) ^{i}	1.0^{c}	1.0^{d}	1.0^{f}
Grand mean	76.81 (1.73)	138.73 (2.04)	196.65 (2.22)	1.05	1.60	2.35
CV (%)	48.54 (13.74)	34.0 (8.54)	23.55 (5.40)	17.00	24.85	18.58
SEM	7.49 (0.056)	10.70 (0.042)	13.00 (0.034)	0.027	0.086	0.11
LSD (0.05)	61.49 (0.39)	77.74 (0.29)	76.32 (0.20)	0.29	0.66	0.72
P	***	***	***	**	***	***

Key: Means followed by the same letter(s) along the columns are not significantly different at p<0.05: LSD. Values in parenthesis are log-transformed {$log_{10}(X+1)$ values of Striga count

*w.a.c.e: Weeks after crop emergence. CV: Coefficient of variation. LSD: Least significant difference:SEM: Standard error of the mean.***- Highly significant at (P<0.001, **-significant at P <0.01, *-Significant at p<0.05)*

4.1.3 Plant height

The results of the significantly different plant heights ($p<0.001$) (Appendix 1) recorded in the sorghum genotypes evaluated under *Striga* infestation are presented in Table 4.1.2. N 57 sorghum genotype had the highest mean plant height of 207 cm which was statistically different at ($p<0.05$) (Table 4.1.2) with the lowest mean plant heights of 103 cm and 107.0 cm in E117B and Nyadundo 1 sorghum genotypes.

4.1.4 Dry plant biomass yield

The dry plant biomass yield means of sorghum genotypes evaluated under *Striga* infestation are presented in Table 4.1.2. N 57 (0.51 Kg), Uyoma 47 white (0.43 Kg), and (Uyoma 47 Brown and IESV 92036-SH) both having a similar mean of 0.35 Kg recorded high dry biomass means. The high dry biomass means recorded in N 57, Uyoma 47 white, Uyoma 47 Brown, and IESV 92036-SH were statistically different at ($p<0.05$) (Table 4.1.2) with the lowest means recorded in Uyoma 8 (0.13 Kg), Nyadundo 1(0.14 Kg) and Muk 60 (0.16 Kg) sorghum genotypes.

4.1.5 Grain yield

The grain yields of sorghum genotypes evaluated under *Striga* infestation are shown in Table 4.1.2. Uyoma 47 white, T53B, IESV 92036-SH, IESV 92042-SH, and N 57 had good grain yield means above 2.0 t/ha which were statistically different at ($p<0.05$) (Table 4.1.2) with the lowest yielding means in Uyoma 8 (0.59 t/ha), Nyadundo 1(0.64 t/ha) and Nyadundo 2 (0.81 t/ha) sorghum genotypes.

Table 4.1 2: Mean Plant height, Dry shoot Biomass yield, and Grain yield of sorghum genotypes evaluated under *Striga* infestation at Nyahera site during the short rains of September 2018.

Genotype	Plant Height (cm)	Dry shoot biomass (kg)	Grain yield (t/ha)
Uyoma 47 white	180.0^{b}	0.43^{b}	2.14^{a}
T 53 B	177.67^{cb}	0.21^{fgh}	2.03^{a}
IESV 92036-SH	174.0^{cbd}	0.35^{cb}	2.03^{a}
IESV 92042-SH	155.0^{feg}	0.31^{cd}	2.02^{a}
N 57	207.0^{a}	0.51^{a}	2.02^{a}
T 30 B	146.0^{hg}	0.22^{fge}	1.96^{a}
N 68	162.33^{fed}	0.20^{figh}	1.86^{ba}
C 26	150.0^{eg}	0.27^{fde}	1.85^{ba}
Uyoma 47 Brown	148.33^{fg}	0.35^{cb}	1.84^{ba}
IESV 92038/2-SH	147.0^{g}	0.29^{cde}	1.78^{bac}
Maseno 49	132.0^{ih}	0.19^{figh}	1.50^{bdc}
Maseno 6	129.0^{ij}	0.23^{fge}	1.43^{edc}
IESV 92022/1-SH	125.33^{ijk}	0.31^{cd}	1.40^{ed}
Muk 60	114.67^{ljk}	0.16^{igh}	1.29^{edf}
Uyoma 6	129.33^{i}	0.18^{igh}	1.10^{egf}
Uyoma 42 STR	146.0^{hg}	0.19^{figh}	0.96^{hgf}
N 13	163.67^{ced}	0.22^{gge}	0.88^{hg}
E 117B	103.0^{l}	0.20^{figh}	0.88^{hg}
Nyadundo 2	111,67^{lk}	0.17^{igh}	0.81^{hg}
Nyadundo 1	107.0^{l}	0.14^{ih}	0.64^{h}
Uyoma 8	111.33^{lk}	0.13^{i}	0.59^{h}
Grand mean	143.83	0.25	1.48
CV(%)	6.07	18.88	15.54
SEM	3.53	0.013	0.069
LSD (0.05)	14.39	0.08	0.38
P	***	***	***

Key: Means followed by the same letter(s) along the columns are not significantly different at p<0.05: LSD
CV: Coefficient of variation
LSD: Least significance difference
SEM: Standard error of the mean
****- Highly significant at (P<0.001, **-significant at P <0.01, *-Significant at p<0.05);* LSD

4.2 Evaluation of sorghum genotypes for resistance to *Striga hermonthica* under field conditions at Kadel during the short rains of Sept 2018.

Evaluation of sorghum genotypes at Kadel during the short rains of Sept 2018 failed due to very low amounts of rainfall received in the area. As a result, no data was recorded on *Striga* count, *Striga* damage ratings, and yield components and yield.

4.3 Evaluation of sorghum genotypes for resistance to *Striga* hermonthica under field conditions at Kadel during the long rains of March to June 2019.

4.3.1. Emerged *Striga* hermonthica counts

The numbers of emerged *Striga* plants presented in Table 4.3.1 differed significantly ($p<0.001$) (Appendix 2a) among the sorghum genotypes evaluated at Kadel. Field evaluation of sorghum genotypes at Kadel during the long rains of March 2019 had a higher emerged mean *Striga* count of 295.62 which was significantly different ($p<0.001$) (Appendix 2b) with a mean *Striga* count of 203.71 (Table 4.4.1) realized in the long rains of March 2019 at Nyahera. C 26 (146) and Uyoma 47 Brown (166) sorghum genotypes supported the growth of few *Striga* plants with significantly different means at ($p<0.05$) (Table 4.3.1) with the resistant check N 13 (173.7). E117B, Uyoma 8, Nyadundo 2, T53B, Nyadundo 1, and T30B, on the other hand, supported the growth of numerous *Striga* plants with respective means of 555.3, 517, 421, 403, 396.7, and 397.

4.3.2. *Striga* damage ratings (SDR)

The differences in the severity of *Striga* attack in the sorghum accessions presented in Table 4.3.1 were highly significant ($P<0.001$) (Appendix 2a) at 8, 10, and 12 weeks after crop emergence. Nyadundo 2, Uyoma 8, and Nyadundo 1 were the most affected sorghum genotypes under *Striga* infestation. The genotypes all had a mean SDR score of 4.0 at 12 weeks after crop emergence

which was statistically different at ($p<0.05$) (Table 4.3.1) with the lowest mean SDR score of 1.3 in C 26 and N13 sorghum genotypes.

Table 4.3.1: Mean emerged *Striga hermonthica* counts and *Striga* damage ratings (SDR) of sorghum genotypes evaluated at Kadel during the long rains of March to June 2019.

Genotype	Numbers of emerged *Striga* plants per plot			SDR		
	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e
E 117B	224.3 (2.35)^{a}	373.0 (2.57)^{a}	555.3 (2.74)^{a}	2.0^{a}	3.0^{a}	3.3^{b}
Uyoma 8	173.0 (2.24)^{ba}	331.7 (2.52)^{a}	517.0 (2.71)^{ba}	2.0^{a}	2.7^{ba}	4.0^{a}
Nyadundo 2	110.0(2.04)^{hfedg}	329.3 (2.52)^{a}	421.3 (2.62)^{bc}	1.3^{bc}	3.0^{a}	4.0^{a}
T53B	176.7 (2.24)^{bac}	310.0 (2.49)^{ba}	403.0 (2.60)^{bc}	1.0^{c}	2.0^{bdc}	2.0^{d}
T 30B	139.0 (2.13)^{bdc}	253.3 (2.40)^{bc}	397.0 (2.60)^{c}	1.3^{bc}	2.0^{bdc}	2.0^{d}
Nyadundo 1	111.7 (2.05)^{fedg}	219.0 (2.34)^{dc}	396.7 (2.59)^{c}	2.0^{a}	2.3^{bac}	4.0^{a}
N 57	120.0 (2.08)^{fed}	217.3 (2.34)^{dc}	380.3 (2.58)^{dc}	1.7^{ba}	1.7^{edc}	2.3^{dc}
N 68	134.3 (2.13)^{bedc}	289.3 (2.46)^{ba}	370.7 (2.57)^{dc}	1.3^{bc}	1.3^{ed}	2.0^{d}
Maseno 6	98.7 (2.0)^{hfeig}	194.0 (2.27)^{dfe}	304.7 (2.48)^{de}	1.3^{bc}	2.0^{bdc}	2.3^{dc}
Uyoma 42 STR	128.7 (2.1)^{fedc}	208.7 (2.32)^{dce}	302.7 (2.48)^{de}	2.0^{a}	2.0^{bdc}	2.7^{c}
Uyoma 47 white	97.0 (1.99)^{hfjig}	162.7 (2.21)^{hgfe}	268.7 (2.43)^{fe}	1.3^{bc}	2.0^{bdc}	2.0^{d}
Muk 60	95.7 (1.99)^{hfjig}	172.3 (2.24)^{dgfe}	248.3 (2.39)^{feg}	1.0^{c}	1.7^{edc}	2.3^{dc}
Maseno 49	70.7 (1.85)^{kl}	107.3 (2.03)^{lk}	216.7 (2.33)^{fhg}	1.0^{c}	1.7^{edc}	2.0^{d}
Uyoma 6	83.7 (1.92)^{hkjig}	145.3 (2.16)^{hgfi}	210.3 (2.32)^{fhg}	1.0^{c}	2.0^{bdc}	2.0^{d}
IESV 92042-SH	86.3 (1.94)^{hkjig}	131.0 (2.11)^{hkji}	195.7 (2.29)^{ihg}	1.0^{c}	1.7^{edc}	2.0^{d}
IESV92022/1-SH	66.7 (1.82)^{kl}	112.0 (2.05)^{lkj}	183.0 (2.26)^{ihj}	1.0^{c}	2.0^{bdc}	2.0^{d}
IESV 92036-SH	80.0 (1.89)^{kjil}	143.3 (2.16)^{hgji}	177.0 (2.25)^{ihj}	1.0^{c}	1.3^{ed}	2.0^{d}
IESV92038/2-SH	70.7 (1.85)^{kl}	109.3 (2.04)^{lk}	174.0 (2.24)^{ihj}	1.0^{c}	1.7^{edc}	2.0^{d}
N13	70.0 (1.85)^{kjl}	115.7 (2.07)^{lkji}	173.7 (2.24)^{ihj}	1.0^{c}	1.3^{ed}	1.3^{e}
Uyoma 47 Brown	59.0 (1.77)^{l}	98.0 (2.0)^{l}	166.0 (2.15)^{ij}	1.0^{c}	1.3^{ed}	2.0^{d}
C 26	80.0 (1.98)^{hkjil}	115.0 (2.07)^{lkji}	146.0 (2.24)^{j}	1.0^{c}	1.0^{e}	1.3^{e}
Grand mean	108.41 (2.00)	197.1 (2.25)	295.62 (2.43)	1.30	1.89	2.37
CV (%)	19.55 (4.10)	15.86 (2.98)	13.47 (2.70)	23.71	22.12	14.09
SEM	5.75 (0.021)	11.31 (0.024)	15.98 (0.024)	0.06	0.08	0.11
Lsd (0.05)	34.92 (0.14)	51.50 (0.11)	65.63 (0.108)	0.51	0.69	0.55
P	***	***	***	***	***	***

*Key: Means followed by the same letter(s) along the columns are not significantly different at p<0.05 LSD. Values in parenthesis are log-transformed {log10(X+1) values of Striga count;w.a.c.e: Weeks after crop emergence.CV: Co-efficient of variation.LSD: Least significance difference.SEM: Standard error of the mean.***- Highly significant at (P<0.001, **-significant at P <0.01, *-Significant at p<0.05): LSD.*

4.3.3 Plant height

The sorghum plant heights presented in Table 4.3.2 differed significantly ($p<0.001$) (Appendix 2a) under *Striga* infestation. The tallest sorghum genotypes under *Striga* infestation were; T 53 B (183.7 cm), N 57 (181.3 cm), and N 68 (175.3 cm). The tallest mean plant heights recorded in T53B, N 57, and N 68 were significantly different at ($p<0.05$) (Table 4.3.2) with the shortest mean plant heights of 97, 97.3, 106.7 and 112.3 (cm) obtained respectively in Nyadundo 1, Nyadundo 2, E117B, and Uyoma 8 sorghum genotypes.

4.3.4 Dry shoot Biomass

The dry shoot biomass yield means of sorghum genotypes presented in Table 4.3.2 differed significantly ($p<0.001$) (Appendix 2a) under *Striga* infestation. N 57 (0.44 kg), C 26 (0.36 Kg), Uyoma 47 Brown (0.34 Kg), and IESV 92036-SH (0.34 Kg) genotypes had high dry-shoot biomass yield means which were significantly different at ($p<0.05$) (Table 4.3.2) with the lowest means of 0.12 Kg and 0.08 Kg recorded in Nyadundo 1 and Nyadundo 2 genotypes.

4.3.5 Grain yield

The results of grain yield means of sorghum genotypes evaluated under *Striga* infestation are in Table 4.3.2. N57, T53 B, N 68, and Uyoma 47 Brown sorghum genotypes all had high grain yield means of between 2.25-2.50 t/ha which were significantly different at ($p<0.05$) (Table 4.3.2) with the lowest grain yield means obtained in Nyadundo 1 (0.57 t/ha) and Nyadundo 2 (0.58 t/ha) sorghum genotypes.

Table 4.3.2: Mean agronomic performance of sorghum genotypes evaluated at Kadel during the long rains of March to June 2019.

Genotype	Plant height (cm)	Dry shoot Biomass (Kg)	Grain yield (t/ha)
N57	181.3^{a}	0.44^{a}	2.50^{a}
T53B	183.7^{a}	0.21^{gih}	2.49^{a}
N68	175.3^{ba}	0.30^{cebd}	2.40^{a}
47Brown	156.0^{dc}	0.34^{bac}	2.25^{a}
IESV 92036-SH	174.0^{ba}	0.34^{bac}	2.17^{ba}
C26	157.7^{dc}	0.36^{ba}	2.13^{ba}
T30B	166.0^{bc}	0.25^{gef}	2.05^{ba}
47White	165.0^{bc}	0.33^{cbd}	2.0^{ba}
Maseno49	148.0^{de}	0.26^{gefd}	1.96^{ba}
IESV 92038/2-SH	156.0^{dc}	0.26^{gefd}	1.95^{ba}
IESV 92022/1-SH	142.3^{fe}	0.21^{gifh}	1.63^{bc}
Maseno6	130.0^{fg}	0.23^{gfh}	1.23^{dc}
IESV 92042-SH	167.3^{bc}	0.28^{cefd}	1.27^{dc}
Muk 60	123.7^{hg}	0.17^{kijh}	1.24^{ce}
Uyoma 6	130.0^{fg}	0.16^{kijl}	1.19^{dce}
N13	124.7^{hg}	0.20^{gijh}	1.09 ^{dfce}
Uyoma42STR	133.3^{fg}	0.15^{kijl}	1.08^{dfce}
Uyoma 8	112.3^{hi}	0.12^{kml}	0.71^{dfe}
E 117B	106.7^{ji}	0.13^{kmjl}	0.66^{fe}
Nyadundo 2	97.3^{j}	0.08^{m}	0.58^{f}
Nyadundo 1	97.0^{j}	0.12^{kml}	0.57^{f}
Mean	144.17	0.23	1.58
CV	5.41	18.42	22.5
SEM	3.53	0.02	0.75
LSD (0.05)	12.87	0.07	0.60
P	***	***	***

*Key: Means followed by the same letter(s) along the columns are not significantly different at p<0.05: LSD.w.a.c.e: Weeks after crop emergence.CV: Coefficient of variation.LSD: Least significance difference.SEM: Standard error of the mean.***- Highly significant at (P<0.001, **- significant at P<0.01, *-Significant at p<0.05)*

4.4.0 Evaluation of sorghum genotypes under *Striga*-free and *Striga* infested plots at Nyahera site during the long rains of March to June 2019.

4.4.1. Emerged *Striga hermonthica* counts

The numbers of supported *Striga* plants in the sorghum genotypes presented in Table 4.4.1 differed significantly ($p<0.001$) (Appendix 3) under field conditions. Uyoma 8 (357.33), E 117B (325.0), Nyadundo 2 (298.7), and N 57 (291.67) supported the growth of many *Striga* plants which were significantly different at ($p<0.05$) (Table 4.4.1) with the lowest mean *Striga* counts of 95 in Uyoma 47 Brown relative to a *Striga* count of 123 in N 13 check.

4.4.2. *Striga* damage ratings (SDR)

The significantly ($p<0.001$) different (Appendix 3) *Striga* damage ratings of sorghum genotypes evaluated under *Striga* infestation are shown in Table 4.4.1. The most affected sorghum genotypes under *Striga* infestation at 12 w.a.c.e were Uyoma 8 and E117B with mean SDR scores of 4.0 and 3.7. The least affected genotypes were IESV 92042-SH, IESV 92022/1-SH, and IESV 92038/2-SH all with a low SDR score of 1.7 which was significantly different at ($p<0.05$) (Table 4.4.1) with a mean SDR score of 2.0 in the N13 sorghum genotype.

Table 4.4. 1: Mean emerged *Striga hermonthica* counts and *Striga* damage ratings (SDR) of sorghum genotypes evaluated at Nyahera during the long rains of March to June 2019.

Genotype	Numbers of emerged *Striga* plants per plot			*Striga* Damage Ratings (SDR)		
	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e	8 w.a.c.e	10 w.a.c.e	12 w.a.c.e
Uyoma 8	167.3 (2.22)^{a}	233.33 (2.36)^{a}	357.33 (2.55)^{a}	2.0^{a}	3.0^{a}	4.0^{a}
E 117B	170.0 (2.22)^{a}	230.67 (2.35)^{a}	325.0 (2.51)^{ba}	2.0^{a}	3.0^{a}	3.7^{ba}
Nyadundo 2	92.0 (1.97)^{bdac}	136.3 (2.11)^{ebdac}	298.67 (2.48)^{ba}	2.0^{a}	3.0^{b}	3.3^{bc}
N 57	101.33(2.01)^{bdac}	191.0 (2.28)^{ba}	291.67 (2.47)^{ba}	1.0^{a}	2.0^{c}	2.3^{d}
Nyadundo 1	89.67 (1.95)^{bdac}	133.7(2.07)^{bdacf}	288.67 (2.46)^{ba}	2.0^{a}	3.0^{b}	3.0^{c}
T 53B	104.67 (2.02)^{bac}	168.0 (2.22)^{ba}	282.67 (2.45)^{ba}	1.0^{a}	2.0^{c}	2.0^{ed}
N 68	117.67 (2.05)^{ba}	176.0 (2.25)^{ba}	279.33 (2.45)^{ba}	1.0^{a}	1.7^{dc}	2.0^{ed}
T 30 B	97.0 (1.99)^{bdac}	157.0 (2.19)^{bac}	261.67 (2.42)^{b}	1.0^{a}	2.0^{c}	2.0^{ed}
Uyoma 42STR	74.0 (1.84)^{ebdc}	129.3(2.07)^{ebdacf}	258.33 (2.41)^{b}	1.0^{a}	2.0^{c}	3.0^{c}
Uyoma 6	78.0 (1.90)^{bdac}	98.0 (2.14)^{bdac}	187.0 (2.27)^{c}	1.3^{b}	3.0^{b}	3.3^{bc}
IESV92022/1-SH	63.0 (1.66)^{edfg}	108.3(1.94)^{ebdgcf}	195.67 (2.26)^{c}	1.0^{a}	1.0^{e}	1.7^{e}
Maseno 6	68.0 (1.80)^{ebdfc}	90.0 (1.94)^{ebdgcf}	174.67 (2.24)^{c}	1.0^{a}	2.7^{b}	3.0^{c}
Uyoma 47 white	50.67 (1.68)^{edfcg}	77.0 (1.84)^{ehdgcf}	158.33 (2.20)^{dc}	1.0^{a}	1.3^{de}	2.0^{ed}
Muk 60	52.0 (1.69)^{ebdfcg}	88.0 (1.95)^{ebdgcf}	150.67 (2.18)^{dc}	1.0^{a}	2.0^{c}	2.0^{ed}
IESV92038/2-H	34.0 (1.40)^{hg}	65.0 (1.67)^{hg}	127.0 (2.1)^{de}	1.0^{a}	1.0^{e}	1.7^{e}
N 13	77.0 (1.87)^{ebdac}	89.0 (1.95)^{ebdgcf}	123.0 (2.08)^{def}	1.0^{a}	1.0^{e}	2.0^{ed}
Maseno 49	39.0 (1.53)^{ehfg}	63.33 (1.76)^{ehgf}	109.0 (2.04)^{ef}	1.0^{a}	1.3^{de}	2.0^{ed}
IESV 92036-SH	26.0 (1.38)^{hg}	59.33 (1.74)^{hgf}	106.33 (2.03)^{ef}	1.0^{a}	2.0^{c}	2.0^{ed}
IESV 92042-SH	50.33 (1.69)^{bdfcg}	67.33 (1.82)^{ehdgf}	104.33 (2.02)^{ef}	1.0^{a}	1.0^{e}	1.7^{e}
C 26	27.33 (1.45)^{hfg}	57.0 (1.73)^{hgf}	104.0 (2.02)^{ef}	1.0^{a}	1.0^{e}	2.0^{ed}
Uyoma 47 Brown	17.33 (1.25)^{h}	38.0 (1.56)^{h}	95.0 (1.98)^{f}	1.0^{a}	1.0^{e}	2.0^{ed}
Grand mean	75.97 (1.79)	118.94 (2.0)	203.71 (2.27)	1.21	1.99	2.41
CV	35.68 (12.21)	36.07 (10.85)	15.44 (3.28)	10.44	15.68	13.82
SEM	5.89 (0.04)	7.78 (0.04)	11.19 (0.03)	0.041	0.036	0.025
LSD (0.05)	44.66 (0.36)	70.69 (0.36)	51.84 (0.12)	0.21	0.51	0.55
P	***	**	***	***	***	***

Key: Means followed by the same letter(s) along the columns are not significantly different at lsd (p<0.05).Values in parenthesis are log-transformed {log10(X+1) values of Striga count; w.a.c.e: Weeks after crop emergence.CV: Co-efficient of variation .LSD: Least significance difference.SEM: Standard error of the mean

****- Highly significant at (P<0.001, **-significant at P <0.01, *-Significant at p<0.05)*

4.4.3 Plant height

The results of plant heights of sorghum genotypes evaluated under *Striga* and *Striga* free plots are in Table 4.4.2. Sorghum genotypes grew taller in *Striga* free plots compared to *Striga* infested plots with significant mean difference ($p<0.001$) (Appendix 4) in plant height realized between the plots. The tallest and shortest plant heights (cm) under *Striga* infestation were 199.3 and 93.7 in N57 and Nyadundo 2 sorghum genotypes, compared to heights (cm) of 256.7 and 131.7 attained in N57 and Nyadundo 2 sorghum genotypes under *Striga* free infestation.

4.4.4 Dry Shoot Biomass

The differences in the dry biomass yield means of sorghum genotypes evaluated under *Striga* and *Striga* free plots as presented in Table 4.4.2 were highly significant ($p<0.001$) (Appendix 4). Nyadundo 1 and Nyadundo 2, for instance, both recorded dry shoot biomass yield means of 0.09 Kg in the *Striga* plots, which was comparatively very low to yield means of 0.17 Kg and 0.24 Kg realized in the respective genotypes under *Striga* free plots.

4.4.5. Grain yield

The realized grain yield means of sorghum genotypes evaluated under *Striga* and *Striga* free infestations as shown in Table 4.4.2 differed significantly ($P<0.001$) (Appendix 4). T53B had the highest grain yield mean of 2.47 t/ha under *Striga* infestation compared to the genotype's 3.57 t/ha obtained under *Striga* free plots. Similarly, Nyadundo 2 recorded a much lower grain yield mean of 0.57 t/ha under *Striga* infestation relative to the genotypes' mean grain yield of 1.7 t/ha obtained in the *Striga* free plots.

Table 4.4. 2: Mean agronomic performance of sorghum genotypes evaluated in Nyahera both under *Striga* infested and under *Striga* free plots during the long rains of March to June 2019.

	Plant heights (cm)		Dry biomass yield (Kg)		Grain yields t/ha	
Genotype	Height (S)	Height (NS)	Dry biomass (S)	Dry biomass (NS)	Yield (S)	Yield (NS)
T 53B	179^{cb}	271.7^{a}	0.18^{fdeh}	0.24^{j}	2.47^{a}	3.57^{a}
N57	199.3^{a}	256.7^{a}	$0.21^{fbdehcg}$	0.35^{cbd}	2.34^{ba}	2.83^{becd}
C26	170.3^{cbd}	201.0^{cbd}	0.28^{bdac}	0.38^{b}	2.3^{ba}	2.87^{bcd}
N68	184.0^{b}	266.7^{a}	$0.20^{fbdehcg}$	0.33^{ced}	2.23^{bac}	3.07^{bc}
IESV 92042-SH	176.0^{cb}	201.3^{cbd}	0.27^{bdec}	0.38^{b}	2.1^{bac}	2.90^{bcd}
IESV92038/2-SH	174.0^{cb}	202.7^{cb}	0.26^{fbdec}	0.44^{a}	2.1^{bac}	2.70^{fbecd}
Maseno 6	129.7^{fg}	202.7^{cb}	0.27^{fbdec}	0.37^{cb}	2.03^{bc}	2.57^{fgehd}
T 30B	166.0^{cd}	268.3^{a}	0.19^{fdehcg}	0.29^{fgeh}	2.0^{bdc}	3.17^{ba}
Uyoma 47 Brown	166.3^{cd}	206.7^{b}	0.33^{ba}	0.38^{b}	1.87^{edc}	2.37^{fgehi}
IESV 92036-SH	167.7^{cd}	203.0^{b}	0.42^{a}	0.44^{a}	1.87^{edc}	2.57^{fgehd}
Maseno 49	170.7^{cbd}	199.0^{cbd}	$0.23^{fbdehcg}$	0.31^{fged}	1.83^{edc}	2.17^{ghji}
Uyoma 47 white	174.3^{cb}	198.0^{cebd}	0.33^{ba}	0.45^{a}	1.83^{edc}	2.50^{fgehd}
N13	119.0^{g}	184.7^{cefd}	0.17^{fdehg}	0.29^{fgih}	1.60^{edf}	2.03^{ji}
Uyoma 42STR	142.0^{fe}	180.0^{ef}	0.25^{fbdecg}	0.35^{cbd}	1.27^{egf}	2.23^{fghi}
IESV92022/1-SH	156.3^{ed}	179.3^{f}	$0.20^{fbdehcg}$	0.28^{jfgih}	1.47^{egf}	2.63^{fgecd}
Muk60	139.7^{f}	184.3^{efd}	0.11^{hg}	0.31^{fed}	1.40^{gf}	2.27^{fghi}
E117B	116.3^{g}	171.3^{gf}	0.13^{fehg}	0.25^{jih}	1.07^{hg}	2.63^{fgecd}
Uyoma 6	139.7^{f}	160.3^{gh}	0.18^{fdehg}	0.27^{jgih}	0.87^{hi}	2.10^{hji}
Nyadundo 1	98.0^{h}	151.0^{h}	0.09^{h}	0.17^{k}	0.67^{hi}	2.27^{fghi}
Nyadundo 2	93.7^{h}	131.7^{i}	0.09^{h}	0.24^{ji}	0.57^{i}	1.7^{j}
Uyoma 8	140.7^{f}	212.0^{b}	0.13^{fhg}	0.38^{b}	0.54^{i}	2.2^{ghi}
Grand mean	152.50	201.54	0.21	0.32	1.65	2.54
CV	6.07	5.45	40.74	8.67	14.78	11.69
SEM	3.70	4.81	0.014	0.009	0.78	0.06
LSD (0.05)	15.27	18.09	0.14	0.05	0.40	0.49
P	***	***	***	***	***	***

Key: Means followed by the same letter(s) along the columns are not significantly different at $p<0.05$ lsd.Values in parenthesis are log-transformed {$log_{10}(X+1)$ values of Striga count.w.a.c.e: Weeks after crop emergence. CV: Coefficient of variation. LSD: Least significance difference
Yield(S)-Yield under Striga hermonthica infestation
Yield (NS)-Yield under Striga free infestation
W.a.c.e-Weeks after crop emergence
SEM: Standard error of the mean
****- Highly significant at ($P<0.001$, **-significant at $P<0.01$, *-Significant at $p<0.05$)*

4.4.6 Relative losses in plant height, dry shoot biomass yield, and grain yield due to *Striga hermonthica* infestation in sorghum genotypes evaluated at Nyahera in March 2019

The relative grain yield losses, which is the percentage difference in the agronomic performance of the genotypes evaluated under *Striga* and *Striga* free plots presented in Table 4.4.3 ranged between 16% to 75%. Uyoma 8 and E117B sorghum genotypes had the highest relative grain yield losses of 75% and 74% respectively while Maseno 49 (16%), N57 (17%), C 26 (20%), Uyoma 47 Brown (21%), and N13 (21%) genotypes had the lowest relative yield losses. Reductions in plant dry shoot biomass yields and plant heights also occurred in the genotypes due to *Striga* infestation. The highest reductions in plant shoot dry biomass yields were observed in the genotypes; Muk 60 (65%), Nyadundo 2 (63%), and Uyoma 8 (66%) while the lowest reductions of 5% and 13% were recorded respectively in IESV 92036-SH and Uyoma 47 Brown sorghum genotypes. In-plant heights, the highest and lowest reductions of 38 % and 12 % were respectively recorded in T30B and Uyoma 47 white sorghum genotypes.

Table 4.4. 3: Percentage relative yield losses of plant height, dry shoot biomass yield, and grain yield of sorghum genotypes evaluated under *Striga* infestation at Nyahera; March to June 2019 season

Genotype	Relative Yield Loss (%)		
	Plant height	Dry Shoot Biomass yield	Grain yield
Maseno 49	14	26	16
N57	22	40	17
C 26	15	26	20
N 13	36	41	21
Uyoma 47 Brown	20	13	21
Maseno 6	36	27	21
IESV92038/2-SH	14	40	22
N 68	31	39	27
Uyoma 47 white	12	27	27
IESV 92036-SH	17	5	27
IESV 92042-SH	13	29	28
T 53B	34	33	31
Muk60	24	65	38
T 30B	38	34	40
Uyoma 42STR	21	29	43
IESV92022/1-SH	13	29	44
Uyoma 6	13	33	59
Nyadundo 2	29	63	66
Nyadundo 1	35	47	70
E117B	32	48	74
Uyoma 8	34	66	75
Mean	23.95	36.19	37.45

4.4.7 General performance of genotypes under *Striga* infestation at Kadel and Nyahera

T53B, N 57, N 68, and T 30B genotypes had stable and high grain yield means ranging between 1.9-2.5 t/ha at Kadel (Table 4.3.2) and Nyahera (season 1; Table 4.1.2 and season 2; Table 4.4.2) under high *Striga hermonthica* infestation levels of 252-403 (Tables; 4.1.1,4.3.1 and 4.4.1). C 26, IESV 92036-SH and Uyoma 47 white were some of the genotypes with good yields above 1.85 t/ha under relatively low *Striga* infestations less than 200 *Striga* plants. Uyoma 8, Nyadundo 1, and Nyadundo 2 had poor yields less than 1 t/ha under high *Striga* infestations levels similar to T53B, N 57, N 68, and T 30B. Interaction effects between (Genotype*Environment), (Genotype*Season), and (season*Environment) were found to be significant (Appendix 5).

4.4.8 Correlation between *Striga* emergence, *Striga* damage ratings, and yield components and yield of sorghum genotypes evaluated at Kadel and Nyahera sites

Field *Striga* count and *Striga* damage ratings correlated negatively and significantly with plant height, dry shoot biomass yield, and grain yield in the two sites as shown in Table 4.4.4. However, a positive and significant correlation existed between field *Striga* count and *Striga* damage ratings.

Table 4.4. 4: Correlation between *Striga* count, *Striga* damage ratings and yield components, and yield of sorghum genotypes evaluated at Kadel and Nyahera sites

Season		*Striga* count (12 w.a.c.e)	SDR (12 w.a.c.e)
Nyahera short rains of Sept 2018	SDR (12 w.a.c.e)	.732**	_____
	Plant Height	-.253*	-.503**
	Dry shoot biomass	-.333**	-.487**
	Grain yield	-.425**	-.531**
Nyahera long rains of March 2019	SDR (12 w.a.c.e)	.597**	___
	Plant Height	-.291*	-.576**
	Dry shoot biomass	-.481**	-.363**
	Grain yield	-.411**	-.651**
Kadel long rains of March 2019	SDR (12 w.a.c.e)	.682**	____
	Plant Height	-.316*	-.659**
	Dry shoot biomass	-.276*	-.307*
	Grain yield	-.272*	-.631**

Key
SDR.Striga Damage Ratings
w.a.c.e.Weeks after crop emergence
***. Correlation is significant at the 0.01 level (2-tailed).*
**. Correlation is significant at the 0.05 level (2-tailed).*

4.5: Numbers of induced and maximum distance of germinated *Striga* seeds in the agar gel experiment

4.5.1: Mean numbers of induced germinated *Striga* seeds

The mean numbers of induced germinated *Striga* seeds which differed significantly ($p<001$) (Appendix 6) among the sorghum genotypes evaluated under *Striga* infestation are presented in Table 4.5.1. E 117B, T 30B, Uyoma 8, and Uyoma 42 STR induced more than 30 mean counts of germinated *Striga* seeds. E117B (35.67) and T30B (33.33) induced the highest invitro *Striga* seed germination which were significantly different at ($p<0.05$) (Table 4.5.1) with the lowest induced mean numbers of germinated *Striga* seeds in Uyoma 47 Brown (10.0), IESV 92038/2-SH (10.67), IESV 92036-SH (10.67) and the resistant check N13 (18.3). High numbers of induced germinated *Striga* seeds were also observed around the root periphery (Plate 1a) together with different developmental stages of the germinated *Striga* seeds in some of the sorghum genotypes. T53B for instance had a developing radicle (Plate 1b) while the presence of intrusive cell at the tip of the radicle was observed in E117B (Plate 1c) and even the establishment of a haustorium connection with Nyadundo 1 sorghum root (Plate 1d).

Plate 1a: Germinated *Striga* seeds around in Nyadundo 1 root periphery

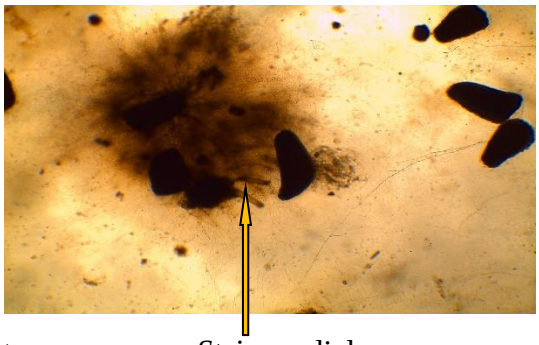
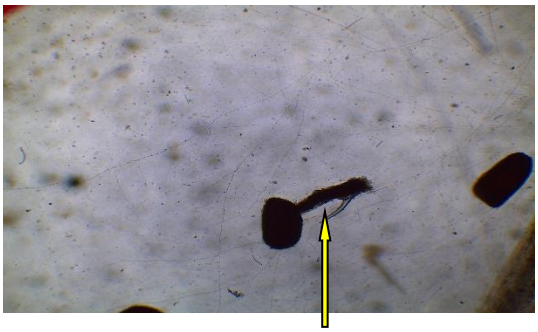


Plate 1b: Developing radicle in *Striga* seeds the gel of T53B sorghum genotype



Intrusive cell

Plate 1c: intrusive cell developing in *Striga* seed in The agar gel of E117B sorghum genotype

haustorium

Plate 1d: Haustorium establishment in Nyadundo1 sorghum root

4.5.2 Maximum germination distance (MGD)

The differences in the maximum distances of induced germinated *Striga* seeds among the sorghum genotypes evaluated in the agar gel experiment are presented in Table 4.5.1. E 117B and T 30B sorghum genotypes had the highest mean MGD of above 4 cm whereas Uyoma 47 Brown (1.5 cm) and C 26 (2.4 cm) had the lowest means which were significantly different at ($p<0.05$) (Table 4.5.1) with a mean MGD of 2.9 in N13 genotype.

Table 4.5. 1: Mean numbers of induced germinated *Striga* seeds and Maximum germination Distance (MGD) of sorghum genotypes evaluated in the Agar Gel experiment

Genotype	No. of induced germinated *Striga* seeds	MGD (cm)
E 117B	35.67^{a}	4.27^{a}
T 30B	33.33^{ba}	4.0^{ba}
Uyoma 8	31.0^{bc}	3.7^{bc}
Uyoma 42 STR	30.0^{bcd}	3.93^{ba}
T 53 B	28.67^{cd}	3.83^{bac}
N 57	28.33^{cd}	3.23^{ed}
N68	28.0^{ecd}	3.0^{edf}
Nyadundo 1	28.0^{ecd}	3.87^{ba}
Nyadundo 2	26.67^{ed}	3.87^{ba}
Maseno 49	24.0^{ef}	3.40^{dc}
Uyoma 47 white	21.67^{gf}	2.87^{ehgf}
IESV 92022/1-SH	19.67^{gh}	3.07^{edf}
N 13	18.33^{gh}	2.93^{egf}
Maseno 6	16.67^{ih}	2.77^{ihgf}
Muk 60	16.0^{ihj}	2.63^{ihgf}
Uyoma 6	15.67^{ihj}	2.47^{ih}
C 26	12.67^{ikj}	2.37^{i}
IESV 92042-SH	12.0^{kj}	2.43^{ih}
IESV 92036-SH	10.67^{k}	2.40^{i}
IESV 92038/2-SH	10.67^{k}	2.53^{ihg}
Uyoma 47 Brown	10.0^{k}	1.47^{j}
Mean	21.79	3.10
CV (%)	11.47	8.52
SEM	1.04	0.09
Lsd (0.05)	4.12	0.44
P	***	***

Key; Means followed by the same letter(s) along the columns are not significantly different at $p<0.05$ LSD; MGD: CV: Coefficient of variation; LSD: Least significance difference

4.5.3 Correlations between numbers of induced germinated *Striga* seeds, maximum germination distance, and number of field *Striga* plants in Kadel and Nyahera

A significant and positive correlation (Table 4.5.2) existed between maximum germination distance (MGD), numbers of induced germinated *Striga* seeds, and field *Striga* count in Kadel and Nyahera first season of field *Striga* evaluation. However, the correlation between MGD, numbers of induced germinated *Striga* seeds, and field *Striga* count in Nyahera second season (long rains of March 2019) of field evaluation was not significant.

Table 4.5. 2: Correlations between field *Striga* count, maximum germination distance, and number of induced germinated *Striga* seeds in agar gel experiment

	Kadel (Long rains, March 2019)		Nyahera Short rains (Sept 2018)		Nyahera long rains (March 2019)	
	(FSC)	MGD	(FSC)	MGD	(FSC)	MGD
MGD	0.739**	_____	0.711**	_____	0.172	_____
IGSC	0.832**	0.853**	0.766**	0.853**	0.055	0.853**

Key;
FSC: Field Striga Count
MGD: Maximum Germinated Distance
IGSC: Induced Germinated Striga Count

CHAPTER FIVE

DISCUSSION

5.1 Variations in field levels of *Striga hermonthica* weed infestation in Nyahera and Kadel

Striga infestation differed between Nyahera and Kadel sites (March 2019; season) and within the two seasons of September 2018 and March 2019 in field evaluation of genotypes at Nyahera (Appendix 2b). To minimize natural field *Striga* heterogeneity, the fields used in this study were carefully selected for homogeneity of *Striga* infestation, based on their history. Evaluation of sorghum genotypes at Kadel recorded a higher mean *Striga* count of 295.6 (Table 4.3.1) than 203.71 recorded at Nyahera (Table 4.4.1). 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 Kadel. This is because field *Striga* infestation levels have been found to strongly and positively correlate with soil *Striga* seed bank (Gasura *et al.* 2019). Moreover, Van Delft *et al.* (1997) have also demonstrated that the downward penetration of the newly shed *Striga* seeds was much greater in loose and very fine-textured soils typical of that of Kadel.

The significant total genotype × environment (G × E) variance (Appendix 5) that contains interaction effects between the genotypes and 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 sites' (Kadel; Table 4.3.1 and Nyahera; Table 4.4.1) field numbers of emerged *Striga* plants. This finding conforms with the findings of Haussmann *et al*. (2001) who investigated genotype × environment interaction patterns for *Striga* resistance in sorghum in Kenya and Mali and reported sites' differences in levels of *Striga* infestations to have been caused by genotypes' different response to climatic conditions.

Field evaluation of genotypes at Nyahera site during the long rains of March 2019 had a higher emerged *Striga* count of 203.7 (Table 4.4.1) than 196.7 recorded in the short rains of September 2018 (Table 4.1.1). The significant difference (p<.008) (Appendix 2b) in *Striga* count between the two seasons at Nyahera may be attributed to a possible additional input of *Striga* seeds in the soil following evaluation of sorghum genotypes in the same field during the short rains of September 2018. This finding agrees with that of Mbogo *et al.* (2016) who investigated *Striga* resistance in maize in the same field and reported the same *Striga* distribution trend within the two seasons.

5.2 Variations in the genotypes' field *Striga* infestation levels and *Striga* damage ratings

Sorghum genotypes such as Nyadundo 1, Uyoma 8, and Nyadundo 2 had higher *Striga* damage rating scores ranging between 3 and 4 which corresponded with high *Striga* infestation levels (Table 4.3.1, Table 4.1.1, and Table 4.4.1). N57, T53B, T30B, N68 genotypes, on the other hand, had relatively low SDR scores of 2 and therefore, were not affected even after supporting equally severe levels of *Striga* plants. Uyoma 47 Brown, IESV 92036-SH, and IESV 92038/2-SH also recorded low SDR scores less than 2 after supporting the growth of few *Striga* plants. The linear relationship between the genotypes' field *Striga* count and SDR (Table 4.4. 5) explains the observations made in (Nyadundo 1, Uyoma 8 and Nyadundo 2) and (Uyoma 47 Brown, IESV 92036-SH and IESV 92038/2-SH) with respect to both having high *Striga* counts and *Striga* damage ratings and vice versa. Contrary, N57, T53B, T30B, N68 sorghum genotypes had low SDR and even good yields after supporting the growth of many *Striga* plants. N57, T53B, T30B, and N68 sorghum genotypes probably had post-*Striga* defense reaction mechanisms such as lignified root cortex, hypersensitivity response, incompatibility response, and insensitivity to *Striga* toxins. The mechanisms that maintained normal physiological functions such as

absorption of water and nutrients from the soil and rate of photosynthesis in host crop despite high *Striga* infestation levels as had been reported by Mutinda *et al*. (2018) and Tokuma and Patrick (2016) who respectively investigated post attachment and Pre-attachment resistance to *Striga* in open-pollinated maize and sorghum varieties.

The observed variations in the genotypes' field levels of *Striga* infestations at Kadel (Table 4.3.1) and Nyahera (Table 4.1.1 and Table 4.4.1) could have resulted due to the genotypes' differences in the amount of secreted strigolactones in response to significant differences in genotype × environment variance (Appendix 5) (Waters *et al*., 2017). Besides, the productions of strigolactones and *Striga* seed germination have been found to correlate positively (Dafaallah, 2020). Previous supporting studies by Mohemed *et al.* (2016) who evaluated sorghum genotypes for field resistance to *Striga* in relation to strigolactone secretion and Vurro *et al.* (2019) who studied the relationship between strigolactones and parasitic plants reported field levels of *Striga* infestation to be highly influenced by genetic variations in the produced quantity and quality of hosts' strigolactone.

5.3 Agronomic response of sorghum genotypes to *Striga* hermonthica infestation

The sorghum genotypes responded differently to *Striga* infestation in regards to plant height, dry shoot biomass yield, and grain yield at Kadel (Table 4.3.2) and Nyahera (Table 4.1.2 and 4.4.2). The differences in the agronomic performances among the sorghum genotypes under *Striga* infestation indicated the existence of a large genetic variation among the genotypes and probable differences in their response to *Striga* infestation. This was expected since the evaluated genotypes were obtained from different sources (ICRISAT, Maseno, and Rongo Universities). The resistance, tolerance, or susceptibility of sorghum genotypes to *Striga* infestation determined the genotypes' differences in yield components and yield under *Striga* infestation. N 57, T 53 B, and N 68 had

the tallest plant heights at Kadel (Table 4.3.2) and Nyahera (Table 4.1.2 and 4.4.2) while Nyadundo 1, Nyadundo 2, and Uyoma 8 exhibited the shortest plant heights with low dry shoot biomass yields.

In addition to differences in plant heights and dry shoot biomass yields under *Striga* infestation in the evaluated genotypes, T53B, N57, N 68, and T30B sorghum genotypes were highly infested with *Striga* at Kadel (Table 4.3.1) and Nyahera (season 1; Table 4.1.1 and season 2; Table 4.4.1) yet sustained high yields about 2 t/ha at Kadel (Table 4.3.2) and Nyahera (Table 4.1.2 and 4.4.2), and therefore, were considered as tolerant. C26, IESV 92036-SH and Uyoma 47 Brown sorghum genotypes on the other hand supported the growth of few *Striga* plants with high grain yield means above 1.85 t/ha hence were considered as resistant. Nyadundo 1, Nyadundo 2, and Uyoma 8 were the genotypes that were adversely affected under high *Striga* infestation as reflected in the genotypes' high SDR above 3 and very low grain yield less than 1 t/ha both at Kadel (Table 4.3.2) and Nyahera (Table 4.1.2 and 4.4.2) therefore, were considered as susceptible. The differences in the genotypes' grain yield, when evaluated either under high or low *Striga* infestation, could have resulted due to the varietal differences in *Striga* resistance mechanisms. T53B, N57, N 68, T30B C26, IESV 92036-SH, and Uyoma 47 Brown sorghum genotypes probably deployed either or both pre/post *Striga* resistance mechanisms whereas Nyadundo 1, Nyadundo 2, and Uyoma 8 failed to initiate any *Striga* resistance mechanisms.

These findings compare well with those of Dafaallah and Babiker (2019) who assessed the damage caused by *Striga hermonthica* on the performance of cereal hosts in Gadarif State in eastern Sudan and Frost *et al.* (1997) who studied the effect of *Striga hermonthica* on the growth and photosynthesis of CSH-1, a susceptible sorghum variety and Ochuti, a tolerant sorghum variety. Dafaallah and Babiker (2019) and Frost *et al.* (1997) both established that the susceptible sorghum

genotypes had significantly lower dry biomass yields and reduced plant heights compared to the tolerant genotypes. Similarly, Van *et al.* (2000) carried out a comparative study on the effect of *Striga* infestation on the sensitive and tolerant sorghum genotypes and reported low SDR scores, and relatively higher yields in the tolerant/resistant genotypes than in their susceptible counterparts. Uyoma 6 could be considered a sensitive sorghum genotype since it had low grain yield after supporting the growth of few *Striga* plants, an indication of lack of any *Striga* resistance mechanism. Similar results have been reported by Akaogu *et al*. (2013) who studied the response of maize inbred lines to *Striga hermionthica* and observed that the susceptible inbreds had poor grain yields despite supporting fewer numbers of emerged *Striga* plants than in the resistant inbred checks.

5.4 Relative grain yield, height, and dry shoot biomass losses due to *Striga* in the evaluated sorghum genotypes

Evaluation of sorghum genotypes under *Striga* and *Striga* free plots revealed great differences in the genotypes' agronomic performances. Generally, genotypes under *Striga* free plots recorded higher and significantly different ($p<0.001$) (Appendix 4) plant heights, dry shoot biomass yields, and grain yields than yields obtained in the same genotypes under *Striga* infestation (Table 4.4.2). Overall grain yield means of 2.54 t/ha and 1.65 t/ha were respectively realized in *Striga* free and *Striga* infested plots (Table 4.4.2) which translates into a 54 % yield loss. The yield loss showed that *Striga* weed significantly affected the performance of genotypes in the *Striga* hot spots. The sorghum genotypes that were least affected based on the percentage grain yield losses were; Maseno 49 (16 %,) N 57 (17%), C 26 (20 %,) and Maseno 6, Uyoma 47 Brown and N 13 all with a yield reduction of 21% (Table 4.4.3). Uyoma 8 (75%), E117B (74%), Nyadundo 1(70%), and Nyadundo 2 (66%) genotypes had the highest grain yield reductions. This explains the incurred

high grain yield losses in the sorghum growing regions of western Kenya owing to continued cultivation of susceptible local varieties. Showemimo and Kimbeng (2005) found similar results after evaluating sorghum genotypes under *Striga* and *Striga* free plots and reported respective high percentage grain yield reductions of 90%, 80%, and 60% in the susceptible sorghum genotypes NR-71150, NR-71182, and L-2123. Equally, plant height and dry shoot biomass yield under *Striga* free plots gave significantly ($p<0.001$) (Appendix 4) higher average means of 201.54 cm and 0.32 kg respectively compared to 152.50 cm for heights and 0.21 kg for dry biomass yield attained in *Striga* plots (Table 4.4.2). These findings are comparable with a report by Beyene and Egigu (2020) who studied the dual negative effect of *Striga hermonthica* on host sorghum and found great reductions in the shoot, root lengths as well as dry weights in the infested host compared to those under control treatment.

The observed reductions in growth and yield parameters of host sorghum under *Striga* infestation indicate the damage caused by *Striga* parasitism on its host which is consistent with those reported in earlier studies by Graves *et al.* (1990) and Gurney *et al.*(1995). Graves *et al.* (1990) studied the growth and carbon allocation in *Pennisetum typhoides* infected with *Striga hermonthica* and reported losses of 53% and 80% in dry stem weight and grain yield. Gurney *et al.* (1995) evaluated the parasitic effect of *Striga* on the rate of photosynthesis in sorghum and millet and reported an overall growth loss of 46% in sorghum and 31% in millet. Both Graves *et al.* (1990) and Gurney *et al.* (1995) concluded that withdrawal of host photoassimilates, allelopathy, and disruptions of host photosynthetic pathways were the major ways in which *Striga* affected their host physiology.

The parasitic effect of *Striga* on the yield components and yield of sorghum genotypes were computed in correlation studies, and the associations between (emerged *Striga* counts and *Striga*

damage ratings) with (plant height, plant dry shoot biomass yield, and grain yield) were found to be significant and negative (Table 4.4.4). The non-linear relationship between *Striga* count, SDR, and yield components and yield indicate the parasitic effect of *Striga* on its host linked to increased withdrawal of hosts' nutrient associated with additional numbers of *Striga* plants supported by the host plant. The findings of this study are comparable to the previous study in maize by Mbogo *et al*. (2016) who studied the effects of *Striga* on yield components and yield in maize hybrids and reported a negative and significant correlation between grain yield and *Striga* damage ratings.

5.5 Variability in the amount of secreted *Striga* seed germination stimulant in the sorghum genotypes

The differences exhibited in the maximum germination distances and numbers of induced germinated *Striga* seeds (Table 4.5.1) in the evaluated genotypes signify genotypic differences for secretion of strigolactones. Higher maximum germination distances together with higher numbers of induced germinated *Striga* seeds indicate higher amounts of secreted strigolactones in the sorghum genotypes and vice versa (Omanya *et al*., 2004; Mandumbu *et al*., 2018). In this experiment, E117B, T30B, Uyoma 8, and Uyoma 42STR induced more than 30 mean counts of in vitro germinated *Striga* seeds, which corresponded with high mean maximum germination distances between 3.7-4.3 cm (Table 4.5.1), thus represent a high stimulant-secreting group. The resistant and low stimulant secreting Uyoma 47 Brown (10), IESV 92038/2-SH (10.7), and IESV 92036-SH (10.7) sorghum genotypes, on the other hand, recorded the lowest mean numbers of induced germinated *Striga* seeds and distances (cm) of the furthest germinated *Striga* seeds of 1.5,2.5 and 2.4 respectively (Table 4.5.1). These findings compare well with that of Mohamed *et al.* (2010) who studied specific *Striga* resistance mechanisms in sorghum and reported maximum germination distances of 0.058 (SRN 39), 0.3 (Framida), 1.8 (Dobbs), and 2.1 (Serena) cm in the

resistant sorghum genotypes compared to 2.9cm (Shanqui-Red) and 2.8cm (IS4225.) in the susceptible varieties. It was also observed in the present study that the highest numbers of induced germinated *Striga* seeds were found around the roots' periphery (Plate 1a). This suggests increased concentrations of secreted *Striga* germination stimulant that was much closer to the roots. This finding conforms with that of Karaya *et al*. (2012) who studied variations in *Striga* germination stimulants produced in maize and noted that the closer the *Striga* seeds to the source of stimulant the higher were the number of seeds stimulated to germinate. Similarly, Hess *et al*. (1991) reported host's germination stimulant to be exuded and concentrated mainly in a distance closer to the radius of the root from the root apex. Yoneyama *et al.* (2010) also stated that only *Striga* seeds within the host rhizosphere are capable of germinating upon perception of root strigolactones.

The development of radicles in the germinated *Striga* seeds in the agar gels of T 53 B (Plate 1 b) and E 117 B (1 c) sorghum genotypes and establishment of haustorium connection with Nyadundo 1 sorghum root (Plate 1d) indicated secretion of a secondary metabolite in the genotypes' host root. The development and differentiation of radicle into a specialized structure, haustoria is dependent on a second host-derived signal, failure of which the seedling will die after four days (Fernández *et al.*, 2016). The establishment of haustorium connection with Nyadundo 1 sorghum root suggested that this variety failed to initiate a post-attachment hypersensitivity defense reaction mechanism to *Striga* hence it's susceptible to the weed.

The associations between maximum germination distance and numbers of induced germinated *Striga* seeds and field host-*Striga* infestation levels among the genotypes were computed in the correlation co-efficient study presented in Table 4.5.2. The data showed field *Striga* counts in Kadel and Nyahera site except for Nyahera's long rains of March 2019 to correlate positively, and significantly ($P < 0.001$) with both maximum germination distance and numbers of induced

germinated *Striga* seeds. This, therefore, signifies the role of strigolactones in influencing field-host *Striga* infestation levels. This finding is in agreement with those of Xie *et al*. (2008) who conducted a study on both agar gel experiment and field *Striga* trials and Hess *et al*. (1992) who analyzed and compared strigolactone levels under laboratory conditions and field *Striga* infection levels in the sorghum genotypes. Xie *et al*. (2008) established a close association between strigolactone levels analyzed and sorghum genotypes' field levels of *Striga* infection while Hess *et al*. (1992) reported lower field *Striga* infestation levels among the low stimulant-secreting group of genotypes. However, no significant correlation existed between maximum germination distance, numbers of induced germinated *Striga* seeds, and field *Striga* count in the long rains of March 2019 at Nyahera. This could have been caused by waterlogging of the soils three weeks into sowing which perhaps interfered with the germination response of the conditioned soil *Striga* seeds (Ayongwa *et al.*, 2011).

5.6 General discussion

The present study evaluated the response of sorghum genotypes in terms of plant height, dry biomass yield, and grain yield under field *Striga* infestation at Kadel and Nyahera. Site comparison of *Striga* infestation levels revealed Kadel to be highly infested with *Striga* than Nyahera in the same season of March 2019 probably due to a higher pre-existing soil *Striga* seed bank at Kadel. Additional factors such as significant GxE interactions that varied between the sites (Kadel) and Nyahera (Short rains of Sept 2018 and Long rains Of March 2019) could have also influenced the different *Striga* infestation levels between the seasons and sites. Generally, 53B, N57, T30B, and N 68 sorghum genotypes had consistently high grain yields in field evaluation at Kadel (March 2019) and Nyahera (short rains of Sept 2018 and long rains of March 2019) whereas Uyoma 8, Nyadundo 1 and Nyadundo 2 sorghum genotypes had very low yields under high *Striga*

infestation. C26, IESV 92036-SH, and Uyoma 47 Brown were the genotypes that had good yields under low *Striga* infestations. The difference in numbers of *Striga* plants supported by the sorghum genotypes could have resulted due to the genotypes' differences in the amount of secreted strigolactones as reflected in the respective genotypes' numbers of induced and maximum distance of germinated *Striga* seeds in the agar gel experiment.

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

6.1: Conclusions

This study obtained significant variations among the genotypes in response to *Striga* infestations both under field and laboratory conditions. *Striga* weed significantly reduced sorghum performance in terms of plant height, dry shoot mass, and grain yield with susceptible genotypes suffering severe losses and recording higher *Striga* damage ratings. This study has identified four *Striga* tolerant (T53B, N57, N68, and T30 B) and three *Striga* resistant (C26, IESV 92036-SH, and Uyoma 47 Brown,) sorghum genotypes based on both field and laboratory *Striga* screening techniques. The identified genotypes can be used directly by farmers to improve their yields in *Striga* prone areas or for further breeding

6.2: Recommendations and suggestions for further research

This study recommends evaluation of the identified resistant and tolerant sorghum genotypes in more *Striga* hot spots environments and seasons to determine agronomic stability and suitability for commercial release. The study also recommends characterization and quantification of the germination stimulants secreted by the sorghum genotypes used in this study using ultra-performance liquid chromatography-tandem mass spectrometry as described by Sato *et al*., 2003

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APPENDICES

Appendix 1: Analysis of variance for *Striga* count, *Striga* damage ratings and yield components, and yield of sorghum genotypes evaluated at Nyahera during the short rains of September 2018

		Sum of Squares	Df	Mean Square	F	Sig.
Striga count (12 w.a.c.e)	Between Groups	569759.651	20	28487.983	13.278	.000
	Within Groups	90108.667	42	2145.444		
	Total	659868.317	62			
SDR (12 w.a.c.e)	Between Groups	38.317	20	1.916	10.058	.000
	Within Groups	8.000	42	.190		
	Total	46.317	62			
Plant height	Between Groups	45507.079	20	2275.354	29.845	.000
	Within Groups	3202.000	42	76.238		
	Total	48709.079	62			
DryBiomass	Between Groups	.577	20	.029	12.959	.000
	Within Groups	.093	42	.002		
	Total	.670	62			
Grain yield	Between Groups	16.469	20	.823	15.653	.000
	Within Groups	2.210	42	.053		
	Total	18.679	62			

Appendix 2a: Analysis of variance for *Striga* count, *Striga* damage ratings and yield components, and yield of sorghum genotypes evaluated at Kadel during the long rains of March 2019

		Sum of Squares	df	Mean Square	F	Sig.
Striga count (12 w.a.c.e)	Between Groups	882315.043	20	44115.752	21.784	.000
	Within Groups	83029.167	41	2025.102		
	Total	965344.210	61			
SDR3 (12 w.a.c.e)	Between Groups	38.194	20	1.910	19.574	.000
	Within Groups	4.000	41	.098		
	Total	42.194	61			
Height	Between Groups	44545.500	20	2227.275	35.692	.000
	Within Groups	2558.500	41	62.402		
	Total	47104.000	61			
Dry biomass yield	Between Groups	.515	20	.026	2.099	.022
	Within Groups	.503	41	.012		
	Total	1.019	61			
Grain yield	Between Groups	28.513	20	1.426	10.456	.000
	Within Groups	5.590	41	.136		
	Total	34.103	61			

Appendix 2b: Pairwise Comparisons for *Striga* emergence between seasons

Dependent Variable	(I) Season	(J) Season	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Striga count (12 w.a.c.e)	Kadel S2	Nyahera S1	.2102*	.01603	.000	.1785	.2419
		Nyahera S2	.1669*	.01603	.000	.1352	.1986
	Nyahera S1	Kadel S2	-.2102*	.01603	.000	-.2419	-.1785
		Nyahera S2	-.0433*	.01603	.008	-.0750	-.0115

Based on observed means.

The error term is Mean Square(Error) = 1573.894.S 1;Season1 and S2;season 2

**. The mean difference is significant at the .05 level.*

Appendix 3: Analysis of variance for *Striga* count, *Striga* damage ratings and yield components, and yield of sorghum genotypes evaluated at Nyahera during the long rains of March 2019

		Sum of Squares	Df	Mean Square	F	Sig.
Striga count (12 w.a.c.e)	Between Groups	396235.357	19	20854.492	9.690	.000
	Within Groups	92539.500	43	2152.081		
	Total	488774.857	62			
SDR (12 w.a.c.e)	Between Groups	30.603	19	1.611	14.841	.000
	Within Groups	4.667	43	.109		
	Total	35.270	62			
Plant height (*Striga* plots)	Between Groups	49356.913	19	2597.732	27.426	.000
	Within Groups	4072.833	43	94.717		
	Total	53429.746	62			
Plant height (*Striga* free-plots)	Between Groups	79812.317	19	4200.648	17.270	.000
	Within Groups	10459.333	43	243.240		
	Total	90271.651	62			
Dry biomass yield (*Striga* plots)	Between Groups	.425	19	.022	2.779	.003
	Within Groups	.346	43	.008		
	Total	.771	62			
Dry biomass yield (*Striga* free-plots)	Between Groups	.279	19	.015	17.406	.000
	Within Groups	.036	43	.001		
	Total	.315	62			
Grain yield (*Striga* plots)	Between Groups	21.122	19	1.112	17.738	.000
	Within Groups	2.695	43	.063		
	Total	23.817	62			
Grain yield (*Striga* free-plots)	Between Groups	10.596	19	.558	5.407	.000
	Within Groups	4.435	43	.103		
	Total	15.031	62			

Appendix 4: Paired test between yield and yield components of sorghum genotypes evaluated at Nyahera under *Striga* and *Striga* free plots

	Paired Differences				
	Mean	Std. Deviation	Std. Error Mean	Df	Sig. (2-tailed)
Pair 1 Yield (S) – Yield(NS)	-.88730	.48543	.06116	62	.000
Pair 2 Drybiomass(S) – Drybiomass (NS)	-.10849	.09603	.01210	62	.000
Pair 3 Height (S) – Height (NS)	-49.03175	26.48918	3.33732	62	.000

Key: (S): *Striga* plots

(NS) *Striga* free plots

Appendix 5: Analysis of variance for effects of environment and seasons

Effect		Value	F	Erro diff	Sig diff
Intercept	Pillai's Trace	1.000	148510.719[b]	125.000	.000
	Wilks' Lambda	.000	148510.719[b]	125.000	.000
	Hotelling's Trace	2376.172	148510.719[b]	125.000	.000
	Roy's Largest Root	2376.172	148510.719[b]	125.000	.000
Genotype	Pillai's Trace	1.416	15.285	252.000	.000
	Wilks' Lambda	.048	22.298[b]	250.000	.000
	Hotelling's Trace	10.179	31.555	248.000	.000
	Roy's Largest Root	9.117	57.435[c]	126.000	.000
Environment (Kadel and Nyahera)	Pillai's Trace	.747	37.584	252.000	.000
	Wilks' Lambda	.310	49.714[b]	250.000	.000
	Hotelling's Trace	2.038	63.181	248.000	.000
	Roy's Largest Root	1.943	122.385[c]	126.000	.000
Season	Pillai's Trace	.747	37.584	252.000	.000
	Wilks' Lambda	.310	49.714[b]	250.000	.000
	Hotelling's Trace	2.038	63.181	248.000	.000
	Roy's Largest Root	1.943	122.385[c]	126.000	.000
genotype*Environment	Pillai's Trace	.984	3.049	252.000	.000
	Wilks' Lambda	.231	3.379[b]	250.000	.000
	Hotelling's Trace	2.402	3.723	248.000	.000
	Roy's Largest Root	1.918	6.040[c]	126.000	.000
genotype * Season	Pillai's Trace	.984	3.049	252.000	.000
	Wilks' Lambda	.231	3.379[b]	250.000	.000
	Hotelling's Trace	2.402	3.723	248.000	.000
	Roy's Largest Root	1.918	6.040[c]	126.000	.000
Season * Environment	Pillai's Trace	.761	4.681	252.000	.000
	Wilks' Lambda	.214	16.132	250.000	.000
	Hotelling's Trace	3.122	5.988	248.000	.000
	Roy's Largest Root	1.732	6.040[c]	126.000	.000

Appendix 6: Analysis of variance for numbers of induced and maximum distance of the germinated *Striga* seed in Agar Gel experiment

		Sum of Squares	df	Mean Square	F	Sig.
Numbers Of induced germinated *Striga* seeds	Between Groups	3872.317	20	193.616	30.928	.000
	Within Groups	256.667	41	6.260		
	Total	4128.984	61			
Maximum distance of the germinated *Striga* seeds	Between Groups	29.450	20	1.473	21.874	.000
	Within Groups	2.760	41	.067		
	Total	32.210	61			