CHAPTER ONE

INTRODUCTION

Maize (*Zea mays* L.) belongs to the family Poaceae, is one of the most important cereal crops in many developed and developing countries of the world. It was originated in America and first cultivated in the area of Mexico more than 7.000 years ago, and spread throughout North and South America (Hailare, 2000). It is extensively grown in temperate, subtropical and tropical regions and grown principally during the summer season in the world. Maize production in the world ranked as the third major cereal crop after (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) (Zamir *et al*., 2013). It is an important source of carbohydrates, protein, Iron, Vitamin B and minerals. These crops also serve as sources of income to small and large scale farmers in developing countries (Ahmed and Yusuf, 2007). Maize has the highest numbers of ways it can be used, with all parts of the plant finding economic value. The grain, cob, stalk, leaves and tassel can all be used to produce a large variety of food and non-food products It is used as forage and in the manufacture of livestock feed, food stuffs, sweeteners, beverage and industrial alcohol, and oil (Moyin-Jesu, 2010).

In developing countries including Sudan maize is a major source of income to many farmers. Moreover, the possibility of blending maize with wheat for bread making has also increased the demand of maize in Sudan (Ali *et al*., 2009). Therefore, farmers are encouraged to incorporate the crop into the farming systems under both irrigated and rain fed agriculture. Maize is a promising cereal crop in Sudan with the potential usefulness for both human beings and livestock (Salih *et al*., 2008). It ranks the fourth important cereal crop in Sudan after sorghum, wheat and pearl millet. The crop is less popular as food; hence it received intention as potential food crop. Maize was growth as rain fed crop,

mainly in the Nubba Mountains, southern Blue Nile and southern Darfur. It's also produced in the irrigated areas as a winter crop, and food in the Northern and River Nile states. In Sudan grain yield of maize is very low compared to other growing countries, the demand for maize is increasing due to the increasing poultry production, establishments of many poultry and dairy plants (Salih *et al.*, 2008). Abuali *et al*. (2011) reported that, in the Sudan, the total cultivated area of maize increased from 17000 hectares in 1971 to 37000 hectares in 2010 and the average grain yield of maize (1.9 T/ha). Work on maize improvement in Sudan is limited and only three cultivars have been released. These are Var.113, a selection from local material; Giza 2 and Mogtama 45 (Salva *et al.,* 2016*).* Most of the local varieties in the Sudan are named after locations where they are commonly grown (Meseka, 2000). Some of these local varieties include Dallenge (in Nuba Mountains), Sennar and Damazin (in Sennar and Southern Blue Nile States) (Meseka and Ishaaq, 2012).

Weed infestation is potential problem to realize higher yield of maize around the global. Weed not only decrease crop yield but also harbor insects, pest and diseases in some cases. They serve as on alternate host for these pests. Among weed, parasitic weed of the genus *Striga* (Orobanchaceae) strongly affect host crops such as maize, sorghum (*Sorghum bicolar* (L.) Moench), pearl millet (*Pennisetum glaucum* (L.), rice and cowpea (*Vigna unguiculata* L. Walp) as a consequence, these weeds are important growth reducing factors in crops in vast areas of the Savannah zone in Africa (Parker, and Riches, 1993).

S.hermonthica infests about 40% of the arable land and causes between 30 and 100% loss of maize yield in East Africa (Khan *et al.,* 2001; Gressel *et al.*, 2004). The actual Striga infested area is estimated at 44 million hectares worldwide (Mignouna *et al*., 2013). However, the percentage yield loss depends on a number of factors included *Striga* density, host species, land use system, soil nutrient status and rainfall patterns (Atera *et al*., 2012). *S.hermonthica*

reduces yields by competing for water, nutrients, space, light and photosynthesis with the host plants. Seed bank density is an important aspect that determines the amount of damage that the *S. hermonthica* causes on its crop hosts.

There are several methods that are used or have been tried to control *Striga* infestation in maize included use of cultural and mechanical control practices, nitrogen fertilizers, push pull technology, biological control practices, resistant host crops, use of herbicides and integrated Striga control methods (Teka, 2014; Avedi *et al*., 2014). Furthermore, the selection of good variety is a necessary requirement for successful crop production in line with strength growth, and yield. The use of *Striga* tolerant or resistant varieties of maize can be an effective way of reducing *Striga* damage, reduces labor and time needed for physical control, helps in environmental preservation and reduces production cost. Development of resistant maize genotypes is further complicated by the existence of biotypes and the presence of three different and economically important Striga species in Africa that infest maize and the potential buildup of the parasite where tolerant maize lines are used.

The use of genotypes that support reduced *S. hermonthica* emergence can form an important basis for developing resistant cultivars. The objectives of this study were designed to i) study the effect of maize root exudates on *Striga* germination ii) determine the effect of maize residues on *Striga* and to iii) evaluate the response of various local maize cultivars to *Striga* infestation.

CHAPTER TWO

LITERATURE REVIEW

2.1. Maize

Maize and also called corn is a coarse annual grass belonging to the large and important family Poaceae and it is edible grain. The crop is a native to the Americas (Gordon and Thottapilly, 2003) where nearly one-half of the total world production is done. It is believed to have originated in Southern Mexico and Central America because of the great diversity of the native forms found in cultivated fields in those regions (Lorroki, 2009). Maize crop is characterized by its wide adaptability to the different ranges of growing conditions, it is grown at latitudes varying from equator to slightly north and south of latitude 50°, from sea level to over 3000 meters elevation, under heavy rainfall to semi-arid conditions and cool to very hot climates. Thus, it has gained adaptation and productivity in all continents through introductions and breeding. The cereal has two close wild relatives; *teosinte* and *tripsacum* (Lorroki, 2009).

Maize is the most widely-grown staple food crop in sub-Saharan Africa (SSA) occupying more than 33 million ha each year (FAOSTAT, 2015). The crop covers nearly 17% of the estimated 200 million ha cultivated land in SSA, and is produced in diverse production environments and consumed by people with varying food preferences and socio-economic backgrounds. More than 300 million people in SSA depend on maize as source of food and livelihood. Maize contains approximately 72% starch, 10% protein, and 4% fat, supplying an energy density of 365 Kcal/100 g and is grown throughout the world, with the United States, China, and Brazil being the top three maize-producing countries in the world, producing approximately 563 of the 717 million metric tons/year. Maize can be processed into a variety of food and industrial products, including

starch, sweeteners, oil, beverages, glue, industrial alcohol, and fuel ethanol (Ranum *et al*., 2014).

2.2. *Striga*:

Striga weed is commonly known as witch-weed or witches weed. It is a destructive root hemi-parasite that has devastated cereal production in Sub-Saharan Africa (SSA) (Runo *et al*., 2012). The genus is composed of 30 to 35 species and now classified in the family of Orobanchaceae although earlier authors placed it in Scrophulariaceae family (Gethi *et al*., 2005). Striga possibly originates from a region between the Semien Mountains of Ethiopia and the Nubian Hills of Sudan (Atera and Itoh, 2011). This region is also postulated to be the center of diversity for sorghum which is a major host species for several *Striga* species, including *S. hermonthica* and *S. asiatica*. The genus is most widespread in western Africa where it covers 64% (17 million hectares) of the cereal production area (Gressel *et al*., 2004). *Striga* genus includes the *S.hermonthica*, *S. asiatica*, *S. gesnerioides*, *S. aspera* and *S. forbesii* are *considered* to be most destructive to crops. Over 80 % of *Striga* species are found in Africa, while the rest occur in Asia (Westwood, 2009). According to Teka (2014), approximately 30 Striga species have been described and most parasitize grass species, but *S. gesnerioides* (Willd.) Vatke is the only *Striga* species that is virulent to dicocts.

Striga spp. are hemi-parasitic plants that parasitize the root systems of their hosts. *Striga hermonthica* is the most widely spread root parasitic weed among all species and parasitize cereal crops such as sorghum, maize, millet and rice (Atera and Itoh, 2011; Parker and Riches 1993). *S. hermonthica* is common throughout northern tropical Africa and extends from Ethiopia and Sudan to West Africa. It also extends from the western Arabian region southwards into Angola and Namibia (Gethi and Smith, 2004).

2.2.1. Life cycle of *Striga*

The life cycle of *S. hermonthica* is highly synchronized with that of its host and generally involves the stages of germination, attachment to host, haustoria formation, penetration, establishment of vascular connections, accumulation of nutrients, flowering and seed production (Plate 2.1) (Parker and Riches, 1993).

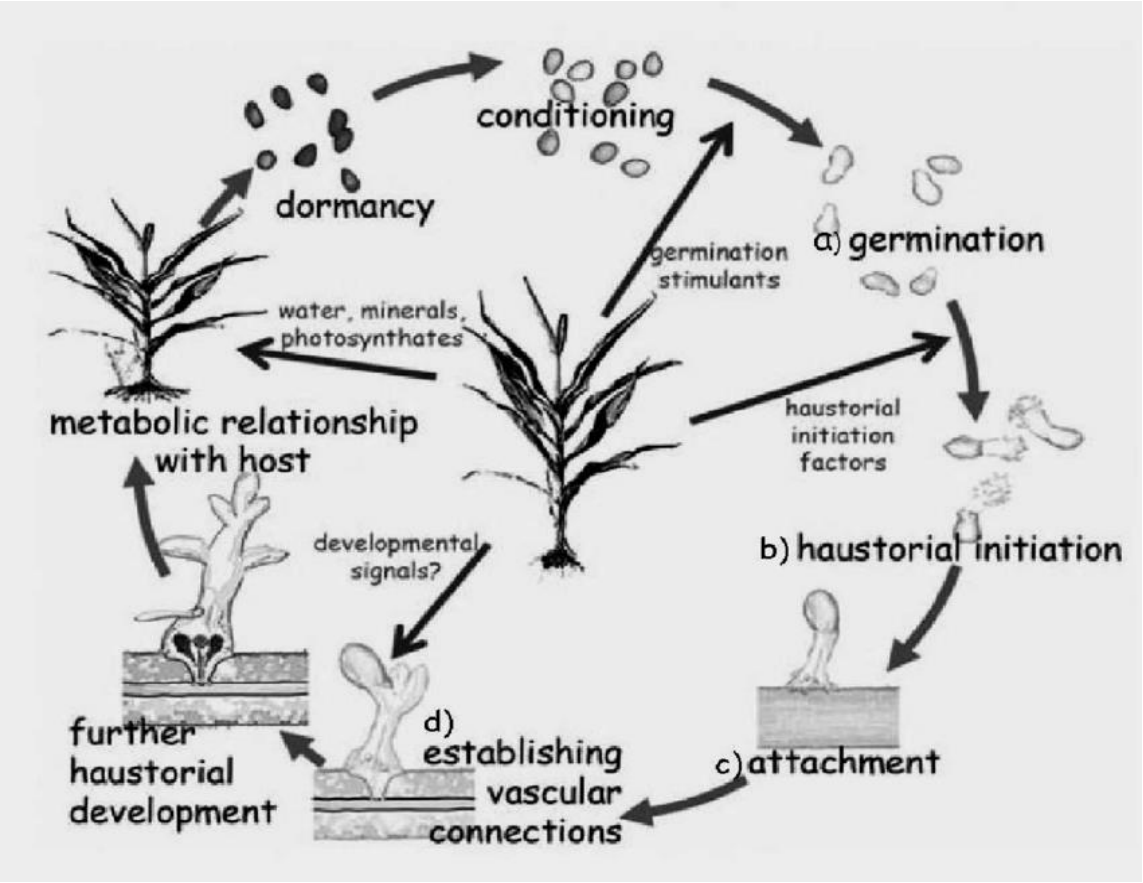

Plate 2.1. The Striga life-cycle. Adapted from Rich and Ejeta (2007).

Striga plants have green opposite leaves, bright irregular flowers with corolla tube slightly bent at the middle. The flowers are pink, red, white or yellow. There is a considerable variation in flower color. Striga seeds are minute, with the average seed size being 200µ wide and 300µ long (Koichi *et al*., 2010) and possess limited energy reserves compared to those produced by facultative parasites or free-living angiosperms. A single *Striga* plant can produce up to 10.000-500.000 dust like seeds that remain dormant in the soil for up to 20 years

(Koichi *et al*., 2010; Ma *et al*., 2004). The seeds are easy dispersed by wind, water, cattle, man and farm machinery. The seeds require a dormant after-ripening period of several months and exposure to moist and warm (22ºC to 35º C) conditions for 1 to 3 weeks before responding to a germination stimulant (Parker and Riches, 1993).

After conditioning Striga seeds only germinate in response to stimulants exuded by the host and non-host roots. A number of these stimulants have been reported by several authors (Garcia-Garrido *et al*., 2009; Matusova *et al*., 2005), but their nature and mechanism of action is not well understood. Strigol, a synthetic compound belonging to the strigolactones, was first isolated from cotton (*Gossypium* spp.) and is used as a germination trigger for *Striga* (Cardoso *et al*., 2011). Several germination stimulants have been isolated and include strigolactones, dihydrosorogoleone, sesquiterpene, kinetin, coumarin, jasmonate, ethylene and fungal metabolites (Cardoso *et al*., 2010).This germination stimulant mainly is exuded in a region 3 to 6 mm from the root apex (Hess *et al*., 1991). The germinating seed produces a root-like structure, the radicle. The radical tip grows chemotropically towards potential host roots after germination. On contact, St ؤriga radicals stop growing, attach to host roots, form a haustorium and penetrate into the root cortex of potential hosts *S.hermonthica* normally emerges about 4-7 weeks after planting maize, and the germinated seedlings attach to host's roots within 3-7 days. If not stimulated to germinate, seeds may stay dormant in the soil for over 20 years (De Groote *et al.*, 2007). The haustoria formation and subsequent attachment to the host is further guided by the host-derived chemical signals. After penetration to the cortex, haustoria cells undergo a differentiation process and form vessels that form a continuous bridge with the host xylem that serve as a conduit for host derived nutrients and water (Dorr, 1997). After a connection being established between host and parasite, the parasite exhibits a holoparasitic subterranean stage of development

at which time damage is inflicted. The parasite then emerges from the soil, develops chlorophyllous shoots (hemi-parasitic stage) and produces flowers and seeds. The Striga plant flowers 4week after emergence, after 4 more weeks the seeds are mature. The minimal length of the life cycle of the parasite, from germination to seed production comprises an average of 4 months
(Babiker, 2007).

2.2.2. Impact of *Striga* on the host*:*

Parasitic weeds of the genus *Striga* are considered to be the largest single biotic constraint to food production in Africa. *Striga* hinders the efforts to attain food security and economic growth in the continent. Nearly 300 million people in sub-Saharan Africa are adversely affected by *Striga* weed, and up to 50 million hectares of crop lands in the continent show varying degrees of *Striga* infestation (Ejeta, 2002*).*

Striga hermonthica constitutes a major biotic constraint to staple food production in Africa. They deprive water, nutrients and organic solutes from their host and further influence host physiology by causing depression of photosynthesis, as most obvious effect. Parasite induced reduction in host photosynthesis has been reported as the most important mechanism of growth reduction. Graves *et al*. (1989) estimated that 80% of the decrease in host growth rate can be attributed to the impact *Striga* has on host photosynthesis. The symptoms are however hard to distinguish from symptoms caused by drought, lack of nutrients and other diseases (Babiker, 2007). Symptoms displayed by infected hosts include stunting, reduction in internodes expansion, wilting, chlorosis, increased root: shoot ratio, reduced photosynthetic rate, increased photorespiration and decreased growth and yield (Parker and Riches, 1993; Gurney *et al*., 2000). It impairs normal host-plant growth, resulting in a large reduction in plant height, biomass, and eventual grain yield (Gurney *et al*., 1995). Its infection results in chlorosis, wilting, stunting, and death to the host, resulting to losses of up to

100% (Rich and Ejeta, 2007).Therefore, yield is reduced when crops are infested with *Striga* (Gurney *et al*., 2000). The most affected are subsistence farmers losing about 20–80% of their crop yield (Atera *et al*., 2011). *S.hermonthica* infests about 40% of the arable land and causes between 30 and 100% loss of maize yield in East Africa (Khan *et al*., 2001; Gressel *et al*., 2004).Yield losses associated with *Striga* spp infestation depends on a number of factors; Striga density, host species, land use system, soil nutrient status and rainfall patterns (Atera *et al*., 2012). Interestingly, by the time the parasite emerges from the soil, damage is already done to the host plant. The parasite is more damaging and debilitating under drought and low soil fertility conditions (Orr and Ritchie, 2004; Oswald, 2005). Some fields have become so badly infested with *Striga* that farmers are forced to abandon the field or grow other crops.

2.2.3. Methods of control

Single control strategies for management of Striga have not proven to effectively manage the weed and the use of a multiple integrated management approach for controlling Striga infestations has been commonly proposed. The weed can be managed using one or more methods included use of cultural and mechanical control practices, nitrogen fertilizers, push pull technology, biological control practices, resistant host crops, use of herbicides and integrated Striga control methods (Teka, 2014; Avedi *et al*., 2014). Effective *S. hermonthica* control technologies should target reducing the seed bank, limiting the production of new seeds and their spread from infested to non-infested soils, improving soil fertility and methods that healthy within the farmers' cropping system, all of which should result in good crop yield (Ejeta, 2007; Khan *et al*., 2006).

2.2.3.1. Cultural methods*:*

The cultural control practices are those Striga management procedures that farmers can easily carry out without necessarily applying chemicals. They

include practices like hand weeding, crop rotation, trap-cropping, timely planting and management of soil fertility.

2.2.3.1. 1. Hand weeding:

Hand-weeding is an effective method to control *Striga* especially in fields with a low infestation level. The removal of mature plants prevents the increase of the parasitic weed seed bank. However, when the parasite emerges from the soil, most of the damage to the host crop has already occurred. The method is however time consuming and labor intensive (Khan *et al*., 2003). *Striga* also continues to mature in the field after maize has been harvested (Woomer and Savala, 2008), which is a time when hand weeding is not done. This therefore leads to further flowering and shedding of seeds which increases the *Striga* seed soil bank. The optimum time for hand pulling of Striga is 2-3 weeks after flowering and repeating the operation at 3-4 weeks interval. New shoots may sprout out below the soil from infected plants requiring a second weeding before crop maturity. Uprooted Striga plants have to be removed from the field and dried and burned to minimize the risk of re infection (Derebe, 2018).

2.2.3.1. 2. Crop rotation:

Rotation with non-host crops interrupts further production of *Striga* seed and leads to decline in the seed population in the soil. It is a low cost technology and addresses the problem of low soil fertility and *Striga* infestation. The practical limitations of this technique are the more than 3 years required for rotation. Legume-maize rotation has been found to reduce *Striga* infestation by 35% after one year and by 76% after two years of legumes in the rotation (Kureh *et al*., 2006). Soybean was more effective in reducing *Striga* infestation and also gave higher maize grain yield than cowpea in Guinea savanna of Nigeria (Kureh *et al.*, 2006). Schulz *et al.* (2003) achieved 50% seed bank reduction after one year's rotation with soybean and cowpea under farmer-managed conditions. Carsky *et al*. (2000) reported that *S. hermonthica* incidence in maize after soybean,

compared to maize after sorghum, was significantly reduced from 3.2 to 1.3 emerged plants per maize plant, resulting in greatly improved grain yields.

2.2.3.1. 3. Trap and catch crops:

Another control approach, based on suicidal germination is the use of trap and catch crops in monoculture or in intercropping**.** Trap cropping to induce suicidal germination is one of the effective and low cost input options that farmers could use for *Striga* control. Trap crops offer the advantage of stimulating germination of *Striga* or other root parasites without themselves being parasitized. Most of the Striga trap crops being legumes (cowpea, pigionpea, and soybean) solve the twin problem of depleting of Striga seed bank and soil fertility (Parkinson *et al*., 1988). Effective trap crops include varieties of groundnut (*Arachis hypogaea*), soybean (*Glycine max*), cowpea (*Vigna unguiculata*) and sesame (*Sesamum indicum*) (Carsky *et al*., 2000; Dashiell *et al*., 2000; Hess and Dodo, 2003). Trap crops as a control technique should be included in the regular rotation and fallow management of infested fields and integrated with other control measures (Fernández-Aparicio *et al*., 2011).

Catch crops are true hosts that promote high rates of parasite germination and attachment and also sustain the parasite to maturity (Parker and Riches 1993). Seeding of the parasite is generally prevented by destroying the crop before any parasite seeds can be formed. Oswald *et al*. (1997) described the practice of sowing the *S. hermonthica* susceptible *Sorghum vulgare* Pers. var. sudanense (Piper) Hitchc. and then burning the field at the time of Striga emergence, thereby removing the chance of spread and reducing the seed population in the soil. The ideal situation would be an economically valuable crop that could be harvested as a green vegetable after the parasite has germinated and attached, but before the parasite has significantly impacted the crop (Fernández-Aparicio *et al*., 2011).

2.2.3.1. 4. Intercropping:

Intercropping is a predominant cropping system in Sub-Sahara African countries where it is used for maximizing use of limited farmlands, food security and improving soil fertility. Use of legume trap crops is an important low cost method for depletion of *Striga* seed bank in the soil. Legume crops like desmodium, cowpea and soybeans have been found to release exudates that induce germination of *Striga* but are themselves not parasitized (Aliyu and Emechebe, 2006). Intercropping of cereals with legumes such as green gram, cowpea, and groundnut may help to suppress *Striga* through suicidal germination. According Odhiambo *et al*. (2011) growing maize in association with soybean in the field resulted in lower *Striga* incidences, hence better growth and yield of associated maize. Khan *et al*. (2011) reported lower number of the weed population when maize and mungbean were planted simultaneously. Integrating these crops into cropping systems could reduce the *Striga* seed bank and improve soil fertility and livelihood of farmers. Intercropping maize and beans in the same hole had the highest grain yield, which was 78.6 % above the yield of pure maize stands due to the fact that beans is able to fix nitrogen which will improve maize yield (Odhiambo and Ariga, 2001). Intercropping cereal crops and legumes also increases the soil fertility and provides shade that gives *S. hermonthica* a disadvantage (Khan *et al*., 2006; Midega *et al*., 2013).

2.2.3.1. 5. Host Resistance or tolerant

The development of resistant and tolerant lines of susceptible crops constitutes an important, practical and reliable approach to controlling *Stri*ga. Resistance is the ability of the crop to prevent attack by the parasite while a tolerant variety is one that is attacked by parasitic weed to the same extent but suffers less damage than a standard variety (Parker and Riches, 1993). Host plant resistance is seen as the most promising method of *Striga* control especially in subsistence

agriculture (Elzein and Kroschel, 2003). The use of Striga resistant or tolerant varieties reduces labor and time needed for physical control, helps in environmental preservation and reduces production cost, unlike chemical control measures. Therefore, a combination of technologies is necessary for successful control of the weed.

Some crop varieties have been shown to resist Striga infestation through reduced production of the required germination stimulant (Olupot, 2011). Maize inbred sources with mature plant resistance to *S. hermonthica* were first discovered in 1983 at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria (Kim, 1991). Maize cultivars that show mature plant resistance to *Striga hermonthica* have been developed using these sources, and have shown stable performance in experimental stations and on-farm trials in West and Central Africa (Carsky *et al*., 1998; Lagoke *et al*., 1997).

Partial resistance to *Striga* has been exhibited by some maize varieties in Kenya, such as Katumani Maize Composite. Maize hybrid *Tzi-30* also has been reported to resist *S. hermonthica* infestation (Ransom *et al*., 1990). The development of crop plants with resistance to Striga has been limited because of the complexity of interactions between host, parasite, and the physical environment (Ejeta, 2007). *Striga* resistant cultivars of sorghum, maize and millet have been developed but none is yet available that can be applied in all the different ecological zones due to poor adaptation to wide range of a groecological zones (Parker and Riches, 1993). Different mechanisms of resistance to Striga have been suggested by various scientists. According to Mohamed *et al.* (2003) and Rich *et al.* (2004), some mechanisms of resistance to Striga involved mutant host plants with low germination stimulation and low haustorial induction, formation of necrotic lesions (hypersensitive reaction) when *Striga* first attaches, and incompatibility where by early post-attachment growth of the parasite is stopped or slowed. In a study by Ejeta (2007), the natural resistance available in a

primary sorghum gene pool was introduced into other agronomical important crop cultivars. Laboratory studies by Olupot (2011) showed that some of the new sorghum genotypes expressed both the low germination stimulant character and low haustoria initiation as mechanisms of resistance to *S. hermonthica* while others expressed either of the mechanisms.

2.2.3.1.6. Soil fertilization:

Low fertility of soil is considered to be an important factor associated with severe infestation of fields by weedy root parasites. Good soil management practices involving the use of crop residues, organic manure, and nitrogen or phosphorus application can contribute to an effective control of parasitic weeds (Jain and Foy, 1992; Etagegnehu and Rungsit, 2004).

Addition of nitrogen to the soil is generally considered to alleviate the effects of Striga and to lower the amount of Striga supported by the host (Mbwaga *et al*., 2001). Recent work, however, showed that nitrogen reduces stimulants production, however, its effect is genotype dependent therefore, does not reduce *Striga* incidence, but seems to neutralize the harmful effects of *Striga* without reducing the extent of parasitism. Further, both rate and timing of nitrogen application are important in maintaining roots and in reducing S. *hermonthica* germination in the field (Ayongwa *et al.*, 2006). Some nitrogenous compounds reduce the severity of *S. hermonthica* attack by direct suppression of *Striga* growth and development at the post-germination stage and after shoots have been formed. Mumera and Below (1993) recorded a 64% reduction in *S. hermonthica* emergence in maize using 39 kg N ha as calcium ammonium nitrate (CAN).

2.2.3.*2*. Chemical Control:

Various chemicals including herbicides, fumigants (e.g, methyl bromide) and germination stimulants (e.g, ethylene) have been reported as means of control of *Striga*. Management of Striga using chemical herbicides is large; pre and post-

emergence vegetative herbicides have been used, soil fumigants to destroy *Striga* seeds and synthetic compounds aimed at stimulating suicidal germination (Derebe, 2018). A number of herbicides are available for controlling pre-flowering *Striga* spp., but they are largely unavailable to smallholder farmers, mainly because of cost. A natural mutant of maize provides the maize with imidazolinone resistance (IR) (Kanampiu *et al*., 2003). Imidazolinones are highly effective and widely used herbicides having low toxicity, with an oral LD50 for rats of more than 5000 mg/kg, (i.e. immeasurable) (Gagne *et al*., 1991). Seed dressing of these IR-maize varieties with imazapyr, a systemic herbicide from that group, provides the plant with good protection from *Striga* infestation for several weeks after emerging, largely sufficient to ward off damage (Kanampiu *et al*., 2001). Seed-dressing of IR maize allows direct action on *S. hermonthica* seeds that are near the maize. When *S. hermonthica* plants attach themselves to the maize roots near coated seeds, they immediately die. Imazapyr that is not taken up by the maize seedlings diffuses into the surrounding soil and is absorbed by un-germinated dormant *S. hermonthica* seeds, killing them when they germinate upon stimulation. The maize remains *S. hermonthica* free for the first weeks after planting, and this considerably increases yield (Kanampiu *et al*., 2003).

2.2.3.3. Biological control:

Biological control is considered an attractive approach for suppressing parasitic weeds, especially using fungal antagonists against Striga, has gained considerable attention in recent years and appears to be promising as a viable supplement to other control methods. Many mycoherbicide candidates against Striga are still in the developmental stage, including evaluation of formulations and delivery (Schaub *et al.*, 2006). The genus of greatest interest for biological control is Smicronyx, an insect, of which several species are highly specific to *Striga*.

2.2.3.4. **Integrated *Striga* Management**:

Management of *Striga* using a single control method is less effective (Rebeka *et al*., 2013). A combination of several options can be efficient and economical with better control of Striga (Tesso *et al*., 2007). Franke *et al*. (2006) found that Integrated Striga control (ISC) that combined rotation of *Striga* resistant maize, trap crops and fertilizer application reduced the *Striga* soil seed bank by 46% and increased crop productivity by 88% while Kamara *et al*. (2008) showed that these practices reduced *Striga* infestation and damage on farmers' fields and increased productivity by more than 20%. Similarly, a report by (Kamara *et al*., 2009) showed that applying N fertilizer may not be feasible as a stand-alone solution to managing purple witch weed in cereals because of the high cost of fertilizer, but the combined use of N fertilizer and *Striga* tolerant / resistant maize and sorghum varieties has shown promise in the west African Savanas. An integrated management approach, if properly designed, using a combination of suitable control measures, has the potential to provide a lasting solution to Striga problems.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Experimental site:

A series of laboratory and green house experiments was undertaken at the College of Agricultural Studies (CAS), Sudan University of Science and Technology (SUST) at Shambat, Khartoum North, during the season (2019-2020) to evaluate the performance of various maize cultivars to infestation by *S. hermonthica*.

3.2. Experimental materials:

The seed of maize cultivars Hudeiba2 and Var113 was obtained from the Arab Sudanese Seeds Company (ASSCO). However, Sennar1 and Sennar2 (local cultivars) were obtained from the Agricultural Research Corporation (ABC), Wad-Medani, Sudan. *S. hermonthica* seeds (sorghum strain) was obtained from WRL, SUST.

3.3. Laboratory experiments:

The laboratory experiments were undertaken at (WRL) at the (CAS), (SUST) to study the effects of root exudates and residues of maize cultivars on *Striga* germination, radicle length and haustorium initiation.

3.3.1. Preparation of maize powder:

Maize cultivars grown in pots for two months in the greenhouse at the CAS, Shambat, subsequently the plants was cut at the ground level and severed into shoots and roots. The severed parts were dried at 104 ºC in oven for 48 hour. The sample collected pounded into powder using a household electric grinder and preserved in polythene bags and kept till used.

3.3.2. *Striga* seed conditioning:

Glass fiber filter papers (GFFP) discs (8mm diameter) were cut, moistened thoroughly with distilled water and placed in an oven set at 104 ºC for one hour to be sterilized previous to use. For pre-conditioning about 30-40 sterilized discs, placed in 9cm Petri dishes lined with a single sheet of glass fiber filter papers, were wetted with 5ml of distilled water. Consequently, 30-50, surface sterilized *Striga* seeds were added on each of the glass fiber discs. The Petri dishes closed with Parafilm to avoid moisture loss and covered with aluminum foil to provide absolute darkness. These were then placed in dark controlled growth chambers at 30 ºC, for 14 days**.**

3.3.3. Effect of maize root exudates on *Striga* germination

3.3.3.1. Growth conditions and root exudates collection

Maize seeds for each cultivar previously mention in 3.2, was surface-sterilized by immersion in 1% sodium hypochlorite obtained by dilution of the respective amount of commercial bleach solution (NaOCl), for 5min. Consequently the seeds were thoroughly washed with sterilized distilled water and then air dried in a laminar flow cabinet and stored at ambient temperature, till used.

Maize seeds surface disinfection seeds were germinated for 48h on moistened filter paper at 30°C in darkness. Subsequently, the seedlings were grown hydroponically in 50ml glass tubes containing 40% Long Ashton (LA) nutrient solution 40 in Biotron (Lighting) at 30°C: 28°C with 16 h: 8 h photoperiod and 70% humidity. The nutrient solution was completed to volume every 24h.The seedlings were removed from the hydroponics system after 2 weeks and the aqueous phase were collected and extracted with ethylacetate (3x100 ml)(liquid –liquid extraction).

3.3.3.2. Bioassay of root exudates of maize

Aliquots (10, 15, 20, 25µl) of each maize root exudates were applied to glass fiber discs and allowed to place for 2h in a laminar flow to ensure evaporation of ethylacetate. The treated discs were overlaid by discs containing conditioned of the *S. hermonthica* seeds. Each pair of discs was moistened with 40 µl sterilized distilled water. The seeds were re-incubated in the dark at 30°C for 48h. Germination, haustorium initiation and radicle length was examined after 48h.

3.3.4. Effects of maize residues on *Striga* germination

Sandwich method previously described by Fujii *et al*. (2004) was used to investigate the effects of maize powder (root and shoot) on *Striga* germination and haustorium initiation. Low nutrient agar medium (gelling temperature 30-31ºC, Nacalai Tesque, Kyoto, Japan) was prepared by adding 7.5g to 1000ml of distilled water and subsequent autoclaving at 15 bars and 121ºC for 15minutes. The autoclaved agar was allowed to cool at room temperature for one hour prior to use. Aliquots of the autoclaved agar (5ml each) were pipette into each well of a multi-well and allowed to solidify. Consequent to gelatinization samples of maize powder root or shoot (5, 10, 15, 20 and 25 mg) were added and another 5ml agar was appended to each well on top of the sample, and allowed to solidify. Glass fiber discs containing conditioned *Striga* seeds (4/well) were placed on top of the second agar layer. Controls without test samples were included for comparison. The multi-well-plates were sealed with Parafilm, covered with aluminum foil and incubated in the dark at 30ºC for 24 hour. The seeds were subsequently examined for germination and haustorium initiation using a binocular stereo-microscope. Seeds were considered germinated when the radicle protruded through the seed coat. Germination percentage (%) was calculated by dividing of germinated seeds with total seeds. Treatments were arranged in a Complete Randomized Design (CRD) with four replicates.

3.4. Greenhouse experiment:

3.4.1. Preparation of soil artificial infestation:

The experiment was conducted under artificial infestation of soil by *Striga* seeds. Two gram of *Striga* seeds was mixed with one Kilogram soil, and subsequently required infestation levels (8, 16 and 32mg/pot) were weighted. Plastic pots (13cm diameter) were filled by Shambat soil and subsequently known weights of *Striga* was added to the top 10cm of soil in each pot and thoroughly mixed by hand to achieve the required seed bank size per pot. Pots filled with Striga a free soil (0mg) were included as control for comparison.

3.4. 2.Cultural practices

Five seeds of maize from each cultivar were planted at 2cm soil depth. The pots were immediately irrigated. All pots were irrigated at 2-3 days intervals throughout the growing period. Two weeks after emergence, seedlings were thinned to maintain three plants per pot. Weeds were controlled by hand removal.

3.4.3. Experimental design:

The experiment was laid out as a Complete Randomized Block Design (CRBD), (two factors), with three replicates.

3.5. Data collection:

3.5.1. *Striga*

Data collected on *S. hermonthica* included:

3.5.1.1. Number of *Striga*/pot

Striga count was done every two weeks starting from the six week and ending at 12 week from planting.

3.5.1.2. *Striga* dry weight (g)

Striga plants was collected 100 days after maize sowing from each pot, sun dried and subsequently dry weight of Striga (g) determined.

3.5.2. Maize parameters

At 90 days after sowing, from the three plants for each pot, the following parameters were recorded.

3.5.2.1. Plant height (cm)

Plant height was taken from the first node to the apical bud of the main stem axis. Then the mean of the three plants was obtained in cm.

3.5.2.2. Number of leaves /plant

Number of leaves was counted from two plants for each pot and subsequent the mean was calculated.

3.5.2.3. Leaf area (cm^2)

The maximum length and width of the leaf at the fourth inter node was measured in each of the three tagged plant then leaf area (LA) was calculated by taking the leaf length multiplied by leaf width multiplied by 0.75.

The Leaf area was calculated as follow:

$$LA\ (cm)^2 = length \times width \times 0.75$$

3.5.2.4. Chlorophyll content

Average of SPAD readings at 3 points using a chlorophyll meter (SPAD-502, Konica Minolta Sensing, Japan) was recorded for each leaf

3.5.2.5. Maize dry weight (g).

At harvest, maize shoots were cut at ground level, air-dried and weighed.

3.6. Statistical analysis

The collected data were subjected to the analysis of variance (ANOVA) followed by a comparison of means with the least significant difference (LSD) at 5% probability level using the statistic 8 software package version 10.

CHAPTER FOUR

RESULTS

4.1. Laboratory experiments:

4.1.1. Effect of maize root exudates on *Striga:*

4.1.1. 1. Effect on *Striga* germination:

The results of analysis of variance showed that the *Striga* germination inducing activity various with maize cultivars and root exudates level**. (**Table 4.1) *Striga* seeds treated with distilled water displayed negligible germination in all experiment (Data not shown). Root exudates from Sennar2 induced variable and inconsistent *Striga* germination which showed no significant differences between exudates levels. Root exudates at 15µl displayed the highest *Striga* germination 27.5%, while at 20µl obtained the lowest germination 19.6% (Table 4.1). For Hudeiba2, *Striga* germination percentage showed slight non- significant increase with root exudates level. *Striga* seed treated with root exudates of Hudeiba2at 10, 15, 20 and 25µl displayed 13.9, 18.3, 21.6 and 30.3% germination, respectively (Table 4.1).

Root exudates from Var113at 10µl displayed 43.5% germination. Increasing levels to15, 20 and 25µl induced highest germination and reached to 68.2, 56.2 and 69.0%, respectively. At 10µl root exudates from Sennar1 induced little germination (2.7%). Increasing exudates level to 15 and 20µl showed a progressive increase in germination inducing activity reaching to 24.5 and 22.6%, respectively, and subsequently declined to 16.3% at 25µl (Table 4.1).

Among cultivars, root exudates from Var113 induced the highest germination 59.2%, while root exudates from Sennar2, Hudeiba2 and Sennar1 displayed comparable germination inducing activity which is significantly lower than that obtained from Var113. Across root exudates levels, *Striga* germination was

lowest at 10µl. Increasing root exudates level to 15, 20 and 25µl increased *Striga* seed germination significantly with no significant differences between individual treatments (Table 4.1).

Table 4.1. Effect of maize root exudates on *Striga* germination

Germination %					
	Root exudates level (µl) (L)				
Cultivars (C)	**10**	**1 5**	**20**	**25**	**Mean ©**
Sennar2	23.0	27.5	19.6	23.6	23.4 **b**
Hudeiba2	13.9	18.3	21.6	30.3	21.0 **b**
Var113	43.5	68.2	56.2	69.0	59.2 **a**
Sennar1	2.7	24.5	22.6	16.3	16.8 **b**
Mean(L)	20.8 **b**	34.9 **a**	30.0 **a**	34.8 **a**	
LSD ^{C}			8.9		
LSD L			8.9		
LSD $^{C\times L}$			17.9		
Two Way ANOVA					
Source			**F-Value**		
C			38.95***		
L			4.43**		
C×L			1.09 ns		

****=P≤0.01, ***=P≤0.001, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

4.1.1. 2. Effect on radicle length:

According to the statistical analysis it was clear that there were highly significant differences in *Striga* radicle length between maize cultivars, while no significant among root exudates levels. Root exudates from Var113 significantly showed the highest radicle length ($10.2\mu m \times 10^{-2}$), followed by descending order by Hudeiba2 and Sennar2 ($8.0\mu m \times 10^{-2}$). However, root exudates from Sennar1 sustained lowest radicle length (Table 4.2).

Root exudates from cultivars Sennar2 and Hudeiba2 at 10µl exhibited lowest radicle length ($6.4\mu m \times 10^{-2}$). Increasing level to 15µl or more displayed slight increased in radicle length (Table 4.2).

Root exudates from Var113 at the lowest root exudates level (10µl) displayed the largest radicle length. A further increase in root exudates level to 15µl or more resulted in non significant decreased in radicle length. The lowest level of root exudates from Sennar1 (10µl), sustained the lower radicle length. Increasing root exudates to 20µl, displayed further increased in radicle length significantly (Table 4.2).

4.1.1. 3. Effect on haustorium initiation:

Result of analysis of variance revealed that there were no significant differences in haustorium initiation between maize cultivars, root exudates level and their interaction (Table 4.3). As general, all cultivars produced little haustorium%. Root exudates from Var113 and Sennar1 exhibited comparable and highest haustorium initiation and displayed 12.5 and 12.9%, respectively. However, Sennar2 induced negligible haustorium formation (4.6%), irrespective to root exudates levels. Root exudates at 25µl from Sennar2 sustained the highest haustorium initiation 21.1% (Table 4.3).

Table 4.2. Effect of maize root exudates on radicle length

Radicle length					
Root exudates level (µl) (L)					
Cultivars (C)	**10**	**1 5**	**20**	**25**	**Mean ©**
Sennar2	6.4	7.9	9.5	8.3	8.0 **ab**
Hudeiba2	6.4	8.9	7.3	9.8	8.1 **ab**
Var113	11.1	10.9	10.3	8.6	10.2 **a**
Sennar1	5.0	6.5	8.3	6.8	6.6 **c**
Mean (L)	7.2 **a**	8.5 **ab**	8.8 **a**	8.3 **ab**	
LSD ^{C}	1.3				
LSD ^{L}	1.3				
LSD $^{C\times L}$	2.7				
Two Way ANOVA					
Source	**F-Value**				
C	10.02***				
L	2.17 ns				
C×L	1.94*				

***=P≤0.05, ***=P≤0.001, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

Table 4.3. Effect of maize root exudates on haustorium

Haustorium %					
Root exudates level (µl) (L)					
Cultivars (C)	**10**	**1 5**	**20**	**25**	**Mean ©**
Sennar2	3.1	5.4	3.6	6.3	4.6 **a**
Hudeiba2	12.5	8.8	7.8	3.7	8.1 **a**
Var113	17.8	12.7	11.1	8.6	12.5 **a**
Sennar1	0.0	15.0	15.6	21.1	12.9 **a**
Mean (L)	8.3 **a**	10.5 **a**	9.5 **a**	9.9 **a**	
LSD ^{C}	8.9				
LSD ^{L}	8.9				
LSD $^{C\times L}$	17.9				
Two Way ANOVA					
Source	**F-Value**				
C	1.59 ns				
L	0.08 ns				
C×L	0.92 ns				

ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.

4.1.2. Effects of maize residues on *Striga*

4.1.2. 1. Effects on *Striga* germination:

Maize residues powder, irrespective of cultivars or plant parts induced germination of *S .hermonthica* seeds. However, the response showed dependence on cultivars and amount of powder (Tables 4.4 and 4.5).

Germination response to shoot powder from Hudeiba2, at 5 and 10mg/well induced 23.9 and 18.2% germination, respectively. Germination further increased with increasing powder concentration, but not significantly. At 15-25 mg/well germination increased to 31.9-34.0%, respectively (Table 4.4). Var113 shoot powder at 15 and 20mg/well induced the highest germination 50.6 and 52.1%, respectively. However, at 10mg/well germination decreased significantly to 26.7% (Table 4.4). Sennar1 shoot powder at 5mg/well induced poor germination (< 20%). However, increasing shoot powder level to 25mg/well, increased germination to 32.9 %, but not significantly (Table 4.4). Shoot powder from Sennar2 showed a comparable trend to that of Sennar1. Sennar2 shoot powder at 5and 10 mg/well induced poor germination (< 20%). Increasing shoot powder to 25 mg/well increased germination, albeit not significantly (35.6%).

Across cultivars, shoot powder from Var113 significantly induced the highest germination (43.7%) followed in descending order by Sennar2 (28.0%), Hudeiba2 (26.9%) and Sennar1 (23.3%) (Table 4.4).

Germination inducing activity of maize root powder showed slight declined with increasing powder level (Table 4.5). Root powder of Hudeiba2 at 5mg/well displayed high germination inducing activity (62%). However, germination at 10 mg/well was 23.4 % displayed a sharp decline. Increasing powder level to 20 and 25 mg/well, resulted significant declined (Table 4.5). Root powder from Var113 at 5, 10, 15 and 20mg/well, induced comparable germination (44.2-56.7%) with non-significant difference between powder levels. A further increase in powder

level to 25mg/well resulted in a significant decline in germination (Table 4.5). For Sennar1 at 5mg/well root powder induced 37.8% germination. Increasing powder level to 10 and 15mg/well resulted in a slight non significant increase in germination (44.1-51.5%). On further increase of the powder to 20 and 25mg/well a gradual albeit non significant decline in germination inducing activity was observed (Table 4.5). Sennar2 at all levels of powder induced comparable germination 47.8-54.7%.

Among the cultivars tested, root powder from Sennar2 displayed the highest germination 52.3%, followed in descending order by Var113 49.3.0% and Sennar1 45.1%. However, Hudeiba2 induced the lowest germination 41.2 %.

Statistical analysis showed highly significant differences in *Striga* germination across the maize cultivars, maize parts (root and shoot), and showed significant differences between maize powder (Appendix 1). The result of combined analysis showed that, maize root residues significantly induced highest *Striga* germination 47.0%, while the shoot part sustained the lowest 30.4% (Appendix 2). Among the maize cultivars, Var113 gave the highest germination 46.5%, followed in descending order by powder from Sennar2 40.0%. However, powder from Hudeiba2 and Sennar1 induced comparable germination 34.1% (Appendix 2).

Table 4.4. Effect of shoot maize residues on *S. hermonthica* germination

	***Striga* germination%**					
	Powder level (mg)					
Cultivars C	**5**	**10**	**15**	**20**	**25**	**Mean ©**
Hudeiba2	23.9	18.2	31.9	26.5	34.0	**26.9 b**
Var113	45.7	26.7	50.6	52.1	43.6	**43.7 a**
Sennar1	19.0	21.7	20.8	21.9	32.9	**23.3 b**
Sennar2	18.9	19.4	25.3	39.8	35.6	**28.0 b**
Mean (PL)	**26.9 bc**	**21.5 c**	**32.1 ab**	**35.1 ab**	**36.5 a**	
LSD c	8.2					
LSD PL	9.1					
LSD C*PL	18.4					
	Tow-Way ANOVA					
Source	**F-Value**					
C	10.04***					
PL	3.74*					
C*PL	0.88**ns**					

***=P≤0.05, ***=P≤0.001, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

Table 4.5. Effect of root maize residues on *S. hermonthica* germination

	***Striga* germination%**					
	Powder level (mg) (PL)					
Cultivars (C)	**5**	**10**	**15**	**20**	**25**	**Mean ©**
Hudeiba2	62.0	23.4	51.9	31.0	37.9	**41.2 b**
Var113	55.6	44.2	53.2	56.7	36.9	**49.3 a**
Sennar1	37.9	44,1	51.5	45.5	46.7	**45.1 ab**
Sennar2	54.7	54.8	52.1	47.8	52.2	**52.3 a**
Mean (PL)	**52.5 a**	**41.6c**	**52.2 ab**	**45.3 abc**	**43.4 bc**	
LSD C	8.1					
LSD PL	9.0					
LSD C*PL	181					
	Tow-Way ANOVA					
Source	**F-Value**					
C	2.95*					
PL	2.57*					
C*PL	2.06*					

***=P≤0.05. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

4.1.2. 2. Effect on haustorium initiation

Germilings from seeds induced to germination by maize, irrespective of cultivars and plant parts showed poor pre-mature haustoria. Maize shoot powder at all levels induced comparable haustorium and the mean ranged between 14.9-23.3% (Table 4.6)

Hudeiba2 shoot powder at 5, 10 and 15 mg/well induced 15.1-21.8% haustorium initiation. A further increase in powder to 20 and 25 mg/well they increased haustorium initiation to 38.3 and 31.3%, respectively (Table 4.6). Var113 powder at 5 and 10 mg / well induced 15.1 and 23.5%, respectively, with no significant differences between treatments. Increasing amount of powder level to15mg/well or more resulted, negligible haustorium initiation (0-6.4%). Shoot powder from Sennar1 at 5mg/well induced 35.6% haustorium initiation. Increasing shoot powder to 10, 15, 20 and 25mg/well decreased haustorium formation to 19.5, 17.9, 16.2 and 10.0%, respectively. However, differences between treatments were not significant (Table 4.6). For Sennar2 powder at 5-25mg/well induced18.7- 27.8 % with no significant differences between treatments.

Among the cultivars studied Hudeiba2, Sennar1 and Sennar2 showed highest and comparable average haustorium initiation (19.8-25.5%), while Var113 sustained the lowest 9.5% (Table 4.6).

Maize root powder, showed negligible haustorium initiation, irrespective of crop cultivar and amount of powder (Table 4.7).

The result of combined analysis showed that maize root powder induced poor haustorium initiation 4.9%, as compared to shoot powder 19.5% (Appendix 2).

Table 4.6. Effect of shoot maize residues on haustorium initiation

	Haustorium%					
	Powder level (mg) (PL)					
Cultivars (c)	**5**	**10**	**15**	**20**	**25**	**Mean**
Hudeiba2	20.8	15.1	21.8	38.3	31.3	**25.5 a**
Var113	15.1	23.6	27.0	6.4	0.0	**9.5 b**
Sennar1	35.1	19.4	17.9	16.2	10.0	**19.8 a**
Sennar2	21.7	27.8	22.2	25.8	18.7	**23.2 a**
Mean (PL)	**23.3**	**21.5 a**	**16.1a**	**21.5 a**	**15.0 a**	
LSD ^{C}			10.1			
LSD ^{PL}			11.3			
LSD ^{C*PL}			22.5			
	Tow-Way ANOVA					
Source	**F-Value**					
C	3.99*					
PL	0.88**ns**					
C*PL	1.23**ns**					

***=P≤0.05, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

Table 4.7. Effect of root maize residues on haustorium initiation

	Haustorium%					
	Powder level (mg) (PL)					
Cultivars	**5**	**10**	**15**	**20**	**25**	**Mean ©**
Hudeiba2	10.6	2.4	0.0	8.7	2.5	**8.6 a**
Var113	10.8	1.9	4.4	5.9	2.8	**3.4 b**
Sennar1	6.3	0.0	13.3	1.7	2.2	**5.5 ab**
Sennar2	6.8	8.7	4.4	2.0	1.5	**5.2 b**
Mean (PL)	**8.6 a**	**4.8 a**	**5.5 ab**	**4.5 ab**	**3.6 a**	
LSD ^{C}			4.2			
LSD ^{Pl}			4.7			
LSD ^{C*Pl}			9.5			
	Tow-Way ANOVA					
Source	**F-Value**					
C	0.42**ns**					
PL	2.19*					
C*PL	1.08**ns**					

***=P≤0.05, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at**

4.2. Green house experiment:

4.2.1. Effects of maize cultivars on *S. hermonthica*

4.2.1.1. Effect on *Striga* emergence

The results showed that, *Striga* started to emergence 60 days after sowing (DAS)(Table 4.8). *Striga* count made after 90 DAS revealed that *S. hermonthica* emergence, irrespective of seed bank size, was influenced by maize cultivars. Among cultivars, Sennar2 significantly displayed the highest *Striga* emergence (3.0/pot), while Hudeiba2 and Var113 exhibited negligible *Striga* number. On Sennar1 no *Striga* emergence was observed at the all seedbank size (Table 4.8). At the lowest seed bank size (8mg /pot) Sennar2 showed a mean of 6.0 *Striga* plants/pot. Increasing seed bank size to 16 and 32 mg/pot significantly decreased *Striga* emergence to 1-2 plants/pot (Table 4.8). On Hudeiba2 and Var113, irrespective of seed bank size, the mean of *Striga* emergence ranged between 1-2 plant/pot and 0-1 plant/pot, respectively.

The results of statistical analysis showed that there were not significant differences in *Striga* number between seed bank size (Appendix 3). At seed bank size of 8, 16 and 32mg/pot, *Striga* emergence was 2.0, 0.8 and 0.8 plant/pot, respectively (Table 4.8).

4.2.1.2. Effect on *Striga* dry weight

The results of statistical analysis showed that there were highly significant differences in *Striga* dry weight between maize cultivars and also between *Striga* seed bank size (Appendix 3). Further within cultivars, Hudeiba2 exhibited the highest *Striga* dry weight (3.0 g), followed in descending order by Sennar2 (2.0 g) and Var113 (1.6 g).

In general, *Striga* dry weight progressively increased with seed bank size (Table 4.9). At 8 mg/pot, *Striga* dry weight on four cultivars was very low (0.0 -1.7 mg /pot). However, increasing *Striga* seed bank size to 16 mg/pot increased significantly the parasite dry weight to 2.1and 2.2g on Hudeiba2 and Var113,

respectively. At the highest seed bank size (32mg /pot) *Striga* dry weight increased significantly on Hudeiba2 (Table 4.9). However, on Var113 and Sennar2 increasing seed bank level to 32 mg/pot displayed slight increased in *Striga* dry weight, but not significantly (Table 4.9).

Table 4. 8. Effect of maize cultivars on *Striga* number

Number of *Striga*/ pot				
***Striga* seed bank size (mg)**				
Maize cultivars	**8**	**16**	**32**	**Mean ©**
Hudeiba2	2.0	1.0	1.0	1.3 b
Var113	0.0	0.3	1.0	0.4 b
Sennar 1	0.0	0.0	0.0	0.0 b
Sennar 2	6.0	2.0	1.0	3.0 a
Mean (Ssb)	2.0 a	0.8 a	0.8 a	
LSD cultivars (CV)		**2.0**		
LSD Striga seed bank (Ssb)		**1.6**		
LSD CV× Ssb		**3.3**		

Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%. *=P≤0.05; ns=not significant

Table 4. 9. Effect of maize cultivars on *Striga* dry weight

***Striga* dry weight (g)**				
***Striga* seed bank size (mg)**				
Maize cultivars	**8**	**16**	**32**	**Mean ©**
Hudeiba2	0.5	2.1	6.5	3.0 a
Var113	0.0	2.2	2.5	1.6 b
Sennar 1	0.0	0.0	0.0	0.0 c
Sennar 2	1.7	1.9	2.4	2.0 b
Mean (Ssb)	0.5 c	1.5 b	2.8 a	
LSD cultivars (CV)		**0.4**		
LSD Striga seed bank (Ssb)		**0.4**		
LSD CV× Ssb		**0.8**		

Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%. ns= not significant.

4.2.1.2. Effect of *Striga* seed bank size on maize cultivars

4.2.1.2. 1. Effect on plant height (cm)

The results of statistical analysis showed highly significant differences on plant height between maize cultivars. However, differences between individual seed bank size were not significant (Table 4.10). Across maize varieties, Sennar1 showed the highest plant height followed in descending order by Sennar 2 and Hudeiba2, while Var113 exhibited the lowest (Table 4.10). As general, all *Striga* levels reduced maize height (7.8-33.8%), albeit not significantly, as compared to un-infested control (Table 4.10).

The different cultivars displayed differential response to the parasite. In Hudeiba 2 and Sennar 2, *Strig*a at all levels did not reduce plant height, in comparison to the corresponding control. However, at seed bank size of 8, 16 and 32mg/pot, height of Var113 reduced, but not significantly. However, the observed reductions were considerable (36.7-46.7 %). In Sennar1 *Striga* seed bank size at 8 and 16mg/pot decreased maize height by 19.8 and 29.9%, respectively, as compared to the control (Table 4.10).

4.2.1.2. 2. Effect on number of leaves

Number of leaves varied significantly with cultivars (Table 4.11). Among the cultivars Sennar1 had the highest number of leaves, followed by Hudeiba2 and Sennar2, while Var113 had the lowest (Table 4.10). *Striga* at all seed bank size had no significant effect on number of leaves, in comparison to *Striga* free control (Table 4.11). The leaves number at all *Striga* seed bank size ranged between 6.3-7.2 leaf/plant.

Table 4. 10. Effect of *Striga* seed bank size on maize height

Plant height (cm)					
	Striga Seed bank Size (Ssb) (mg)				
Cultivars (C)	**0**	**8**	**16**	**32**	**Mean ©**
Hudeiba2	42.8	62.1	56.3	42.5	50.9 **b**
Var113	46.9	25.4	25.0	29.8	31.8 **c**
Sennar1	76.6	61.5	53.8	70.3	65.6 **a**
Sennar2	48.4	46.3	63.0	50.0	52.0 **ab**
Mean (Ssb)	53.7 **a**	48.8 **a**	49.5 **a**	48.1 **a**	
LSD ^{C}			14.4		
LSD ^{Ssb}			14.4		
LSD $^{C\times Ssb}$			28.7		
			Two Way ANOVA		
Source			**F-Value**		
C			7.81***		
Ssb			0.25 **ns**		
C×Ssb			1.13**ns**		

*****=P≤0.001, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

Table 4.11. Effect of *Striga* seed bank size on number of leaves

Number of leaves/plant					
	Striga Seed bank Size (mg)				
Cultivars (C)	**0**	**8**	**16**	**32**	**Mean ©**
Hudeiba2	5.8	7.0	6.3	8.3	6.8 **ab**
Var113	6.0	4.1	6.3	6.5	5.7 **b**
Sennar1	8.0	7.1	7.5	7.3	7.5 **a**
Sennar2	7.3	7.0	6.0	6.7	6.7 **ab**
Mean (Ssb)	6.7 **a**	6.3 **a**	6.5 **a**	7.2 **a**	
LSD ^{C}			1.3		
LSD ^{Ssb}			1.3		
LSD $^{C\times Ssb}$			2.5		
			Two Way ANOVA		
Source			**F-Value**		
C			2.81*		
Ssb			0.76 **ns**		
C×Ssb			0.99 **ns**		

***=P≤0.05, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

4.2.1.2. 3. Effect on leaf area

The result of statistical analysis showed that there were highly significant differences in leaf area between maize cultivars, while no significant across seed bank size and their interaction (Table 4.12). *Striga* at seed bank size of 8 and 32 mg/ pot reduced leaf area by 20.9 and 20.5 %, respectively, but not significantly, as compared to *Striga* free control (Table 4.12). In Var113, *Striga* at seed bank size of 8, 16 and 32 mg/ pot reduced leaf area by 44.1, 73.6 and 66.8%, respectively, as compared to the control. In Sennar1, at the lowest *Striga* seed bank size (8 mg/pot) leaf area was reduced by 52.0%. However, in Sennar2 did not show reduction in leaf area at all *Striga* seed bank size, in comparison to the un-infested control (Table 4.12). On Hudeiba2, Striga at 32mg/pot decreased leaf area significantly by 45.2%, as compared to *Striga* free control (Table 4.12).

4.2.1.2. 4. Effect on chlorophyll content

The results of statistical analysis revealed that, chlorophyll content with few exceptions progressively decreased with increasing seed bank size. *Striga* at 8 and 16 mg/pot, reduced chlorophyll content by 21.7 and 14.7%, respectively, but not significantly, to *Striga* free control (Table 4.13). However, increasing seed bank size to 32 mg/pot reduced chlorophyll content significantly, as compared to the control. However, the observed reduction was considerable 33.4%. Further within cultivars, Sennar1 exhibited the highest chlorophyll content followed in descending order by Hudeiba2. However, Sennar 2 and Var113 showed lowest and comparable chlorophyll content (Table 4.13).

Striga at seed bank size of 32mg/pot caused considerable reduction in chlorophyll content on Hudeiba 2, Var113, Sennar1 and Sennar 2 by 54.7, 26.7, 21.0 and 23.8%, respectively, as compared to the corresponding control (Table 4.13)**.**

Table 4.12. Effect of *Striga* seed bank size on leaf area

Leaf area (cm^2)					
	***Striga* Seed bank Size (mg)**				
Cultivars (C)	**0**	**8**	**16**	**32**	**Mean**
Hudeiba2	50.9	70.6	62.3	27.9	52.9 **b**
Var113	66.6	37.2	17.6	22.1	35.9 **b**
Sennar1	105.5	50.6	104.5	107.7	92.1 **a**
Sennar2	52.1	59.6	77.8	61.1	62.6 **ab**
Mean	68.8 **a**	54.5 **a**	65.5 **a**	54.7 **a**	
LSD ^{C}			29.4		
LSD ^{Ssb}			29.4		
LSD $^{C\times Ssb}$			58.8		
Two Way ANOVA					
Source			**F-Value**		
C			5.34*		
Ssb			0.52 **ns**		
C×Ssb			0.33 **ns**		

***=P≤0.05, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

Table 4.13. Effect of *Striga* seed bank size on Maize chlorophyll content

Chlorophyll content					
	***Striga* Seed bank Size (mg)**				
Cultivars (C)	**0**	**8**	**16**	**32**	**Mean**
Hudeiba 2	38.4	28.8	22.2	17.4	26.7 **a**b
Variety 113	24.3	14.1	20.5	17.8	19.2 **b**
Sennar1	35.1	30.0	33.8	27.7	31.7 **a**
Sennar 2	21.8	20.8	25.7	16.6	21.2 **b**
Mean	29.9 **a**	23.4 **ab**	25.5 **ab**	19.9 **b**	
LSD ^{C}			7.5		
LSD ^{Ssb}			7.5		
LSD $^{C\times Ssb}$			15.1		
Two Way ANOVA					
Source			**F-Value**		
C			4.65 **		
Ssb			2.56 *		
C×Ssb			0.69 **ns**		

***=P≤0.05, **=P≤0.01, ns= non significant. Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.**

4.2.1.2. 5. Effect on maize dry weight (g):

Result of statistical analysis revealed that maize dry weight was significantly different among cultivars (Table 4.14). Sennar1 cultivar gave significantly the highest dry weight (19.5 g), followed descending order by Hudeiba2 (11.5g), Sennar2 (9.7 g) and Var113 (5.3 g).

There were no significant differences among Striga seed size in this parameter. The average means of un-infested control displayed highest plant dry weight (15.3 g). At 8, 16 and 32mg/pot, the maize dry weight decreased by 29.4, 28.8 and 41.8%, but not significantly, as compared to the control. Interaction between cultivars and seed bank size was not significant (Table 4.14).

Table 4.14. Effect of *Striga* seed bank size on maize dry weight

Maize dry weight (g)					
	***Striga* seed bank size/ pot (mg)**				
Cultivars	**0**	**8**	**16**	**32**	**Mean ©**
Hudeiba2	14.0	16.0	10.5	5.5	11.5 b
Var113	12.7	4.2	1.2	3.0	5.3 b
Sennar1	27.7	15.0	18.3	17.0	19.5 a
Sennar2	6.8	8.0	13.8	10.3	9.7 b
Mean (Ssb)	15.3 a	10.8 a	10.9 a	8.9 a	
Two Way ANOVA					
Source	**F-Value**				
Cultivars (CV)	**5.22****				
Striga seed bank (Ssb)	**0.99 ns**				
CV× Ssb	**0.65 ns**				

Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%. **=P≤0.01; ns=not significant

CHAPTER FIVE

DISCUSSION

Striga hermonthica a root obligate hemi-parasitic weed is one of the biotic factors, that limits maize production and results in up to between 40% and 100% annual yield loss (Rich and Ejeta, 2008). There are several methods that are used or have been tried to control *Striga* infestation in maize. The development of resistant and tolerant lines of susceptible crops constitutes an important, practical and reliable approach to controlling *Striga*. Host plant resistance is an effective means to reduce the reproduction of the parasite (Esilaba, 2006).

The present study revealed that roots exudates of maize induced *Striga* germination depend on maize cultivars and root exudates level. Root exudates obtained from Var113 induced the highest germination 59.2%, while root exudates from Sennar2, Hudeiba2 and Sennar1 displayed comparable germination inducing activity which is significantly lower than that obtained from Var113 (Table 4.1). This suggests that quantity or activity of stimulant produced was lower. Crop species and genotypes within the same species have different abilities to induce germination of *Striga* due to the content of their root exudates (Traore *et al*., 2011). The results also showed that maize residues, irrespective of cultivars, plant parts and amount of powder, induced germination of *S. hermonthica* (Table 4.4). The result of combined analysis showed that, maize root residues significantly induced highest *Striga* germination (47.0%), while the shoot part sustained the lowest (30.4%), this may be attributed to accumulation of germination stimulants in the root of the host plant. *S. hermonthica* seeds only germinate in response to specific chemical stimulants (Strigolactones) that are present in the root exudates of the host (Graves *et al*., 1989; Dörr,1997; Joel *et al*., 2007; Amusan *et al*., 2008; Runo *et al*., 2012). The maize cultivars differed significantly ($P<0.001$) in their capacities to induce

germination of *Striga* (Tables 4.4 and 4.5). Cultivar Var113 gave the highest germination (46.5%), followed in descending order by powder from Sennar2 (40.0%). Powder from Hudeiba2 and Sennar1 induced comparable germination (34.1%). The difference between the cultivars may be related to differential stimulant production and differential stimulants contents of the respective powders.

The results of this study showed that, roots exudates from maize cultivars produced little haustorium (4-12.9%), and also germilings from seeds induced to germination by maize residues, irrespective of cultivars and plant parts showed fewer pre-mature haustoria (Tables 4.2, 4.6 and 4.7). The result of combined analysis showed that maize root powder induced less haustorium initiation (4.9%), as compared to shoot powder (19.5%). Olupot (2011) reported that sorghum genotypes were rated as producing low haustoria initiation signals hence possessing the low haustoria initiation trait as a mechanism of resistance to *Striga*. Absence of a haustorial induction compound in root exudates is unlikely to be a resistance mechanism in sorghum (Frick *et al*., 1996). Several host resistance mechanisms have also been suggested in the literature including low stimulant production by host plants, low production of the haustorial initiation factor, avoidance mechanisms, presence of physical barriers, hypersensitive response (HR) and antibiosis (Ejeta *et al*., 2000).

The results of greenhouse experiment revealed that *S. hermonthica* emerged from the soil 60 DAS. *Striga* count made after 90 DAS revealed that the number of *S. hermonthica* plants that infected maize plants was diverse between the cultivars. In general, maize cultivars support fewer emerged *Striga* plants. Sennar2 significantly displayed the highest *Striga* emergence (3.0 plants /pot). The cultivars Hudeiba2 and Var113 had the lowest *Striga* emergence. On Sennar1 no *Striga* emergence was observed at the all seed bank size. Similar results was obtained by Dinah (2015) who found that two maize cultivars

revealed striking differences in their ability to support growth and development of *S. hermonthica*. Ransom *et al*. (1990) also reported that the severity of infestation vary with genotypes. The difference between the cultivars may be related to differential stimulant production, or differential sensitivity of the parasite. The variability in *Striga* emergence, observed between the maize cultivars, could be related to a multitude of factors including differential stimulant production, differential compatibility between the host and the parasite or to failure of the host to sustain emergence of most of the attached parasite seedlings (Eltayeb, 2013).

The maize cultivars displayed differential response to the parasite. This finding is in agreement with the results obtained by Peter *et al*. (2016) who reported that all the hybrid evaluations under *S.hermonthica* infestation there were varietal differences in response to *S. hermonthica* damage. In Hudeiba2 and Sennar2, *Striga* at all seed bank size did not reduce plant height, in comparison to the control. However, on Var113 *Striga* at all seed bank size reduced height by (36.7-46.7 %). In Sennar1, *Striga* at seed bank size of 8 and 16mg/pot decreased maize height by 19.8 and 29.9%, respectively, as compared to the control. Previous experiments showed that infection of maize by *S. hermonthica* reduced shoot growth of the host, and increased the proportion of biomass and N in the roots (Aflakpui *et al*., 1998; 2002).Symptoms displayed by infected hosts include stunting and reduction in internodes expansion (Parker and Riches, 1993).

In Var113, *Striga* at all seed bank size reduced leaf area by 44.1-73.6%. In Sennar1, at the lowest *Striga* seed bank size (8mg/pot) leaf area was reduced by 52.0%. On Hudeiba2, at 32mg/pot the reduction in leaf area was reached 45.2%. The effect of *Striga* on maize growth, attributed to a common effect of *Striga* infection on cereals. One plant of *S. hermonthica* per host plant is estimated to cause approximately 5% loss of yield (Parker and Riches, 1993) and high

infestations can cause total crop failure. The damaging effect of *S. hermonthic*a on the host plant is not only from the direct loss of water, minerals, nitrogen and carbohydrate, but from a disturbance of the host photosynthetic efficiency and a profound change in the root/shoot balance of the host, leading to stimulation of the root system and stunting of the shoot (Mbwaga, 1996) The parasite seedlings remain subterranean for 6-8 weeks. During the subterranean period the parasite inflicts most of the damage on its host (Parker and Riches, 1993). Interestingly, by the time the parasite emerges from the soil, damage is already done to the host plant. *Striga* at seed bank size of 32mg/pot reduced chlorophyll content significantly by 33.4%, as compared to the control. Striga negatively affects host photosynthesis. Parasite induced reduction in host photosynthesis has been reported as the most important mechanism of growth reduction. Graves *et al*. (1989) estimated that 80% of the decrease in host growth rate can be attributed to the impact *Striga* has on host photosynthesis. Furthermore, *Striga* strongly affects the water economy of its host by its high transpiration rate and by reducing the stomatal conductance of the host plant (Grimanelli *et al*., 2000). They deprive water, nutrients and organic solutes from their host and further influence host physiology by causing depression of photosynthesis, as most obvious effect. Therefore, yield is reduced when crops are infested with *Striga* (Gurney *et al*., 2000). *Striga* at all seed bank size decreased maize dry weight by 28.8 - 41.8%. Graves *et al.* (1990) reported an 80% reduction in grain yield and a 53% reduction in stem dry weight in pearl millet (*Pennisetum typhoides*) infected with *S. hermonthica*.

The differences among the cultivars in the level of the damage could be due to differences in the level of resistance/tolerance of the maize cultivars studied.

Conclusions and Recommendations

Conclusions

After the study the following conclusions were made:-

i) Maize roots exudates and residues induced considerable germination and few haustorium initiation of *S. hermonthica.*

ii) Root exudates and residues from Var113 induced highest *Striga* germination, however Sennar1 obtained the lowest.

iii) Maize cultivars differed considerably in their support for *Striga* number.

iv) Maize cultivars support fewer emerged *Striga* plants.

v) Sennar2 displayed the highest *Striga* emergence, however, in Sennar1 no *Striga* emergence observed.

vi) The maize cultivars displayed differential response to the parasite

Recommendations

i) The greenhouse experiment should be repeated for another year, in summer and winter season with additional cultivars or hybrids to confirm the results.

REFERENCES

- Abuali, A.I., Abdelmula, A.A. and Khalafalla, M.M. (2011). Assessment of genetic diversity in Sudanese maize (*Zea mays* L.) genotypes using random amplified polymorphic DNA (RAPD) markers. African Journal of Biotechnology, ***10****(42): 8245-8250.*
- Ahmed B. I. and Yusuf, A. U. (2007). Host-plant resistance: A viable non - chemical and environmentally friendly strategy of controlling stored products pests-a review. *Emir. J. Food Agric*, **19**(1): 01-12
- Ali, M.A, Nazi. S., Abbes, A., Saber, W. and Jabbing, K. (2009). Genetic diversity and assessment of drought tolerance sorghum landraces based on morphological traits at different growth stages. *Plant Omits. J,* 2(**5**):214-227.
- Aliyu, B.S., and Emechebe, A.M. (2006). Effect of Intra row and Inter row mixing of Sorghum with two Varieties of Cowpea on Host Crop Yield in a *Striga hermonthica* Infested field. *African Journal Agricultural Research*, **1(2)**: 24-26.
- Aflakpui, G. K. S., Gregory, P. J. and Froud-Williams, R. J. (2002). Growth and biomass partitioning of maize during vegetative growth in response to *Striga hermonthica* infection and nitrogen supply. *Experimental Agriculture*,38:287–294
- Aflakpui, G. K. S., Gregory, P. J. and Froud-Williams, R. J. (1998). Uptake and partitioning of nitrogen by maize infected with Striga *hermonthica*. *Annals of Botany*, 81:287–294.
- Amusan, I.O., Rich, P.S., Menkir, A; Housley, T and Ejeta, G. (2008). Resistance to *Striga hermonthica* in a maize inbred line derived from *Zea diploperennis. New phytologyist*, **178**: 157-166.
- Atera, E. A., Itoh, K. and Onyango, J. C. (2011). Evaluation of ecologies and severity of Striga weed on rice in sub-Saharan Africa. *Agriculture and Biology Journal of North America*, 5: 752-760.

- Atera, E. and Itoh, K. (2011) Evaluation of ecologies and severity of Striga weed on rice in sub-Saharan Africa. *Agric. Biol. J*, **2**: 752-760.
- Atera, E.A., Azuma, T. and Ishii, T. (2012). Farmers‟ perspective on the biotic constraint of Striga hermonthica and its control in Western Kenya. *Weed Biology and Management*, **12**: 53-62.
- Avedi, E.K., Ochieno, D.M., Ajanga, S., Wanyama, C., Wainwright, H., Elzein, A. and Beed, F. (2014). *Fusarium oxysporum* f. sp. strigae strain Foxy 2 did not achieve biological control of *Striga hermonthica* parasitizing maize in Western Kenya. *Biological control*, **77**:7-14.
- Ayongwa, G.C., Stomph, T.J., Emechebe, A.M., and Kuyper, T.W. (2006). Root nitrogen concentration of sorghum above 2% produces least *Striga hermonthica* seed stimulation. *Ann. Appl.Biol*. **149**(3): 255-262. doi:10.1111/j.1744-7348.2006.00094.x
- Babiker, A.G.T. (2007). *Striga*: The spreading scourge in Africa. *The Japanese Society for Chemical Regulation of Plants*, **42**: 74-87.
- Cardoso, C., Ruyter-Spira, C. and Bouwmeester, H. J. (2010). Strigolactones and root infestation by plant-parasitic *Striga*, *Orobanche* and *Phelipanche spp*. *Plant Science*, **180**: 414-420.
- Cardoso, C., Ruyter-Spira, C. and Bouwmeester, H.J. (2011). Strigolactones and root infestation by plant-parasitic *Striga*, *Orobanche* and *Phelipanche* spp. *Plant Sci*ence, **180**:414-420.
- Carsky, R.J., Berner, D.K., Oyewole, B.D., Dashiell, K., Schulz, S. (2000).Reduction of *Striga hermonthica* parasitism on maize using soybean rotation. *International Journal of Pest Manag*ement, **46** (2): 115–120.
- Carsky, R.J., Nokoe, S., Lagoke, S.T.O. and Kim, S.K. (1998). Maize yield determinants in farmer-managed trials in the Nigerian northern Guinea savanna. *Experimental Agriculture*, **34**:407-422.
- Dashiell, K., di Umba, U., Kling, J.G., Melake-Berhan, A., Berner, D.K. (2000). Breeding for integrated management of *Striga hermonthica*. In: Haussman,

B.I.G., Hess, D.E., Koyama, M.L., Grivet, L., Rattunde, H.F.W., Geiger, H.H. (Eds.), *Breeding for Striga Resistance in Cereals*. Margraf Verlag, Weikersheim, Germany, pp. 273–281.

- De Groote, H., Wangare, L., Kanampiu, F., Odendo, M., Diallo, A., Karaya, H. and Friesen, D. (2007). The potential of herbicide resistant maize technology for Striga control in Africa. Elsevier. Kenya
- Derebe, B. (2018). Review the biology, ecology and management of Striga weed in Ethiopia.
- Dinah, K.K. (2015). *Histological and Molecular Developmental Mechanism of Striga Weed (Striga hermonthica) Parasitizing Maize (Zea mays)*. M.SC. Thesis. In: Biotechnology in the Jomo Kenyatta University of Agriculture and Technology, Kenya. pp103.
- Dörr, I. (1997). How *Striga* parasitizes its host. TEM and SEM study. *Annals of Botany*, 79:463-472.
- Eltayeb, R. A. (2013). *Development and Integration of Biocontrol products in Striga hermonthica (Del.) Benth management Strategy*. Ph.D. Thesis. In: Agronomy. Sudan University of Science and Technology, Sudan. pp 128.
- Elzein, A. and Kroschel, J. (2003). Progress on management of parasitic weeds. In: Labrada (Ed.). Weed Management in Developing Countries. FAO Plant Production and Protection Addendum I, Rome pp 109-143.
- Ejeta, G. (2007). Breeding for *S. hermonthica* resistance in Sorghum: exploitation of intricate host parasite biology. *Journal of Crop Science*, **47**:216-227.
- Ejeta, G. (2002). The *Striga* scourge in Africa: A growing pandemic, in: G. Ejeta, J. Gressel (Eds.), Integrating New Technologies for *Striga* Control, towards Ending the Witch-Hunt, World Scientific, Singapore, pp. 3-16.
- Ejeta, G., Mohammed, A., Rich, P., Melakeberhan, A., Housley, T. L. and Hess, D. E. (2000). Selection for mechanisms of resistance *to Striga* in sorghum. In Haussmann, B. I. G., Hess. D. E., Koyama, M. L., Grivent, l., Rattunde , H. F.W. and Geiger, H. H. (eds.). Breeding for *Striga* resistance in

ceraels. *Proc.* Of a workshop held at IITA., Ibadan, Nigeria. Margraf Verlag, Weilkersheim, Germany, **pp**. 29-37.

- Esilaba, A.O. (2006). Options for Striga management in Kenya, KARI Technical report no. 19, 2006. Nairobi, Kenya
- Etagegnehu, G.M., and Rungsit, S. (2004). Effect of nitrogen fertilizers on branched broomrape (*Orobanche ramosa* L.) in tomato (*Lycopersicon esculentum* Mill.). *Kasetsart J. Nat. Sci*, **38**: 311-319.
- Fernández-Aparicio, M., Yoneyama, K., and Rubiales, D. (2011). The role of strigolactones in host specificity of *Orobanche* and *Phelipanche* seed germination. *Seed Sci. Res*, **21**(01): 55–61. doi:10.1017/S0960258510000371
- Franke, A.C, Ellis-Jones, J., Tarawali, G., Schulz, S., Hussaini, M.A., Kureh, I., White, R., Chikoye, D., Douthwaite, B., Oyewole, B.D. and Olanrewaju, A.S. (2006). Evaluating and scaling-up integrated *Striga hermonthica* control technologies among farmers in northern Nigeria. *Crop Protection*, **25**:868-878.
- Frick, E., Frahne, D., Wegmann, K. (1996). Biochemical synthesis of 2,6-Dimethoxy-parabenzo-quinone -a haustorial stimulant of *Striga asiatica* (L.) Kuntze. Nat. Pod. Lett. 9, 1/53–1/59.
- Fujii, Y., Shibuya, T., Nakation, K., Tani, I., Hiradate, S and Mohamed, M. (2004). Assessment method for alleloPathic effect from leaf litter leachates. *Weed biology and management*, **4**:19-23.
- Garcia-Garrido, J.M., Lendzemo, V. Castellanos-Morales, V. Steinkellner, S. and Vierheilig, H. (2009). Strigolactones, signals for parasitic plants and *Arbuscular mycorrhizal* fungi. *Mycorrhiza* **19**(7): 449-459.
- Gethi, J.G. and Smith, M.E. (2004). Genetic responses of single crosses of maize to *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L.) Kuntze. *Crop Science*, **44**: 2068- 2077.
- Gethi, J.G., Smith, S.E., Mitchell, S.E. and Kresovich, S. (2005). Genetic diversity of *Striga hermonthica* and *Striga asiatica* population in Kenya. *Weed Research*, **45**: 64-73.

- Gordon, D.T and Thottapilly, G., (2003). Maize and sorghum in Gad Loebestein and George Thottapilly (eds). Virus and virus-like disease of major crops in developing countries. Kluwer Academic publishers pp 259-335.
- Graves, J. D., Wylde, A., Press, M. C and Stewart, G. R. (1990). Growth and carbon allocation in *Pennisetum typhoides* infected with the parasitic angiosperm *Striga hermonthica. Plant Cell Environment*, **13**: 367- 373.
- Graves, J.D., Press, M.C. and Stewart, G.R. (1989). A carbon balance model of the *Sorghum- Striga hermonthica* host – parasite association. *Plant, Cell and Environment*, **12**: 101-107.
- Gressel, J., Hanafi,A., Head, G, Marasas, W, Obilana, B., Ochanda, J., Souissi, T and Tzotzos, G. (2004). Major heretofore intractable biotic constraints to African food security that may be amenable to noval biotechnological solutions. *Crop Protection*, **23**: 661- 689.
- Grimanelli, D. F., Kanampiu, G., Odhiambo, P. M. Bogo, M.and Hoisinglon, D. (2000). Identification of genes for tolerance to *Striga* in maize using transposable elements. In: Haussmann, B. I. G. (ed.). *Breeding for Striga resistance in cereals*. Margrafverlag Weikersheim, Germany. pp 187.
- Gurney, A.L., Adcock, M., Scholes, J.D. and Press, M.C. (2000). Physiological processes during Striga infestation in maize and sorghum. In: Hausmann, B.I.G., D.E. Hess, M.L. Koyama, L. Grivet, H.F.W. Rattunde, H.H. Geiger (eds.): Breeding for Striga resistance in cereals. *Proceedings of a workshop held at IITA, Ibadan, Nigeria*. Margraf Verlag, Weikersheim, Germany, 3-17.
- Gurney, A.L., Press, M.C. and Ransom, J.K. (1995). The parasitic angiosperm *Striga hermonthica* can reduce photosynthesis of its sorghum and corn hosts in the field. *J Exp Bot*, ***46:***1817-1823.
- Hailare, L. (2000). Corn: An American Native. Spanning the Gap The newsletter of Delaware Water Gap National Recreation Area Vol. 22 No. 1 Spring 2000. U.S. Dept. of the Interior National Park Service

- Hess, D.E. and Dodo, H. (2003). Potential of sesame to contribute to integrated control of *Striga hermonthica* in the West African Sahel. Crop Protection, **23** (6):515–522.
- Hess, D.E., Ejeta, G. and Butler, L.G., (1991). Research into germination of *Striga* seeds by sorghum root exudates. In: *Proceedings of the Fifth International Symposium of Parasitic Weeds*. Eds J.K. Ransom, L.J. Musselman, A.D. Worsham, C. Parker, Nairobi, Kenya, CIMMYT, pp. 217-222.
- Jain, R., and Foy, C.L. (1992). Nutrient effects on parasitism and germination of Egyptian broomrape (*Orobanche aegyptiaca*).*Weed Technol*ogy, **6**: 269-275.
- Joel, D. M., Hershenhorn, Y., Eizenberg, R., Aly, R.., Ejeta, G., Rich, P., Ransom, J. K., Sauerborn, J. and Rubiales, D. (2007). Biology and Management of weedy root parasites. *Horticultural Reviews*, **33**: 267-349.
- Kamara, A.Y., Chikoye, D., Ekeleme, F., Omoiguil, O. and Dugje, I.Y (2008). Field performance of improved cowpea cultivars under natural infestation with *Striga gesneroides*. *International Journal of Pest Management*, **54**(3):189-195.
- Kamara, A.Y., Ekeleme, F., Menkir, A., Chikoye, D. and Omoigui, L.O. (2009). Influence of nitrogen fertilization on the performance of early and late maturing maize cultivars under natural infestation with *Striga hermonthica*. *Archives of Agronomy and Soil Science*, **55(**2):125-145.
- Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K. and Gressel, J. (2003). Multi-site, multi-season field tests demonstrate that herbicide seed-coating herbicide-resistance maize controls *Striga* spp. and increases yields in several African countries. *Crop Protection*, **22** (5): 697-706.
- Kanampiu, F.K., Ransom, J.K. and Gressel, J. (2001). Imazapyr seed dressings for Striga control on acetolactate synthase target-site resistant maize. *Crop Protection*, **20**: 885-895.

- Khan, M.A., Khan, A.N., Khan, R., Kalsoom, U. and Khan, M.A. (2011). Weed control efficiency of intercropping legumes in maize. *Pakistan Journal Weed Science Research*, **17(4)**: 303-312.
- Khan, Z.R., Midega, C.A.O., Hassanali, A., Pickett, J.A., Wadhams, L.J., Wanjoya, A. (2006). Management of witchweed, *Striga hermonthica*, and stem borers in sorghum, *Sorghum bicolor*, through intercropping with green leaf desmodium, *Desmodium intortum*. *Int. J. Pest Manag*, **52**: 297-302
- Khan, Z.R., Hassanali, A., Pickett, J.A., Wadhams, L.J. and Muyekho, F., (2003).Strategies for Control of Cereal stemborers and *Striga* weed in Maize-based Farming Systems in Eastern Africa involving 'Push- Pull' and allelopathic tactics, respectively, *African Crop Science Conference Proceedings*, Uganda, **6**:602-608.
- Khan, Z.R., Pickett, J.A., Wadhams, L.J and Muyekho, F. (2001). Habitat management strategies for the control of cereal stem borer and *Striga* in *Maize* in Kenya . *Insect Science* Appl, **21**:375-380.
- Kim, S.K., (1991). Breeding maize for *Striga* tolerance and the development of a field infestation technique. In: S.K. Kim (Ed.), Combating *Striga* in Africa. *Proceedings, International Workshop organized by IITA, ICRISAT, and IDRC*, Ibadan, Nigeria, pp. 96–108.
- Koichi, Y., Awad, A.A., Xiaonan, X., Kaori, Y. and Takeuchi, Y. (2010). Strigolactones as germination stimulants for root parasitic plants. *Plant Cell Physiology*, **51**(7): 1095-1103.
- Kureh, I., Kamara, A.Y., Tarfa, B.D., (2006). Influence of Cereal Legume Rotation on Striga Control and Maize Grain yield in farmer's field in Northern Guinea Savanna of Nigeria, *Journal of Agriculture and Rural Development in Tropics and Subtropics*, **107**(1): 41-54.
- Lagoke, S.T.O., Shebayan, J.Y., Carsky, R.T., Kim, S.K., Afolabi, T. and Jilly, K. (1997). On-farm evaluation of integrated *Striga* control packages in maize in the Nigerian savanna. In: B. Badu-Apraku, M.O. Akoroda, M. Ouedraogo and F.M. Quin (Eds.), Contributing

to Food Self-Sufficiency: Maize Research and Development in West and Central Africa. *Proceedings, Regional Maize Workshop*, Cotonou, Benin Republic. pp.291-311.

- Lorroki, P. (2009). Genetic analysis of resistance to maize streak virus among mid- altitude maize inbred lines.
- Ma, Y.Q., Cheng, J.M., Inanaga, S., and Shui, J.F. (2004). Induction and inhibition of *Striga hermothica* (Del.) Benth. germination by extracts of traditional Chinese medicinal herbs. *Agronomy Journal*, **96**:1349-1356.
- Matusova, R., Rani, K., Verstappen, F.W.A., Maurice, C.R. F., Beale, M.H. and Bouwmeester, H.J. (2005). The Strigolactone germination stimulants of the plant-parasitic *Striga* and *Orobanche* spp. are derived from the carotenoid pathway. *Plant Physiology*, **139**(2):920-934.
- Mbwaga, A. M., Massawe, C. R., Kaswende A. M. and Hella, P. (2001). *On-farm verification of maize-cowpea intercropping on the control of Striga under subsistence farming*. Seventh Eastern Africa regional *Maize* conference, pp 150-167.
- Meseka, S. and Ishaaq, J. (2012). Combining ability analysis among Sudanese and IITA maize germplasm at Gezira Research Station. *Journal of Applied Biosciences*, **57**:4189-4207.
- Meseka, S.K. (2000). Diallel Analysis for Combining Ability of Grain Yield and Yield Components in Maize (*Zea mays* L.) Landraces, 2000. M.Sc. Thesis in Plant Breeding and Genetics to the Faculty of Agricultural Sciences, University of Gezira, Sudan.
- Midega, CO., Pittchar, J., Salifu, D., Pickett, JA. and Khan, ZR. (2013). Effects of mulching, N-fertilization and intercropping with *Desmodium uncinatum* on *Striga hermonthica* infestation in maize, *Crop Protection*, **44**: 44-49.
- Mignouna, B.D., Abdoulaye, T., Kamara, A., and Oluoch, M., (2013). Baseline study of smallholder farmers in *Striga*-infested maize and cowpea-growing areas of northern Nigeria. International Institute of Tropical Agriculture, Ibadan,

Nigeria. Ministry of Agriculture., (2011). Field Technical Handbook, Vol:1 Food Crops. 60 pp.

- Mohamed, K.I., Bolin, L.J, Musselman, L.J. and Peterson, A.T. (2003). Genetic diversity of Striga and implications for control and modeling future distributions. *Integrated New Technologies for Striga*, **2**: 105-200.
- Moyin-Jesu, E. I. (2010). Comparative evaluation of modified neem leaf, wood ash and neem leaf extracts for seed treatment and pest control in maize (*Zea mays* L.). *Emir. J. Food Agric*, **22**(1): 37-45.
- Mumera, L.M and Below, F.E. (1993). Role of nitrogen in resistance to *Striga* parasitism of maize. *Crop Science*, **33**:758-763.
- Odhiambo, G.D. and Ariga, E.S. (2001). Effects of Intercropping Maize and Beans on *Striga* Incidence and Grain Yield, Seventh Eastern and Southern Africa Regional Maize Conference, pp 183- 186.
- Odhiambo, J.A., Vanlauwe, B., Tabu, I.M., Kanampu, F. and Khan, Z. (2011). Effect of Intercropping Maize and Soybeans on *Striga hermonthica* Parasitism and Yield of Maize, *Archives of Phytopathology and Plant Protection*, **44(2**): 158-167.
- Olupot, J. R. (2011). *Genetic Analysis of Striga hermonthica Resistance in Sorghum (Sorghum bicolor) Genotypes in Eastern Uganda*. Ph. D. Thesis in Plant breeding. University of KwaZulu-Natal, Pietermaritzburg-South Africa. pp132.
- Orr, A. and Ritchie, J.M. (2004). Learning from failure: smallholder farming systems and IPM in Malawi. *Agricultural Systems*, 79: 31-54.
- Oswald, A. (2005). Striga control-technologies and their dissemination. *Crop Protection*, **24**(4): 333-342
- Oswald, A., Abayo, A., Ransom, J.K., Kroschel, J., and Sauerborn, J. (1997). Catch-cropping with Sudan grass. An option to control Striga in subsistence agriculture. Brighton Crop Protection. *Conf.—Weeds*, **1**: 227-232.

- Parker, C and Riches, C. R. (1993). *Parasitic Weeds of the World: Biology and Control*. CAB International, Wallingford, Oxon, UK. pp**332.**
- Parkinson, V., Kim, S.K., Efron, Y., Bello, L., and Dashiel, K. (1988). Potential of Trap crops as a Cultural Measure of *Striga* Control in Africa. FAO Bulletin Number 96.
- Peter, O. M., Mathews, M .D and Barrack, O. (2016). Effect of *Striga hermonthica* (Del.) Benth on Yield and Yield Components of Maize (*Zea mays* L.) Hybrids in Western Kenya. *Journal of Agricultural Science*; Vol. 8, No. 8
- Pieterse, A. H. and Verkleij, J. A. AC. (1991). Effect of soil conditions on *Striga* development- A Review. In: Ransom J. K. Musselman, L. J., Worsham, A.D. and Parker, C. (eds).*Proceedings of the 5th International Symposium on Parasitic Weeds*. CIMMYT, Nairobi.pp 329-339

  pp 132.
- Ransom, J., Eplee, R. E., and Langston, M. A. (1990). Genetic variability for resistance to *Striga asiatica* in maize. *Cereal Research Communication*, **18**: 329-333.
- Ranum, P., Pena-Rosas., J.P., and Garcia-Casal, M.N. (2014). Global maize production, utilization, and consumption. *Annals of the New York Academy of Sciences,* **1312**: 105-112.
- Rebeka, G., Shimelis, H., Laing, M.D., Tongoona, P. and Mandefro, N. (2013). Evaluation of sorghum genotypes compatibility with *Fusarium oxysporum* under *Striga* infestation. *Crop Science,* **53**:385-393.
- Rich, P.J and Ejeta, G. (2008). Towards effective resistance to *S. hermonthica* in African maize. *Plant Signaling and Behavior,* 3:618-621.
- Rich, P.J. and Ejeta, G. (2007). Biology of host-parasite interactions in *Striga* species. In: *Integrating New Technologies for Striga Control: Towards Ending the Witch Hunt* (eds Ejeta G, Gressel J), World Scientific. pp. 3–16.
- Rich, P., Grenier, C. and Ejeta, G. (2004). Striga resistance in the wild relative of sorghum. *Crop science,* **44**: 2221-2229.

- Runo, S., Sarah, M., Alakonya, A., Machuka, J., Neelima, S. and Julie, S. (2012). *Striga hermonthica* parasitizes transgenic hairy roots of *Zea mays* and provides a tool for studying plant-plant interactions, *Plant Methods*, **8**:20.
- Runo, S., Alakonya, A., Machuka, J. and Neelima, S. (2011). RNA interference as a resistance mechanism against crop parasites in Africa: a 'Trojan horse' approach. *Pest Management Science*, **67**: 129-136.

- Salih, M.A., Ali, E. S., Babikir, E.A. and Ali, N.A. (2008). Effect of nitrogen source on yield and nitrogen use efficiency of two maize (*Zea mays* L.) varieties. *Journal of Agricultural Research*, **12**:11-22.
- Salva, G.M., Manute, C. G and Ismail, J. H. (2016). Performance of different maize *(Zea mays L.)* genotypes under field conditions. *African Journal of Agronomy*, **4(7**): 260-263.
- Schaub, B., Marley, P. and Kroschel, J. (2006). Field evaluation of an integrated *Striga hermontica* management in Sub-Saharan Africa: Synergy between Striga-mycoherbicides (biocontrol) and sorghum and maize resistant varieties. *Journal of Plant Diseases and Protection*, 691-699.
- Schulz, S., Hussaini, M.A., Kling, J.G., Berner, D.K. and Ikie, F.O. (2003). Evaluation of integrated *Striga hermonthica* control technologies under farmer management. *Experimental Agriculture*, **39**, 99-108.
  systems and IPM in Malawi. *Agricultural Systems*, 79: 31-54.
- Teka, H. B. (2014). Advance research on *Striga* control: A review Ethiopia Institute of Agriculture Research. *African Journal of Plant Science VOL.8* (**11**): 492-506.
- Tesso, T., Zenbaba, G., Aberra, D. and Ejeta, G. (2007). An integrated *Striga* management option offers effective control of *Striga* in Ethiopia. *In*: Ejeta G, Gressel J (eds). Integrating New Technologies for *Striga* Control: Towards Ending the Witch-hunt. World Scientific Publishing Co.,Singapore. P199-212.

- Traore, H., Yonli, D., Diallo, D. and Sereme, P. (2011). Suicidal Germination of *Striga hermonthica* (Del.) Benth. by Cotton. Cowpea and Groundnut Genotypes in Bukina Faso. *International Journal of Agricultural Research*, **6** (1): 49-57
- Westwood, J.H., John, I., Timko, M.P. and Claude, W. (2010). The evolution of parasitism in plants. *New Trends in Plant Science*, **15** (4): 227-235.
- Woomer, P.L and Savala, C.E.N., (2008). Striga Technology Extension Project (STEP): Long Rains 2008 Report. Forum for Organic Resource management and Agricultural Technology. Nairobi, Kenya.36 pp.
- Zamir, M.S.I., Yasin, G., Javeed, H.M.R., Ahmad, A.U.H., Tanveer A. and Yaseen M., (2013). Effect of different sowing techniques and mulches on the growth and yield behavior of spring planted maize (*Zea mays* L.). *Cercetări Agronomice în Moldova*, 1(**153**): 77-82.

APPENDICES

Appendix1. Three way ANOVA and F- values for *Striga* germination

Source of variation	*Striga* germination %
Maize cultivars (Mc)	8.75***
Plant parts (Pp)	68.54***
Powder level (Pl)	3.39*
Mc*Pp	4.52**
Mc*Pl	1.95*
Pp*Pl	3.03*
Mc*Pp*Pl	1.02ns

*=P<0.05, **=P<0.01, ***=P<0.001, ns=non-significant.

Appendix2. Means of combined analysis between shoot and root residues of maize cultivars

***Striga* germination%**			
Maize parts (MP)			
Cultivars ©	**Shoot**	**Root**	**Mean ©**
Hudeiba2	26.9	41.2	46.5 a
Var113	43.7	49.3	34.1 c
Sennar1	23.2	45.1	34.1 c
Sennar2	27.8	52.3	40.0 b
Mean (MP)	30.4 a	47.0 b	
LSD C	**5.6**		
LSD MP	**3.9**		
LSDC*MP	**7.9**		
Haustorium%			
Cultivars ©	**Shoot**	**Root**	**Mean ©**
Hudeiba2	25.5	4.8	15.1 a
Var113	9.5	5.2	7.4 b
Sennar1	19.8	5.9	12.9 a
Sennar2	23.2	3.6	13.4 a
Mean (MP)	19.5 a	4.9 b	
LSD C	**5.4**		
LSD MP	**3.8**		
LSDC*MP	**7.6**		

Means within a row or a column followed by the same letter(s) are not significantly different according to LSD at 5%.

Appendix3. Tow way ANOVA and F- values for *Striga*

Source of variation	Number of *Striga*	*Striga* dry weight
Maize cultivars (Mc)	4.05*	55.07***
Striga seed bank (Ssb)	2.07ns	62.14***
Mc*Ssb	1.55ns	24.35***

*=P<0.05, ***=P<0.001, ns=non-significant.