EVALUATION OF MAIZE (*Zea mays* L.) GENOTYPES with MULTIPLE RESISTANCE to *Striga hermonthica* (Del.) BENTH and *Striga asiatica* (L.) KUNTZE

By

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DECLARATION

I **KAUBI NAOMI HACHOLI** do hereby declare that this dissertation represents my own work and that to the best of my knowledge, it has not been previously submitted for the award of a degree at this or any other university.

Signed…………………………………………..

Date…………………………………………..

APPROVAL

The University of Zambia approves this dissertation of **KAUBI NAOMI HACHOLI** as fulfilling the requirements for the award of the degree of Master of Science in Agronomy (Plant Science).

Examiner   **Signature**   **Date**

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ABSTRACT

Striga asiatica is a noxious, obligate hemi-parasite of cereal grasses that causes grain yield losses in susceptible maize genotypes in Southern Africa. The development of host plant resistance is one of the most practical *Striga* control strategies. A study was carried out to identify genotypes that were resistant to *Striga asiatica*, and to investigate the mechanism of resistance of selected genotypes of maize to *Striga asiatica*. A total of 14 maize genotypes comprising of 12 developed by IITA with resistance to *Striga hermonthica* (causes grain yield losses in susceptible maize genotypes in West Africa) and two locally grown maize genotypes with unknown reaction to *Striga hermonthica* were assessed through field and laboratory experiments. The field experiment was conducted at Lundazi, Katete and at the UNZA field station during the 2013/14 farming season; while the laboratory experiment was conducted at the IITA biosciences laboratory. Grain yield, *Striga* Damage Rating (SDR) representing the reaction to *Striga* in the field, *Striga* count, plant height, cob length and cob diameter, days to 50% flowering and days to maturity were measured or derived from the field. Significant differences ($p<0.05$) were detected among the genotypes for grain yield with the highest yield being obtained from genotype 1113-13STR (8.68 T/ha) and the lowest for genotype 8338-1 (5.64 T/ha). Genotypes were not significantly different for SDR across locations. A highly significant and negative correlation was observed between grain yield and SDR ($r= -0.29^{**}$). A non-significant and negative correlation was also observed between grain yield and *Striga* counts at 14 weeks after planting (WAP) ($r= -0.056$). Positive correlations were observed between grain yield and cob diameter ($r= 0.908^{***}$), cob length ($r= 0.55^{***}$), days to 50% flowering ($r= 0.4^{***}$) and days to maturity ($r= 0.4^{***}$). A significant positive correlation for *Striga* counts was observed between sampling stage 10 WAP and 12 WAP ($r= 0.85^{***}$) and also between sampling stage 12 WAP and 14 WAP ($r= 0.93^{***}$). A negative correlation was observed between SDR and plant height ($r= -0.37^{***}$) Maize genotypes 1113-13STR, 1113-3STR and 1113-2STR were identified as the most resistant genotypes based on the fewer *Striga* numbers per plant produced, lower SDR scores (scores of 1-4) and were higher yielding. These genotypes also produced lower germination stimulants which did not favour *Striga* germination. The three genotypes can be used in the improvement of resistance to S. *asiatica* in maize genotypes.

I dedicate this piece of work to my children Vyane´ Jonathan Yangailo and Tebuho Justina Yangailo who brighten each day and give me the strength to work hard.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

AAFT	African Agricultural Foundation Technology
ANOVA	Analysis of variance
APHIS	Animal and Plant Health Inspection
a.s.l	Above sea level
CD	Cob diameter
CDFA	California Department of Food and Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CL	Cob length
CSO	Central Statistical Office
D50FLOW	Days to 50% flowering
DMAT	Days to maturity
FAO	Food and Agriculture Organization
FARA	Forum for Agricultural Research in Africa
FFS	Farmer Field School
GXE	genotype by environment
ICRISAT	International Crops Research Institute for Semi-Arid Tropic
IITA	International Institute of Tropical Agriculture
ISMA	Integrated *Striga* Management in Africa
IUPAC	International Union of Pure and Applied Chemistry
JAICAF	Japan Association for International Collaboration of Agriculture and Forestry
KARI	Kenya Agricultural Research Institute (replaced by Kenya Agricultural and Livestock Research Organization, KALRO)
Lgs	low germination stimulant
MAFF	Ministry Of Agriculture, Food And Fisheries
OPV	open pollinated variety

RPF	resource poor farmer
SDR	*Striga* damage rating
SH	small-holder
SSA	sub-saharan africa
UNZA	University of Zambia
USDA	United States Department of Agriculture
WAP	week after planting

CHAPTER ONE – INTRODUCTION

Maize (*Zea mays* L.) is one of the most important and strategic cereal crops in the developed world and Africa (FARA, 2009, IITA 2009). It is the most important crop in Sub- Saharan Africa, and one of the three most important cereal crops in the world, along with rice and wheat. It is the staple food in Zambia. Maize is high yielding, easy to process, readily digested, and cheaper to produce than other cereals. It is also a versatile crop; growing across a range of agro-ecological zones (IITA, 2014). Due to its increasing importance, maize has become a major staple and cash crop for small-holder (SH) farmers (IITA, 2009). It is a preferred staple for about 900 million consumers and plays an important role in nutrition of children. It is estimated that by 2025 maize will become the crop with the greatest production globally and in developing countries and by 2050, the demand for maize will have doubled (CIMMYT, 2010; IITA, 2010; FARA, 2009).

The United States of America is the major producer of maize the world over and this has been for over last five years. It produces 40% of the world's maize amounting to approximately 481.76 million tonnes per annum (O'Brien, 2011). According to a review by FAO (2011), Nigeria is the largest producer in Africa followed by South Africa which is the dominant producer of maize in the sub region accounting for 45 percent of the total production. Zambia is ranked third in the sub-region. In the 2012/13 farming season, Zambia produced 2, 532, 800 metric tonnes (CSO, 2014; (FAO, 2012). Among the provinces in Zambia, Eastern province is the largest maize producer, followed by Central and Southern provinces (CSO, 2014). JAICAF (2006) reported Southern province to be the second largest producer of maize. The rest of the provinces only register small amounts of production (CSO, 2014).

It has been reported that every part of the maize plant has economic value: the grain, leaves, stalk, tassel and the cob can all be used to produce a large variety of food and non-food products (IITA, 2009); Maize is used as livestock feed; it is an important source of carbohydrate, protein, iron, vitamin B, and minerals and is used to make porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled; playing an important role in filling the hunger gap after the dry season (du Plessis, 2003).

Maize production in Zambia faces various constraints due to both abiotic and biotic stresses (Siwale *et. al.,* 2008). Biotic stresses include diseases, insect pest and weeds (Shetto and Kwiligwa, 1990) with losses due to weeds alone accounting for 55 – 90 % (Gianessi and Williams, 2011). Weeds encompass all types of undesirable plants ranging from trees, herbs, sedges, aquatic and parasitic plants (Klingman *et. al.*, 1982). Akobundu (1987) defined a weed as a plant that interferes with human activity and/or welfare or because it occurs spontaneously in human disturbed habitat. Weeds can be harmful or beneficial. Some harmful weeds are parasitic. A parasitic plant is an angiosperm (flowering plant) that directly attaches itself to another plant via a haustorium (Nikrent and Musselman, 2004). Parasitic plants are found in thirteen angiosperm families and occupy a wide range of habitats. The problem of parasitic weeds is intensifying in the Sub-Saharan Africa (SSA) for several reasons. Key among them are the deteriorating soil fertility, shortening of the fallow period, expansion of production into marginal lands with little use of external inputs and the increasing trends towards continuous cultivation of monocultures in place of traditional rotation and intercropping systems (Singh and Emechebe, 1997). The most economically important parasitic plants belong to the families Scrophulariaceae and Orobanchaceae (Runo *et. al*., 2012). Witch weeds (*Striga* spp.) belonging to the family Scrophulariaceae are root parasites that cause serious economic losses in a range of host plants growing in poor soils especially those with low soil nitrogen (N) (Matata *et. al*., 2011; Vasudeva Rao, 1985; IITA, 2010) with *Striga hermonthica* and *Striga asiatica,* being the most important ones. *Striga hermonthica* is the largest among the agronomically important species and the most destructive of all *Striga* species (Mohammad and Musselman, 2006, Aigbokhan *et. al*., 2000). It poses a severe constraint to maize production in SSA (Karaya *et. al*., 2012) and is threatening cereal production in many areas. Losses of 100% in susceptible maize cultivars under severe infestation have been reported (Gurney *et. al*., 2003). Fortunately, there are some genotypes that have been developed and released that are resistant to *S. hermonthica.* The Bulletin, (2003) reported that farmers in Nigeria applauded the coming of the new genotypes which had brought a new dawn in their lives.

Striga asiatica, the next most important species is more common in Southern Africa and also causes considerable yield losses in maize production especially in resource poor farmers' fields (Matata *et. al*., 2011). *Striga asiatica* is an invasive species in Zambia and has caused severe yield losses in most parts of the country. This problem is being exacerbated by low

levels of N in most soils. Unfortunately, there are no genotypes that have been developed that are resistant to *S. asiatica* yet.

Economic losses due to *Striga* are enormous. Based on a wide range of experiments, Parker and Riches (1993), estimate that about 5% yield loss occurs for every *Striga* plant per m². Yield losses of 30-50% are common under typical field infestations and losses over a whole region may average 5-15%. In western Kenya, 100% yield losses have been reported in on-farm and on-station experimental plots (Hassan *et. al.*, 1994). All of the cultivated food-crop cereals (maize, sorghum, millets, wheat and upland rice) are parasitized by one or more *Striga* spp. Overall, *Striga* infests two-thirds of the arable land of Africa and constitutes the biggest single biological cause of crop damage in Africa in terms of grain yield loss, estimated at 40% and worth $US 7 billion (Runo *et. al.*, 2012) to $US 13 billion annually (Matata *et. al.*, 2011).

According to IITA (2010) under the Integrated *Striga* Management in Africa (ISMA) programme, methods in *Striga* control can be grouped in two broad categories, cultural and seed-based. Cultural control of *Striga* include crop rotation, intercropping, use of different planting techniques such as late or deep planting, and management of soil fertility. Seed-based technologies include germplasm based-*Striga* resistance, use of herbicide coated seeds, and biological control.

Breeding crop varieties that are resistant (prevents or limits *Striga* attachment or growth) or tolerant (variety still gives acceptable yields despite *Striga* attack) is the most widely spread seed-based and highly effective method (IITA, 2014). It is the most feasible and environmental friendly method for small-holder farmers to control *Striga*. It has been especially successful in sorghum where great advances have been made in understanding how the tolerance/resistance works through biotechnology and the knowledge used to develop *Striga* -tolerant sorghum varieties using marker-assisted breeding. Maize resistant and tolerant varieties to *S. hermonthica* have also been developed in Kenya and Nigeria using the same approach (IITA, 2014). However, good levels of resistance against *S. asiatica* have been found in maize genotypes that had been identified by IITA to be resistant to *S. hermonthica* in West Africa (Mutengwa, 2004) but no genotypes have been bred.

Precise and reliable screening techniques are pre-requisites for success when breeding for any biotic or abiotic stress factors. Selection for resistance to *Striga* is normally done under field and green house conditions. It can also be done in the laboratory. Complex interactions

between the host, parasite and the environment influence germination, attachment and growth of the parasite on the host's roots. Host resistance is, therefore, not just a result of the interaction between the host and *Striga*, but also of their independent interactions with environmental factors such as soil type, fertility and rainfall (Mutengwa, 2004). This renders field screening for *Striga* resistance to be difficult given the many confounding factors that are involved. It is also difficult to establish a uniform level of *Striga* infestation at an appropriate intensity level for reliable and reproducible results. It is recognized that much damage to the host plant occurs below ground level; hence, screening for field resistance to *Striga* has been slow and largely inefficient. Laboratory techniques, however, are efficient in screening for individual resistance mechanisms, but one cannot do away with field screening which takes into account all resistance. Field screening is the ultimate test to identify *Striga* resistance and high yielding genotypes for some targeted environments (Ejeta *et. al.*, 1991).

Generally, there are no known commercial varieties that have been bred to be resistant to *Striga asiatica* and in particular, in Zambia. This is a problem because *S. asiatica* is an invasive species to Zambia and has already caused severe yield losses in maize growing areas. AAFT (2006) reported that *S. asiatica* had affected 55,000ha of maize cropland in Zambia. The method commonly used is hand weeding which is not helping much because most of the damage would have been done to the crop before the weed emerges, while others would just abandon the field.

In addition, little research has been done on *Striga asiatica* when it comes to control using the plant resistance control method in Zambia. Therefore, this study was designed to contribute to the body of knowledge on the genotypes resistant to *S. hermonthica* and *S. asiatica*.

The overall objective of the study was to evaluate maize genotypes with resistance to *Striga hermonthica* and *S. asiatica*. The specific objectives were to:

a). Identify maize genotypes resistant to *Striga hermonthica* and *S. asiatica.*

b). Investigate the mechanism of resistance of the maize genotypes to *Striga asiatica*

The hypothesis that guided this study was that maize genotypes resistant to *Striga hermonthica* are also resistant to *Striga asiatica* and that there was a specific mechanism conferring this resistance.

CHAPTER TWO - LITERATURE REVIEW

2.1   Maize Crop in Africa

Maize is not native to Africa and arrived in Africa through various introductions as long ago as 500 years (McCann, 2005). Since then its range of production environments has expanded from lowlands to the highlands as well as from the marginal to optimal soil fertility areas with varying success becoming the number one crop on the continent both in cultivated area and total grain production (FAO, 2008). Maize shows greater susceptibility to abiotic and biotic stresses prevalent in the continent, including *Striga,* perhaps owing to its exotic nature (Rich and Ejeta, 2008). There has been an apparent paucity of *Striga* resistance genes among landraces of maize in Africa, although some tolerance was identified (Rich and Ejeta, 2008).

2.2   Maize Genotypes

A genotype refers to the entire set of genes in a cell, an organism or an individual or a set of alleles that determines the expression of a particular characteristic or trait (Biology- online, 2017). Maize is among the most extensively studied plant species in the history of genetics (Coe, 2001). Beyond its considerable agricultural and economic value, maize presents unparalleled biological attributes as a research model for genetic diversity (Llaca *et. al.*, 2011). The diversity/variation of maize is seen in seed colour (red, yellow or white), shape and texture i.e. it is highly varied morphologically (Goodman and Taba, 2007) and also in the physiological differences that make some varieties grow well in certain places.

The US Department of Agriculture's plant introduction station holds 19780 different accessions/genotypes of maize around the world. In China alone, more than 15, 000 accessions of maize have been collected and about 90% of these are landraces (Yao *et. al.*, 2007). In Zambia, there are several local varieties and over 134 improved varieties have been released since 1997. The number of maize accessions/genotypes in the national genebank was 685 in 2007 (Mwila *et. al.*, 2008) and to date this number has increased.   The accessions/genotypes collected serve as a source of resistance to diseases and pests, tolerance to climate and environmental stresses, and improved quality and yield traits for crop improvement (Smale *et. al.*, 1998). The international genebank of the Centro Internacional de

Mejoramiento de Maíz y Trigo (International Maize and Wheat Improvement Center [CIMMYT]), which is the largest genebank for maize (Singh and Jauhar, 2005; Smale *et. al.*, 1998) holds in excess of 27, 500 maize accessions, covering primarily landraces (97% of the accessions) but also breeding lines, teosite, *Tripsacum* spp., and some pools and pre-breeding populations.

2.3   Maize production

Maize (*Zea mays* L.) is most important and strategic cereal crops in the developed world and Africa (FARA, 2009). It is also the staple food in Zambia.

Maize is important because it is high yielding, easy to process, readily digested, and cheaper to produce than other cereals. It is also a versatile crop; growing across a range of agro-ecological zones (IITA, 2014). Due to its increasing importance, maize has become a major staple and cash crop for small-holder (SH) farmers (IITA, 2009). Every part of the maize plant has economic value: the grain, leaves, stalk, tassel and the cob can all be used to produce a large variety of food and non-food products (IITA, 2009); Maize is used as livestock feed; it is an important source of carbohydrate, protein, iron, vitamin B, and minerals and is used to make porridges, pastes, grits, and beer. Green maize (fresh on the cob) is eaten parched, baked, roasted or boiled; playing an important role in filling the hunger gap after the dry season (du Plessis, 2003).

South Africa is the dominant producer of maize in Southern Africa accounting for 45 percent of the total production. Zambia is ranked third (FAO, 2011). In the 2012/13 farming season, Zambia produced 2, 532, 800 metric tonnes (CSO, 2014). Among the different regions of Zambia, Eastern province is the largest maize producer (23%), followed by Central (19) and Southern provinces (18%) (CSO, 2014). The rest of the provinces only register small amounts of production (CSO, 2014).

2.4   Constraint to Maize production

Maize production in Zambia faces various constraints among them are due abiotic and biotic stresses (Siwale *et. al.*, 2009).

2.4.1   Abiotic Stress

Abiotic stresses that affect maize include:

(a). Drought - this is a widespread phenomenon across large areas of SSA, with an estimated 22% of mid-altitude/subtropical and 25% of lowland tropical maize growing regions affected annually by inadequate water supply during the growing season (Heisy and Edmeades, 1999; Grant *et. al.*, 1989; Cairns *et. al.*, 2012).

(b). Heat - Crop production and meteorological records showed that a 6°C increase in temperature during grain filling stage resulted in a 10% yield loss in the US corn belt (Cairns *et. al.*, 2012; Thomson *et. al.*, 1966).

(c). Water logging - over 18% of the total maize production area in south and South-East Asia is frequently affected by floods and water logging problems, causing production losses of 25-30% annually (Cairns *et. al.*, 2012).

(d). Low nitrogen – nitrogen is one of the most important yield-increasing agricultural input ((Witcombe *et. al*., 2008). Low levels of nitrogen in soils have led to the reduction in maize yields; and have also exacerbated the problem of parasitic weeds in SSA (Singh and Emechebe, 1997).

(e). Salinity – salinity has been a major constraint on crop production. Approximately 800Mha are affected by salinity, which can reduce yields leading to increased poverty ((Witcombe *et. al*., 2008).

(f). Aluminium toxicity – approximately 49% of arable land worldwide is affected by acid soils. Aluminium is only phtotoxic under acid soils and causes reduction in yield of many cereal crops (Witcombe *et. al*., 2008).

In Zambia, abiotic stresses depressing maize yield are low and declining soil fertility and drought (Siwale *et. al.*, 2009; JAICAF, 2008; Matata *et. al.*, 2011).

2.4.2 Biotic Stress

Biotic stresses account for a significant proportion of maize yield losses world-wide. Biotic stresses include diseases, insect pests and weeds. Losses in maize, due to pests and diseases account for 36% in Africa and 21.8% in the world (Shetto and Kwiligwa, 1990; Crammer, 1976). Losses in maize due to weeds alone accounted for 35% in Africa and 13% in the rest of the world (Crammer, 1976) and recently it has been reported that losses from weeds account for 55 – 90 % (Gianessi and Williams, 2011). Competition from weeds early in the development of maize remains one of the most serious and widespread production problems

facing smallholder maize producers in southern Africa (Vernon and Parker, 1983; Mashingaidze, 2004). Therefore, breeding for pest and disease resistance is one of the strategies to mitigate biotic stresses such as weeds (Cairns *et. al.*, 2012).

2.5   Weeds as a biotic stress factor

According to Soladoye (2010), weeds are literally everywhere which make them a perfect object to observe and the richest soil if uncultivated produces the rankest weeds. Soladoye (2010) then defined weeds as plants growing where they are not wanted; they are undesirable and considered to be pests just like insects. There are various definitions of weeds agronomically. According to Klingman and co-workers (1982), a weed is defined as a plant growing where it is not desired or out of place. Harper (1944) defined a weed as a plant that grows spontaneously in a habitat that has been greatly modified by human action, while, Thomas (1956) defined a weed as a useless, undesirable and often very unsightly plant of wild nature usually found on land which has been cultivated or in areas developed by man for specific purposes other than cultivation. Akobundu (1987), however, defined a weed as a plant that interferes with human activity and/or welfare or because it occurs spontaneously in human disturbed habitat. From the above, it can be deduced that a good number of people regard weeds as vagabond plants with no homes and no useful purpose and can therefore migrate from place to place in different ecological systems where they are not wanted (Soladoye, 2010). Weeds encompass all types of undesirable plants- trees, broadleaf plants, sedges, aquatic plants and parasitic flowering plants (Klingman *et. al.*, 1982).

Some weeds are alternative hosts of pests and diseases. They reduce profits by lowering the quality, quantity, yields and value with annual yield losses in maize estimated to be approximately ten percent (Du Plessis, 2003). Inefficient weed control is one of the main causes of low maize yield in Zambia (MAFF, 1997). Some weeds are parasitic and poisonous to maize. Yield losses estimated due to weeds vary considerably world-wide depending on the weed species, intensity of the weed population, competitive ability of the crop, duration of weeds infestation, soil fertility, climatic conditions, edaphic and management factors (Shetto and Kwiligwa, 1990; Vasudeva Rao, 1983).

Weeds interact with the crop plants for water, nutrients, space and light (Du Plessis, 2003). These interactions can be harmful or beneficial. The harmful interactions are the interactions were the crop is losing out while the weed is benefitting causing massive crop losses. Therefore, there is need to put all the above into consideration plus the type of interaction that

exists between weed and host, in order to administer the correct control measure (Rich and Ejeta, 2008).

The harmful types of interaction are:

(i). Competition - The early stage of a maize plant (first three weeks) is very sensitive to weed competition (Mashingaidze, 2004). If maize growth is chocked by weeds in its early stages of growth, it never recovers fully, however well weeds are controlled subsequently. Weed infestation should be minimized for the first ten weeks to maximize final yield. Beyond this period, well planted and healthy growing maize would chock weeds sufficiently.

(ii). Allelopathy – Interactions are weed on crop, crop on weed and crop on crop. The chemicals produced are secondary plant products and are called allelochemicals e.g. phenolic compounds, terpenoids, carbohydrates, amino acids, flavanoids, steroids and so on. Though allelochemicals have no made of function, they can affect cell division, pollen germination, nutrient uptake, photosynthesis, specific enzyme function and different plant parts including flowers (Kambikambi, 2006). These chemical can be found in flowers, leaves, stem, bark, roots, leachates, leaf litter, and soil and so on. Examples of plants with allelopathic compounds include sunflower, sorghum, mango leave, and so on. The allelochemicals can be released into the environment by volatilization, leaching and exudation

(iii). Parasitism – The parasite-host relationship is normally species specific. The parasites can be classified as either hemi or holo, facultative or obligate and root or stem parasites. Obligate parasites require a stimulus for them to commence germination, while the facultative parasites will require no stimulus for germination to commence. Root parasites are those that will anchor to the roots of the host, while, stem parasites are those that anchor to the stem (Kambikambi, 2006).

2.6   Parasitic weeds

Parasitic plants are found in 13 angiosperm families and occupy a wide range of habitats. The most economically important parasitic plants are *Striga* (witch weed) and Orobanche species of the family Orobanchaceae, a monophyletic group of root parasites with approximately 90 genera and more than 2000 species (Runo *et. al.*, 2012).

2.6.1 The Witch weeds (*Striga* spp.)

The witch weeds (*Striga spp.*) belong to the family Scrophulariaceae, a genus of hemi, obligate root- parasitic flowering plants. Within the genus, there are 30–35 species (Mohamed and Musselman, 2006), over eighty percent of which are found in Africa, while the rest occur in Asia and the United States (Spallek *et. al.*, 2013). Over two- thirds of the species of *Striga* occur in West and Central Africa, and over half of the *Striga* species occur in East and South Africa. Nine species occur outside of Africa and three of these are endemic to Australia (Spallek *et. al.*, 2013).

2.6.1.1 *Striga* biology

The *Striga* life cycle is highly synchronized with that of the host and generally involves the stages of germination, attachment to host, haustorial formation, penetration, establishment of vascular connections, accumulation of nutrients, flowering and seed production (Berner *et. al*, 1997). Each plant is capable of producing up to 500,000 extremely small seeds each weighing 7μg which may remain viable in the soil for over 10 years (USDA, 2003). An annual plant, witchweed overwinters in the seed stage (Sand, 1990).

Germination of *Striga* seeds only take place in response to chemical cues, most commonly strigolactones, produced by the host and in some cases non-host species (Spallek *et. al.*, 2013). It requires exposure to an exogenous germination stimulant after an environmental conditioning period which the seeds imbibe water. Usually this stimulant is host-root exudates, but some non-host-root exudates and synthetic compounds can stimulate germination (Berner, *et. al.*, 1997). The host-root exudates contain strigolactones, that is, signalling molecules that promote *Striga* seed germination (Maurice *et. al.*, 2005). A bell-like swell forms where the parasitic roots attach to the roots of the host and the pathogen colonizes underground, where it may spend the next four to seven weeks before emergence, when it rapidly flowers and produces seeds (Maurice *et. al.*, 2005). Once germination is stimulated, the *Striga* seed sends out an initial root to probe the soil for the host root. The initial root secretes an oxidizing enzyme that digests the host root surface, releasing quinones. If the quinone product is within the appropriate concentrations, a haustorium will develop from the initial root (Chang, 1986).

The haustorium grows toward the host root until it makes contact with the root surface, establishing parasitic contact in relatively short order and within 12 hours of initial

haustorium growth, the haustorium recognizes the host root and begins rapid cell division and elongation (Hood, 1997). The haustorium forms a wedge shape and uses mechanical force and chemical digestion to penetrate the host root, pushing the host cells out of the way (Dorr, 1996). In a period of 48–72 hours, the haustorium has penetrated the host root cortex and finger-like structures on the haustorium, called osculum, penetrate the host xylem through pits in the membrane (Hood, 1997). Thereafter, the osculum swells to secure their position within the xylem membrane, *Striga* sieve tubes develop along with the osculum and shortly after, the host xylem is penetrated. *Striga* sieve tubes then develop and approach the host phloem within eight cells and this layer allows for nonspecific nutrient transport from the host to the *Striga* seedling. The *Striga* cotyledons emerge from the seed within 24 hours (Dorr, 1995).

After penetration of the cortex, haustorial cells undergo a remarkable differentiation process to form vessels that form a continuous bridge with the host xylem that serve as a conduit for host derived nutrients and water (Berner *et. al.*, 1997; Runo *et. al.*, 2012). *Striga* grows upwards and adventitious roots are produced and these roots (Fig. 1) are able to form lateral (secondary) haustoria on the same or other host plants. According to Westwood *et. al.*, (2010), secondary haustoria are believed to be evolutionarily older than primary or terminal haustoria.

Under natural conditions, host plants are usually parasitized by several *Striga* plants, and the parasites quickly become a metabolic sink for photo-assimilates and nutrients. Nitrogen levels are at least twice as high in *Striga* as in host plants and depletion of nitrogen almost certainly affects host physiology and provokes lower host photosynthesis rates, which are frequently associated with *Striga* infections (Agabawi and Younis, 1965). Several photosynthetic parameters are reduced in sorghum plants infected with *S. hermonthica*, including the electron transport rate through photo-system II.

After emergence from the soil, *Striga* plants begin to photosynthesize, however, the low CO_2 fixation and high dark respiration rates of *S. asiatica* result in a negative carbon gain over the 24-h period, thus making *Striga* still host dependent when growing above ground. In addition, *Striga* leaves are characterized by a degenerated palisade cell layer and a relatively small number of chloroplasts per cell (Johnson, 2005).

Fig 1: Host roots with connected *Striga* roots (source IITA)

The majority of the life cycle takes place below ground and because of this, management of the weed is difficult. If it is not detected before emergence then it is too late to reduce crop loss once the weed emerges (Johnson, 2005). According to Rich and Ejeta (2008), *Striga* parasitism is a series of signal exchanges between host and parasite that lead to successful establishment and suggested effective control methods should target the weed at various stages of the lifecycle so that losses are minimized.

Host plant symptoms include: stunting, wilting and chlorosis and these symptoms are similar to those seen from severe drought damage, nutrient deficiency and vascular diseases (Sand *et. al*., 1990; Johnson, 2005; Agrios, 2005).

2.6.1.2 *Striga* Epidemiology

Striga is an old world parasite, and several species were already recognized as cereal pests in Africa and India at the beginning of the last century (Spallex *et. al*., 2013). *Striga* species are predominantly found on open grasslands and savannahs in semi-arid tropical regions (Spallex *et. al*., 2013). Infestations are more pronounced in infertile soils, but *S. asiatica* can grow in a wide range of different soils. Increased monoculture in some parts of Africa has led to reduced soil fertility, thus further worsening the situation with regard to *Striga* infestations (Berner *et. al*., 1997). The problem of parasitic weeds is intensifying in SSA because of the deteriorating soil fertility, shortening of the fallow period, expansion of production into marginal lands with little use of external inputs and the increasing trends towards continuous

cultivation of monocultures in place of traditional rotation and intercropping systems (Singh and Emechebe, 1997). In addition to the latter, witchweed also seeds spread easily (by wind, water, and soil via animal vectors, chiefly by human interaction, by means of machinery, tools, and clothing). Therefore, to prevent witchweed from spreading it is necessary to plant uncontaminated seeds and clean soil and plant debris off of machinery, shoes, clothing, and tools before entering fields.

According to Spallek *et. al.* (2013) temperature is also an important factor affecting the distribution of *Striga*, as prolonged exposure to high temperatures and humid conditions is required to break seed dormancy in *Striga*. An estimated cereal production area of 50 million hectares, approximately the size of Spain, shows different levels of *Striga* infestation in Africa (Spallek *et. al.*, 2013). De Groote *et. al.*, (2008) reported that twenty – five African countries reported *Striga* infestations in 2005. The socioeconomic consequences are difficult to measure, however, a few estimations have suggested that *Striga* affects the life of more than 100 million people in Africa (Waruru, 2013) and causes economic damage equivalent to approximately 7 billion $US per year (Runo *et. al.*, 2012). Host plants include sorghum, millet, maize, upland rice, sugarcane, cowpeas, representing the most important stable crops grown by subsistence farmers in affected areas. Farmers have reported losses between 20% and 80%, and are eventually forced to abandon highly infested fields. The extent of yield losses cannot be explained solely by competition for nutrients and water (Berner *et. al.*, 1995). As paratism progresses, very severe symptoms such as water-soaked leaf lesions, chlorosis, necrosis and leaf desiccation, occur (Berner *et. al.*, 1997).

Only five *Striga* species are currently of economic importance, with *S. hermonthica* causing by far the most serious damage to sub-Saharan cereal production, followed by *S. asiatica*, *S. gesnerioides* and, to a far lesser extent, *S. aspera* and *S. forbesi* Benth (Spallek *et. al.*, 2013).

Striga hermonthica (Del) Benth is the largest among the agronomically important species, and the most destructive of all *Striga* species. It is common in the SSA from Senegal to Ethiopia reaching its limits in Congo and Tanzania and causes more damage to sorghum, maize and millet than any other crop pest (Aigbokhan *et. al.*, 1998; 2000; Mohammad and Musselman, 2006) and is a severe constraint in maize production (Karaya *et. al.*, 2012; Ogborn, 1987; Lagoke *et. al.*, 1991; Berner *et. al.*, 1994). Because of increasing population pressure, African farmers are relying on continuous and mixed cropping of relatively high yielding cereals, like maize and sorghum, to meet their food needs. This cropping pattern

favours build-up of *S. hermonthica*, which is now threatening cereal production in many areas (Berner et, al., 1994). Grain yield losses in maize from *S. hermonthica* infestation in Africa range from 20 to 80% (Berner *et. al.*, 1995, Karaya *et. al.*, 2012), but can sometimes reach 100% in susceptible maize cultivars under severe infestation (Gurney *et. al.*, 2003; Hausmann *et. al.*, 2000; Karaya *et. al.*, 2012). Figure 2D shows *Striga hermonthica*-infested sorghum field in Kismu and figure 3A shows a maize field infested by *S. hermonthica*.

Striga asiatica (L.) Kuntze is the most widespread *Striga* species (Fig. 2A), with a geographical distribution ranging from Southern Africa to East Africa and from the Arabian Peninsula to Far East Asia, including India and Pakistan (mainly on sorghum and millet), Cambodia, China, Thailand (maize in the 1970s), Vietnam, Malaysia, Indonesia and the Philippines (mainly on rice) (Musselman, 1987). Asian *S. asiatica* occurs mainly in the form of two morphotypes: white flowered *S. asiatica*, which is found in India and Pakistan, and a yellow-flowered race which is predominant in Thailand and Indonesia (Vasudeva Rao, 1984).

African *S. asiatica* plants have mainly red flowers. *Striga asiatica* infestation is less severe in Asia relative to Africa. Until the start of the 1990s, African *S. asiatica* was mainly restricted to South and Central Africa (Mohamed and Musselman, 2006). Although *S. asiatica* is now increasingly being found in other parts of Africa, it is most problematic south of the Equator in East and Southern Africa (Fig. 2A; Aphis, 2000; Hassan *et. al.*, 1994). Tanzania marks a transition zone between *S. hermonthica* and *S. asiatica*, with *S. asiatica* becoming more problematic in countries such as Tanzania, Malawi, Mozambique, Madagascar (Parker, 2009), Kenya, Mauritius, South Africa, Uganda, Zambia and Zimbabwe (Holm, 1991). Mostly unstudied populations of *S. asiatica* can be found outside the usual distribution, for example in the Nile delta. *Striga asiatica* was also accidentally introduced to North and South Carolina (USA) in the 1950s (Hood *et. al*., 1998).

Striga asiatica can cause serious yield losses in maize production especially in resource poor farmers' fields (Matata *et. al.*, 2011). *Striga asiatica* related yield losses are estimated between 30-50% are common under typical field infestation (Aphis, 2000; Hassan *et. al.*, 1994). Much damage can be done even before the weed emerges at 8 weeks. *Striga asiatica* impairs photosynthesis of susceptible maize hosts by limiting stomatal conductance and sensitizes infested plants to photo-inhibition. It robs the host of nutrients, water and carbohydrates (Fig. 3B; CDFA, 2006; Elzein and Broschel, 2004; Gurney *et. al.*, 2002). *S.*

asiatica has seriously infested most crop fields of maize and sorghum in Eastern province in Zambia thereby reducing their yield (NECZ, 2013).

Although *Striga* currently does not pose a high risk for modern high-input agricultural systems, such as those in the south-eastern USA, it remains a significant problem for African farmers with no or only limited access to fertilizers, herbicides and modern mechanical tillage equipment (Berner *et. al.*, 1997). The introduction of new farming systems into rural societies takes time, such that hand weeding often remains the only technique to control *Striga* (Spallek *et. al.*, 2013). Because of this, owing to the fact that *Striga* causes damage even before it emerges, more crop losses are experienced. Therefore, there is need for new farming systems that are beneficial in the control of *Striga* to reach the farmer in good time to minimize losses.
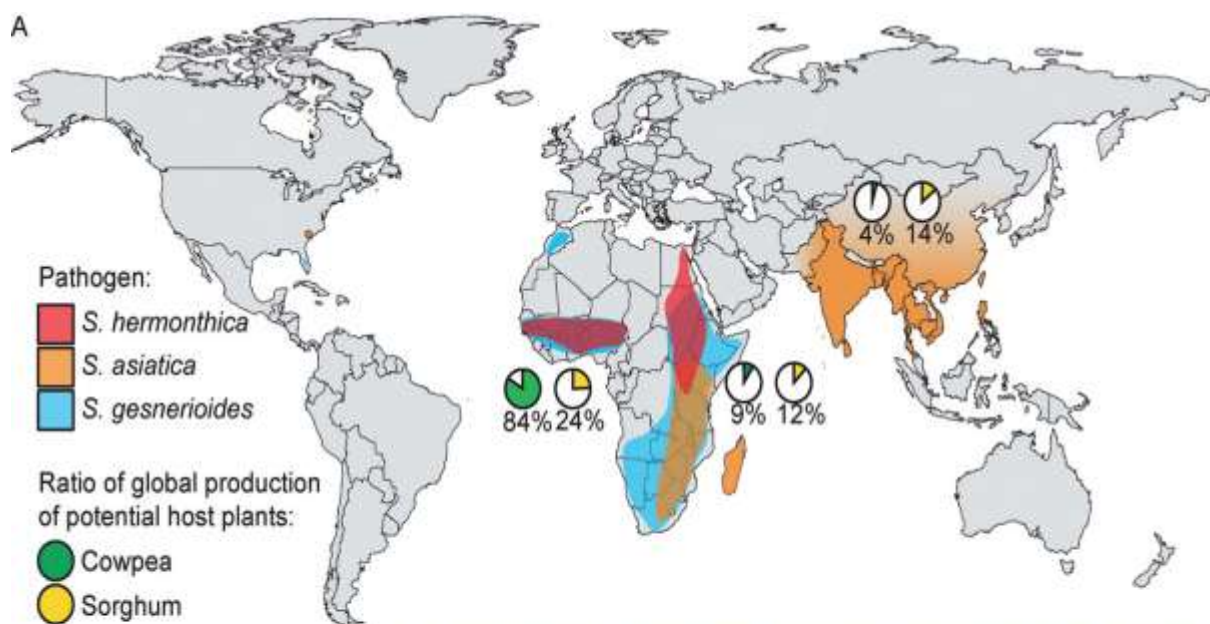
Fig. 2: Global distribution of the economically most destructive *Striga* species (Source: Spallek *et. al.*, 2013)

2.6.2   **Control Methods of *Striga***

According to IITA, 2010 under the Integrated *Striga* Management in Africa (ISMA) programme, methods of *Striga* control can broadly be grouped in two broad categories, cultural and seed-based.

(a). Cultural control of *Striga* – this includes crop rotation, intercropping, use of different planting techniques such as late or deep planting, and management of soil fertility (Teshome,

2013). These help to reduce the *Striga* seed bank and improve fertility. These methods may be challenging especially to resource-poor farmers who make up 70 to 80% of the farmers in SSA (IITA, 2010).

Fig. 3A: A maize field infested by *Striga hermonthica* (Source: IITA, 2009)

Fig. 3B: *Striga asiatica* growing in the experimental plots

b. Seed-based technologies include use of herbicide coated seeds, germplasm based-*Striga* resistance, and biological control. One major disadvantages of these technologies is access to seeds by cash-strapped farmers. The methods include:

i. Developing host resistance/tolerance - Breeding crop varieties that are resistant (prevents or limits *Striga* attachment or growth) or tolerant (variety still gives acceptable yields despite *Striga* attack) is the most widely spread seed-based, highly effective method, the most feasible and environmental friendly method to control *Striga* for small-holder farmers (IITA, 2010). It has been successful in sorghum where great advances have been made in understanding how the tolerance/resistance works through biotechnology and the knowledge used to develop *Striga* -tolerant sorghum varieties using marker-assisted breeding. Maize resistant and tolerant varieties have also been developed in Kenya and Nigeria (IITA, 2014). IITA (2010) observed that the use of resistant maize after a legume crop resulted in net benefits of more than 100% over farmers' practice across seasons, while, the use of *Striga* - resistant varieties alone or in rotation with legumes reduced *Striga* seed density by 29 to 50% (IITA, 2010).

ii. Herbicide dressing is a highly effective method if available and affordable for farmers who have to buy the dressed seeds each season (IITA, 2010).

The most effective and sustainable approach for *Striga* control, however, is an integration of two or more control options as all technologies have shortcomings (Teshome, 2013).

In summary, *Striga* control methodologies can also be grouped into three major categories with different effects on the *Striga* plant, that is, reduction of seed numbers in the soil, prevention of new seed production and prevention of movement of seeds from infested to non-infested areas (IITA, 2010: Mutengwa, 2004).

An effective control strategy should integrate at least one control principal from each of the three major categories (Mutengwa, 2004); IITA 2010). Good crop husbandry practices such as timely planting, weeding or hand pulling of the parasite, application of inorganic fertilizers and manure, rotation, etc, cannot be practised effectively because of the inherent environmental and socio-economic conditions with persistent droughts worsening the problem (Mutengwa, 2004). Furthermore, farmers affected by the parasitic weed live in very heterogeneous biophysical, cultural, social, and economic environments which need to be taken into account in developing appropriate control strategies. The technologies therefore must be responsive to the different constraints faced by farmers and must fit in with their farming practices. They must also be readily available and preferably demand-driven (IITA, 2010).

2.6.3 Constraints to *Striga* control

While there are effective *Striga* control options such as the use of high levels of nitrogenous fertilizers, irrigation and herbicides, these solutions are beyond the means of many African growers (Rich and Ejeta, 2008). Practices that were developed for *S. asiatica and S. hermonthica* control in the United States of America are generally unsuitable in Africa because they require chemical inputs and application equipment that are not available or prohibitively expensive (Berner *et. al.*, 1995). In order to put effective *Striga* control within the reach of African farmers, simple, inexpensive measures need to be developed that are tailored to the diversity of African cropping systems (Berner *et. al.*, 1995).

Runo and his colleagues (2012) reported that control options for *Striga* are limited and include modified/improved cultural practices (such as crop rotation, intercropping/trap crops, different planting techniques, hand weeding, management of soil fertility), use of herbicide containing seed dressing, direct chemical treatment of soil to reduce seed levels in the soil, and use of resistant germplasm.

Traditional African cropping systems which have included prolonged fallow, rotation and inter-cropping, were common management practices that were used in the past to improve

soil fertility and keep infestation of *Striga* spp. at tolerable levels (Matata *et. al.*, 2011; Kureh *et. al.*, 2000). However, increasing human population has resulted into intensive land use and shifting away from traditional cropping systems, which in the long run has resulted in the depletion of soil fertility and increased *Striga* infestation. According to Singh and Emechebe (1997), the growing population pressure in SSA and increase in cropping intensities, has worsened the *Striga* problem particularly in areas with sandy soils, poor soil fertility, low rainfall, where host plants are too weak to compete for assimilates, water and light.

2.6.4 Resistance to *Striga* in maize

2.6.4.1 Source of resistance

According to Rich and Ejeta, (2008) some encouraging reports of *Striga* resistance in maize or its wild relatives have emerged over the last decade. They observed that in a collection of perennial teosintes (*Zea diploperennis*) about 10% of the entries showed resistance relative to the other teosinte accessions and to maize. In addition,the dual observed that the resistant individuals had fewer attached *S. hermonthica* to establish vascular connections and those few parasites that eventually emerged were smaller in the resistant *Z. diploperennis* pots than those on the non-resistant types and on the *Zea mays* check

Another wild relative of maize that expressed resistance to *S. hermonthica* is *Tripsacum dactyloides*, such that *S. hermonthica* attached at a frequency 25% that on *Z. mays*, and the attached *Striga* were less likely to progress to the developmental stages reached by those on maize during the six weeks of observation (Gurney *et. al*., 2003). Although some parasites were able to tap the xylem of the *Tripsacum dactyloides* hosts, subsequent haustorial development was extremely small compared to the acquisition organ developed after vascular connection on the maize hosts (Rich and Ejeta, 2008). According to Adetimirin *et. al*., (2000), tropical maize types which occasionally showed resistance reactions were often associated with avoidance/escape mechanisms while hybrid maize selections (from resistant × resistant inbreds), supported fewer emerged parasites and these were less likely to flower and set seed. Oswald and Ransom, (2004) observed in maize tested in Kenya that short cycle maize entries were less attacked by *Striga* than long cycle varieties.

A cultivated maize inbred line, ZD05 developed through a long-term breeding effort at the International Institute for Tropical Agriculture (IITA) showed resistance reactions in the laboratory (Amusan *et. al*., 2008) and has in its pedigree to *Zea diploperennis* as well as tropical maize germplasm (Rich and Ejeta, 2008). It had reduced numbers of emerged *Striga*

in the field but the underlying mechanism of this resistance was uncharacterized. The *Striga* that did attach usually died on the resistant roots, rarely developing to the growth stages attained on the susceptible maize. With these reports of true resistance reactions captured in cultivated *Z. mays*, building durable *Striga* resistance in the crop appears likely. *Striga* resistance is most effective when expressed early in the parasitic life cycle since *Striga* causes much damage during establishment (Frost *et. al*, 1997). It appears that ZD05 already has three defences: avoidance through less branched root architecture, some ability to resist attachments of nearby germinated *Striga* and an incompatibility that does not support normal growth of attached parasites (Rich and Ejeta, 2008).

 For national and regional deployment, integrating genetic resistance with other control measures is the best possible for effectiveness of control and increasing durability of resistance genes (Ejeta, 2007).

2.6.4.2 Mechanisms of resistance

According to Mutengwa (2004), *Striga* was heavily dependent on the host for survival and Its lifecycle is closely coordinated with that of the host plant. Its seeds having very specific requirements for after-ripening, conditioning, stimulation by chemical compounds exudated from host and non-host plants before they can germinate, form haustorial, attach and penetrate and further grow and develop. Interruption or disruption of one of the signals or resources results in the failure of parasitism by the pest.

Distinct defence responses to *Striga* parasitism have been identified using the agar gel, extended agar gel and the paper roll assays (Hess *et. al.*, 1992; Mutengwa, 2004; Reda *et. al.*, 1994). These responses point to the existence of at least four separate mechanism of *Striga* resistance involving: (i). little or no *Striga* seed germination stimulant (lgs) or presence of *Striga* inhibitors, (ii). low production of the haustorial initiation factor (lhf), (iii). a hypersensitive response (HR) characterised by a distinct necrotic area on the host root at the attachment site, and (iv). An incompatibility response (IR) where parasite development is arrested with no apparent necrosis on the host root, but the attached *Striga* seedlings appear withered or stunted. While the first two mechanisms concern host-parasite interactions during the early infection process, the latter two are associated with the attachment and penetration (Ejeta and Butler, 1993; Mutengwa, 2004). Maize resistance can be expressed through low stimulation of *Striga* seed germination, low haustorial induction, avoidance through root

architecture (fewer thin branches), escape by early maturity, resistance to attachment (as expressed by ZD05 seemingly *not* the result of low haustorial initiation) and failure to support attached parasites (incompatibility) (Rich and Ejeta, 2008).

2.6.4.3 Germination stimulants

Germination stimulants are chemical stimuli (signalling molecules) that initiate the lifecycle of the parasite e.g. Striga (Zhongui, 2008). These are secreted by the host roots and trigger the germination of the seed of the parasite (Bouwmeester *et. al.*, 2003). A number of different classes of secondary metabolites have been described to have germination stimulant activity (Zhongui, 2008). These include: dihydrsorgoleote an active stimulant in root exudates of sorghum and other monocotelydonous hosts, the strigolactones and sesquiterpene lactones (Keyes *et. al.*, 2001). The strigolactones are the best explored class of germination stimulants so far with upto seven natural strigolactones germination stimulants isolated and characterized (Zhongui, 2008). These are strigol (in exudates of millet and maize) (Awad *et. al.*, 2006), orobanchy acetate and orobanchol (isolated from cowpea, red clover and soya bean) (Yokota *et. al.*, 1998), sorgolactone and sorghumol (isolated from sorghum) and 5 − deoxystrigol the major strigolactones (present in root exudates of maize, paso millet and sorghum (Zhongui, 2008). These are a class of secondary metabolites that are exuded by many different plant species such as tomato, tobacco and spinach (Xie *et. al.*, 2006).

GR 24 is a synthetic germination stimulant (strigolactone), which is used worldwide in parasitic weed research to stimulate parasitic weed seed germination (Zhongui, 2008). It has been used (in micromolar doses) in combination with standard preconditioning treatment to break parasitic seed dormancy. At high concentrations (3µM or higher), GR 24 almost always induces high germination. It is not host specific and can induce germination of both Orobanche and *Striga* seeds (Zhongui *et. al.*, 2007).

The strigolactones are of ecological significance in that they are required by arbscular mycorrhizal (AM) fungi for their host root colonization process. One primary role of AM fungi in the symbiotic relationship with plants is to deliver mineral nutrients and phosphate (Zhongui *et. al.*, 2007). There is dramatic increase of *Striga* problem in areas with limited phosphate availability. Besserer *et. al.*, 2008, observed that GR 24 stimulated the mitosis and growth of AM fungi by increasing or boosting its metabolism. Several groups have reported

colonisation of AM fungi can reduce the infection of sorghum and maize by *Striga* (Zhongui *et. al.*, 2007).

Some methods to control *Striga* have used the knowledge of germination stimulants. These methods involve control using enhanced germination (suicidal germination using chemicals, trap and catch crops), control through reduced germination (using chemicals, dormancy, AM fungi and phosphate), control using host specificity and control using breeding (low germination stimulant production) (Zhongui *et. al.*, 2007).

2.6.4.4 Resistant maize varieties to *Striga*

There are some genotypes that have been developed and released that are resistant to *S. hermonthica* (IITA, 2010). In Ethiopia, there are three *Striga* -resistant sorghum varieties that were released by the Sirinka Research Center (SRC) for *S. hermonthica* infested fields in Kobo and Sirinka areas and there has been three-fold increase in yield. In addition, IITA and CIMMYT have developed open-pollinated maize varieties (OPV), hybrids and in-bred lines that are resistant to *S. hermonthica*. In Kenya, two *Striga* -resistant varieties have also been developed by the Kenya Agricultural Research Institute (KARI), KSTP94 and GVF 4 (IITA, 2014). In West Africa, a number of *Striga hermonthica* resistant varieties have been developed (Table 1).

Table 1:- *Striga hermonthica* - Resistant Maize Varieties in West Africa

Variety Name	Type of cultivars	Country	Year of release	Adaptation
SAMMAZ 16	*Striga* resistant late maturing OPV	Nigeria	2008	Moist savannah
Oba Super 17	*Striga* resistant hybrid	Nigeria	2009	Moist savannah
Oba Super 9	*Striga* resistant hybrid	Nigeria	2009	Moist savannah

(Source: IITA, 2014)

An IITA magazine, the Bulletin in 2003 reported that farmers in Abuja, Nigeria praised the *Striga* -resistant maize varieties available at that time saying the coming of the new varieties brought a new dawn in our lives.

In Malawi, researchers found good levels of resistance against S. asiatica in maize genotypes that were identified by IITA to be resistant to S. hermonthica in West Africa (Mutengwa, 2004), but no genotypes have been bred.

A lot of research has been done on the understanding of biology and paratism of *Striga*. Yield losses as a result of *Striga* remain high. Sources of resistance and mechanisms of resistance have been identified. Some genotypes developed at IITA and CYMMT could be incorporated incorporated in breeding programmes. Work still needs to be done on *Striga* resistance in SSA and Zambia in particular.

CHAPTER THREE - MATERIALS AND METHODS

3.1   Field experiment

3.1.1   Sites

The study was conducted in Agro-Ecological Region II of Zambia's zoning system at three sites, namely Lundazi (12.3^{o}S, 33.18^{o}E, 1096 m a. s. l) and Katete (14.08^{o}S, 32.06^{o}E, 1120 m a.s.l) under natural *Striga* infestation; and the University of Zambia Field Station in Lusaka (15.38^{o}S, 28.33^{o}E, 1225 m a.s.l) under *Striga* -free environment. The attributes of this region are that it covers the central part of Zambia with a general elevation between 900 and 1300 m above sea level (a. s. l), receives annual rainfall of between 800 and 1000 mm and temperatures during the growing season range from 23 – 25°C with mean maximum temperatures of 32°C in October. The main soils have slight to severe chemical and physical limitations to crop production (MAFF, 1997).

3.1.2   Soils

The soils for the three sites where tested for soil reaction measured potentiometrically using glass electrodes connected to a pH meter, the soil texture was determined using the USDA Texture Class, the organic matter content was measured using the Walkley and Black method and the Available nitrogen (NH_4^+ and $NO_3^{-)}$) were measured (Songolo and Pauwelyn, 1998). Table 2 below shows the results of the soil sample tests.

Table 2:- Soil sample analysis for the three study sites

Location	pH	Organic Matter (%)	Ammonium Nitrate-N (mg/kg)	Nitrate-N (mg/kg)	USDA Texture Class
Katete	5.40	0.72	35	28	Sand
Lundazi	6.54	1.20	21	35	Sandy loam
UNZA field station	6.65	1.92	28	28	Loamy sand

The soils from UNZA and Lundazi were found to be slightly acidic and suitable for plant growth while Katete soils were more acidic. The three soil samples had very low organic

matter content for plant growth. Soils with organic matter content 3-8 percent improve plant growth (Donahue *et. al*, 1983).

3.1.3 Treatments

Treatments comprised fourteen maize genotypes (Table 3). Twelve of these were hybrids developed at the International Institute of Tropical Agriculture (IITA) for resistance to *S. hermonthica* while two were genotypes commonly grown in Zambia. The 12 genotypes developed at IITA were obtained from IITA, while the two genotypes commonly grown in Zambia were obtained locally.

3.1.4 Experimental Design and Plots layout

The experiment was laid out as a Randomised Complete Block Design (RCBD) with three replications. Each plot consisted of four- rows at an inter-row spacing of 0.75 m and inter-plot spacing of 1 m. Alley pathways of 1.5 m separated one replication from another, and the total number of plots at each location was 42. Each row measured 0.053m in Lundazi and UNZA, while each row was 7 metres (because the land found was bigger than the other two sites).

3.1.5 Agronomic Practices

The agronomic practices carried out were land preparation and planting, fertilizer application and weeding.

3.1.5.1 Land preparation and Planting

Land preparation was done by ploughing and harrowing using oxen and/or hand held hoes. Planting was done at a spacing of 0.75 m x 0.25 m and one seeds planted per station at 2 cm depth, but thinned out to leave one plant per station, giving 53,333 plants/Ha (Enujeke, 2013). Planting was done on 19/12/13, 27/12/13 and 13/01/14) for Lundazi, Katete and Lusaka, respectively.

3.1.5.2 Fertilizer Application

All plots had 250 kg ha^{-1} equivalent of Compound D (10:20:10) fertilizer applied one week after planting (WAP) and 250 kg ha^{-1} equivalent of urea as top dressing fertilizer, six WAP.

The fertilizer was applied at that rate as it is the minimum rate recommended and common practice among small-scale farmers.

Table 3:- List of maize hybrids used in the study and their origin

Hybrid	Source	Reaction to *Striga hermonthica*	Type of cross
0501-1STR	AcrSyn-WS2-173-B/ZDiploBC4-471-2-3-4-3-2-B/IITATZISTR1003 12C19014B 11C120032B 10A3309B	Resistant	3- way
0501-2STR	AcrSyn-WW2-173-B/ZDiploBC4-472-2-3-4-3-2-B/IITATZISTR1005 12C19016B 11C120034B 10A3311B	Resistant	3- way
0804-7STR	ACRSYN-W-S2-173-B*4/TZLCompIC4S1-37-5-BBB 10C110504B 09C6048B 08C13114B	Resistant	Single
1001-3STR	IITATZISTR1004/IITATZISTR1146 12C19012B 11C120046B 10C110506B	Resistant	Single
0601-6STR	IITATZISTR1015/IITATZISTR1146 12C19010B 11C120044B 10C110508B	Resistant	Single
1109-21STR	ACRSYN-W-S2-173-B*4/TZLCompIC4S1-37-5-BBB/IWD-SYN-STR-C3--55-3-BB 12C19020B 11C120050B 10C113350B	Resistant	3- way
1113-2STR	(1393/ZDiploBC4-19-4-1-#-3-1-B-1-B*4)-40-BB/IWD-SYN-STR-C3--50-2-BBB/TZLCompIC4S1-37-1-B*6 12C19026B 11C120054B 10C111698B	Resistant	3- way
1113-3STR	(1393/ZDiploBC4-19-4-1-#-3-1-B-1-B*4)-43-BB/IWD-SYN-STR-C3--52-1-BBB/TZLCompIC4S1-37-5-B*5 12C19028B 11C120056B 10C111699B	Resistant	3- way
1113-13STR	(1393/ZDiploBC4-19-4-1-#-3-1-B-1-B*4)-2-BB/IWD-SYN-STR-C3--52-1-BBB/TZLCompIC4S1-37-1-B*6 12C19022B 11C120060B 10C111714B	Resistant	3- way
9022-13	8338-1	resistant	
8338-1	9022-13	susceptible	
Oba Super 1		Resistant	
SC 627		Not known	
PHB 30G19		Not known	

3.1.5.3 Weeding

All the plots were hand-weeded twice; firstly 3 WAP and the second weeding was at 6 WAP. Both these weedings were done before *Striga* emerged (where it emerged). After the *Striga* emerged, hand pulling was done to remove only the other weeds and only leaving the *Striga* plants.

3.1.6 Data Collection

Data were recorded from each plot on agronomic traits which included: days to 50% flowering, *Striga* damage rating (SDR), *Striga* counts (*Striga* plants per host plant), days to maturity of the maize, plant height at harvest, cob length and cob diameter and grain yield. Days to 50% flowering was determined when fifty percent of the plant in a plot had flowered (visual assessment), *Striga* damage rating (SDR) was recorded using the scale of 1-9 (where $1 - 3$ = no damage, $4 - 6$ = extensive leaf blotching, wilting and stunting, and $7 - 9$ = complete scorching) (Karaya, 2012a). The *Striga* count data was recorded by counting the *Striga* plant emerged per plot starting at 10 weeks and then after every two weeks up to 14 weeks after planting (WAP) (Karaya, 2012a). Plant height was determined at harvest by systematically sampling every fourth plant in the plot and measuring the height using a tape. Cob length was measured using vernier callipers from ten cobs sampled. Cob diameter was determined from ten cobs using vernier callipers. Grain yield was determined by weighing grain from the harvest plot (two inner rows).

3.1.7 Data Analysis

Striga count per plant was calculated and the data transformed using square root transformation $(X + 1)^{\frac{1}{2}}$, where X = count per plant (Fernandeź, 1992). Grain yield data was adjusted . The data so transformed and adjusted together with all the other data collected (the other data was analysed without any adjustments or transformations) were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of GENSTAT 16th Edition (2013).

3.2 Laboratory Experiment

Laboratory methods in *Striga* research are an important aspect. They allow us to observe the individual processes of *Striga* seed germination, radical formation, attachment, penetration, haustorium production and establishment of compatibility.

3.2.1 Assessing *Striga* germination stimulant

Striga asiatica seeds were obtained from the field study areas following the procedures by Berner *et. al.*, (1997). The seed were kept for six months before they could be used in the laboratory. That was done to ensure that seed dormancy was broken.

Surface Disinfestation

Before conditioning, which involves steps outlined below, surface disinfestations was done by putting *Striga* seeds in cornical flask of 100 ml filled with 40 ml of distilled water (Berner *et. al*., 1997). Five drops of hypochlorite solution was then added to the mixture, thereafter, a drop of tween 80 was added to break the surface tension. The mixture was then stirred for 2 minutes. Floating seeds and debris were discarded. The mixture was poured into a funnel lined with filter paper and washed with clean, ideally sterile water. The seeds were collected on the filter paper.

Conditioning and Germination

After surface disinfestations, the seeds of *S. asiatica* were conditioned by placing the seeds in 14 ml of sterile de-ionized water. The seeds were incubated at 30.3°C for 14 days.

Seeds of maize genotypes were also surface disinfested according to the method described for *Striga* seeds but without adding tween 80 (Berner *et. al*., 1997). The seeds of the host cultivar were pre-germinated by soaking the seeds in distilled water until they formed the shoot and root. They were then transferred into test-tubes filled with a nutrient solution and allowed to grow for 21 days. After 21 days, the nutrient solution was discarded and distilled water added to the test-tubes. The plants were then allowed to grow in the distilled water for 3 days. After 3 days, the plants were removed and 5 ml of solution measured, mixed with 1 g of *Striga* seed and put in well-plates. This mixture was incubated for 3 days. As a control, other *Striga* seeds were grown in water (negative control) and an artificial stimulant and positive control (GR24). GR24 is a synthetic analog of *Striga*lactones which have been characterised as seed germination stimulant of the parasitic plants (Giullaume, 2008). After 3 days, *Striga* seeds that germinated were counted using a dissecting microscope and results recorded.

3.2.2 Treatments

The treatments were three maize genotypes identified as being resistant (3 top performers), one genotype widely grown locally, water (a negative control) and GR24 (a positive control).

3.2.3 Experimental design

The experiment was laid out as a Completely Randomised Design (CRD) with treatments repeated four times.

3.2.4 Data collection

The data collected was *S. asiatica* counts (that was determined by counting germinated seeds under a microscope that were viewed at a magnification of 20.

3.2.5 Data analysis

Data collected was subjected to Analysis of Variance using the GENSTAT computer package 16th Edition (VSN international, 2013). Data on germination was transformed using square root (Gomez and Gomez, 1984; Little and Hills, 1977) before being subjected to ANOVA. Treatment means were separated using the Least Significant Difference (LSD) at $p < 0.05$

4.1   Field Experiment

4.1.1   *Striga* -free environment

Under the *Striga* -free environment, there were no significant differences (p<0.05) observed among genotypes for grain yield, cob length, cob diameter, days to flowering and days to maturity except for plant height (Table 4).

Table 4: Analysis of variance of measured parameters of genotypes evaluated at the University of Zambia Field Station under *Striga* -free environment in 2013/2014

SOV	df	GY	CD	CL	DTMAT	D50 FLOW	PHH
		MS	MS	MS	MS	MS	MS
Block	1	4073078	0.0009	3.129	0.57	0.143	1302.9
Variety	13	8428474^{ns}	0.1382^{ns}	3.382^{ns}	6.07^{ns}	1.516^{ns}	841.2^{*}
Error	13	5210606	0.1698	1.973	13.8	3.451	309.9
Total	27						

* and ns indicating significance at p =0.05 and non-significant respectively; GY- grain yield, CD – Cob diameter, CL – Cob length, DTMAT – days to maturity, D50FLOW – days to 50% flowering, PHH – plant height and harvest, SOV – source of variation, df – degree of freedom, MS – mean square

Plant height

A significant maize genotypic effect for plant height was observed under the *Striga* -free environment (Table 4). Table 5 showed that genotype 1113-3STR was significantly taller (228 cm) followed by PHB 30G19 (225 cm), while genotype 0601-6STR (153 cm) was the shortest. Genotype 1113-3STR was significantly different from 1109-21STR (187 cm), Oba Super 1 (179.5 cm), 8338-1 (177 cm), 0501-2STR (176 cm) and 0601-6STR (153 cm) and was not significantly different from the remaining genotypes. PHB 30G19 was not significantly different from 1109-21STR but was significantly different from Oba Super 1, 8338-1, 0501-2STR and 0601-6STR. The ranking order for plant height was 1113-3STR≥ PHB 30G19, 1113-13STR, 1113-2STR, 9022-13, 0804-7STR, SC 627, 0501-1STR, 1001-3STR> 1109-21STR, Oba Super 1, 8338-1, 0501-2STR and 0601-6STR.

4.1.2   *Striga* -infested environment

Under the *Striga* -infested environment, variables were analysed for Katete, Lundazi and across location (G X E).

4.1.2.1 Katete

Table 6 presents the ANOVA for measured parameters at Katete in 2013/14 season. Significant differences (p=0.05) were observed for days to 50% flowering, *Striga* count at 14 WAP days to maturity, cob diameter and cob length. No significant differences were observed for SDR, plant height at harvest, grain yield, *Striga* count at 10 WAP and *Striga* count at 12 WAP.

Table 5: Means of measured parameters of genotypes evaluated at the University of Zambia field station under *Striga* -free environment in 2013/2014

Genotype	GY (T/Ha)	CD (cm)	CL (cm)	D50FLOW	DMAT	PHH (cm)
0501-1STR	4.94	4.47	13.12	64.5	134	201
0501-2STR	12.48	4.60	13.06	66.0	137	176
0601-6STR	5.37	3.97	13.84	64.5	134	153
0804-7STR	4.83	4.21	12.41	65.5	136	204
1001-3STR	7819	4.49	16.01	64.5	134	197
1109-21STR	7.15	4.28	12.81	64.5	134	187
1113-13STR	8.28	4.83	13.62	65.5	136	211
1113-2STR	5.63	3.99	15.51	63.5	132	209
1113-3STR	5.22	4.13	14.98	63.0	131	228
8338-1	6.20	4.11	12.88	65.0	135	177
9022-13	6.49	4.32	14.22	66.0	137	208
Oba Super 1	7.71	4.75	16.44	65.5	136	180
PHB 30G19	4.92	4.28	12.79	64.5	134	225
SC 627	5.55	4.39	13.49	64.5	134	202
Mean	6.61	4.344	13.94	64.79	134.57	196.9
s.e.d	2.283	0.4121	1.405	1.858	3.715	17.6
L.S.D						38.03
C.V	8.2%	0.2%	3.4%	0.2%	0.2%	4.9

s.e.d, l.s.d and C.V indicate standard error of difference, least significant difference and coefficient of variation respectively. GY- grain yield, CD – Cob diameter, CL – Cob length, DTMAT – days to maturity, D50FLOW – days to 50% flowering, PHH – plant height at harvest

Table 6:- Analysis of variance of measured parameters of genotypes evaluated at Katete under natural *Striga* infestation during 2013/14 season

SOV	df	GY	CBD	CBL	PHH	SDR	DT50% FLOW	DTMAT	SC10 WAP	SC12 WAP	SC14 WAP
		MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Blk	2	5946307	0.96	3.91	1478	8.96	9.26	37.01	0.06	0.04	0.03
G	13	$1138826^{n.s}$	3.9***	6.7***	$267^{n.s}$	$1.9^{n.s}$	11.6***	46.3***	$0.0038^{n.s}$	$0.09^{n.s}$	0.17*
Error	26	575369	0.86	1.284	188.1	1.903	2.115	8.459	0.003762	0.086	0.07
Total	41										

*, ***and ns indicate significant (p < 0.05), highly significant (p<0.001) and non-significant respectively. S.O.V – source of variation, df – degree of freedom, GY – grain yield, CD – cob diameter, CL – cob length, PHH – plant height at harvest, SDR – *Striga* damage rating, D50 – days to 50% flowering, DMAT – days to maturity, G-genotype, Blk – block, SC10 – *Striga* count at 10 WAP, SC12 – *Striga* count at 12 WAP and SC 14 - *Striga* count at 14 WAP

Table 7:- Means of measured parameters of genotypes evaluated at Katete under natural *Striga* infestation during the 2013/14 season

Genotype	GY (T/Ha)	CD (cm)	CL (cm)	D50 FlOW	DMAT	PHH (cm)	SDR	SC10 W.A.P	SC12 W.A.P	SC14 W.A.P
0501-1STR	3.31	1.57	14.13	67.00	139.00	167.3	3.00	1.0987	1.099	1.683
0501-2STR	3.37	1.80	15.00	67.00	139.00	145.3	3.00	1.0987	1.099	1.188
0601-6STR	3.73	2.47	12.20	61.00	127.00	146.2	3.33	1.0987	1.099	1.473
0804-7STR	2.80	1.90	13.47	67.00	139.00	146.6	3.67	1.0987	1.099	1.629
1001-3STR	3.41	2.23	12.13	63.00	131.00	148.6	3.67	1.0987	1.099	1.681
1109-21STR	3.11	1.93	14.67	64.33	133.67	160.7	2.67	1.0987	1.099	1.394
1113-13STR	2.42	1.73	11.33	67.00	139.00	139.1	4.33	1.0987	1.099	1.403
1113-2STR	3.45	2.33	13.97	66.82	138.64	157.2	2.62	1.0987	1.085	1.358
1113-3STR	3.61	1.97	14.00	64.67	134.33	156.5	3.67	1.0987	1.099	1.598
8338-1	2.38	1.87	13.47	64.33	133.67	147.8	4.67	1.0987	1.372	1.820
9022-13	2.57	2.20	12.80	65.67	136.33	137.4	4.67	1.0987	1.281	1.734
Oba Super 1	3.47	2.30	12.93	67.00	139.00	164.5	2.67	1.2322	1.738	2.036
PHB 30G19	1.96	2.50	13.83	67.56	140.13	140.5	2.08	1.1109	1.175	1.919
SC 627	1.91	2.60	17.46	67.36	139.72	154.8	3.75	1.1127	1.121	1.424
Mean	2.97	2.10	13.67	65.70	136.39	150.9	3.41	1.1096	1.183	1.596
s.e.d	0.619	0.2398	0.925	1.187	2.375	11.2	1.126	0.05008	0.2394	0.2095
L.S.D		0.4930	1.902	2.441	4.881					0.4307
C.V	22%	8.6%	3.9%	1.2%	1.2%	6.8%	23.4%	1.8%	4.5%	2.8%

Where GY is grain yield, CD is cob diameter, CL is cob length, D50Flow is days to 50% flowering, DMAT is days to maturity, PHH is plant height at harvest, SDR is *Striga* damage rating, W.A.P is weeks after planting, SC is *Striga* count, l.s.d is least significant difference, C.V is coefficient of variation and s.e.d is standard errors of differences of means, KG/Ha –kilogram per hectare, cm- centimeters

a.   Days to 50% flowering

Table 7 showed that genotype PHB 30G19 67.56 days equivalent) had significantly more days to flowering (, followed by SC 627 (67.36 days equivalent), while 0601-6STR (61 days equivalent) had less days to flowering. Genotype PHB 30G19 was not significantly longer from 0501-1STR, 0501-2STR, 0804-7STR, 1113-13STR, 1113-2STR, 9022-13, Oba Super 1 and SC 627, but was significantly longer from 0601-6STR, 1001-3STR, 1109-21STR, 1113-3STR and 8338-1. Genotype 0601-6STR (61 days equivalent) was significantly different from 0501-1STR, 0501-2STR, 0804-7STR, 1113-13STR, Oba Super 1, 1113-2STR, 9022-13STR, PHB 30G19 and SC 627.

b.   *Striga* Counts (*Striga* plants per maize plant)

Table 7 showed that genotype Oba Super 1 had significantly higher number of *Striga* plants per maize plant (2.04 plants plant[-1]) followed by PHB 30G19 (1.919 plants plant[-1]), while genotype 0501-2STR had the lowest *Striga* counts. Among the genotypes, there were no significant differences between Oba Super 1 and 0501-1STR, 0804-7ST, 1001-3STR, 8338-1, 9022-13 and PHB 30G19, but significantly different from 0501-2STR, 0601-6STR, 1109-21STR, 1113-13STR, 1113-2STR, 1113-3STR and SC 627. Genotype PHB 30G19 was not

significantly different from 0501-1STR, 0804-7STR, 1001-3STR, 1113-3STR, 8338-1, Oba Super 1 and 9022-13, but was significantly different from 0501-2STR, 0601-6STR, 1109-21STR, 1113-13STR, 1113-2STR and SC 627. Genotype 0501-2 (1.188 plants plant^{-1}) was significantly different from 8338-1, Oba Super 1 and PHB 30G19.

c.   Days to maturity

Table 7 showed that genotype PHB 30G19 significantly had the highest number of days to maturity (140.13 days eq.) followed by SC 627 (139.72 eq.), while 0601-6STR (127 days eq.) had the lowest days to maturity. Genotype PHB 30G19 was not significantly different from 0501-1STR, 0501-2STR, 0804-7STR, 1113-13STR, 1113-2STR, 9022-13, Oba Super 1 and SC 627, but was significantly different from 0601-6STR, 1001-3STR, 1109-21STR, 1113-3STR and 8338-1. Genotypes 0601-6STR (127 days eq.) was significantly different from 1109-21STR, 1113-3STR and 8338-1.

d.   Cob diameter

Table 7 showed that SC 627 had a significantly higher cob diameter (2.60 cm equivalent) followed by PHB 30G19 (2.50 cm eq.), while 0501-1STR (1.57 cm eq.) had a lowest cob diameter. Genotype PHB 30G19 was not significantly different from 0601-6STR and PHB 30G19, but was significantly different from , 1001-3STR, 9022-13, 1113-2STR, Oba Super 1, 0501-1STR, 0501-2STR, 0804-7STR, 1109-21STR, 1113-13STR, 1113-3STR and 8338-1. The genotype PHB 30G19 was the next highest (2.5 cm equivalent). It was not significantly different from 0601-6STR and SC 627, but was significantly different from the remaining genotypes. The genotype 0501-1STR was significantly different from 0601-6STR, 1001-3STR, 1113-2STR, Oba Super 1, PHB 30G19, 9022-13 and SC 627.

e.   Cob length

Table 7 showed that SC 627 had a significantly ($p < 0.001$) higher cob length (17.46 cm equivalent) followed by 0501-2STR (15 cm equivalent), while 1113-13STR (11.33 cm eq.) had the lowest cob length. Among the genotypes SC 627 was significantly different with all the other genotypes. Genotype 0501-2STR was not significantly different from 0804-7STR, 0501-1STR, 1109-21STR, 1113-2STR, 1113-3STR, 8338-1 and PHB 30G19, but was significantly different from 0601-1STR, 1001-3STR, 1113-13STR, 9022-13, Oba Super 1 and SC 627. The genotype 1113-13STR was significantly different from 0501-1STR, 0501-

2STR, 1109-21STR and SC 627, 0804-7STR, 8338-1, PHB 30G19, 1113-2STR and 1113-3STR.

4.1.2.2 Lundazi

Table 8 presents the ANOVA for measured parameters at Lundazi in 2013/14 season. Significant differences (p=0.05) were observed for SDR, *Striga* count at 12 WAP, *Striga* count at 14 WAP, cob diameter, cob length and grain yield. No significant differences were observed for days to 50% flowering, days to maturity and plant height at harvest.

Table 8:- Analysis of variance of measured parameters for genotypes evaluated at Lundazi under natural *Striga* infestation during the 2013/14 season

S.O.V	df	GY	CD	CL	PHH	SDR	DT50% FLOW	DMAT	SC 10 W.A.P	SC 12 W.A.P	SC 14 W.A.P
		MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Block	2	20712257	0.047	0.362	347.32	1.5	8.357	33.429	1.179	2.587	2.559
G	13	8738929*	0.2***	3.8**	37.04$^{n.s}$	2.6***	2.51$^{n.s}$	10.02$^{n.s}$	0.33$^{n.s}$	1.2***	1.057***
Error	26	3143277	0.015	1.01	32.44	0.577	1.665	6.659	0.207	0.301	0.263
Total	41										

*, **, ***and ns indicate significant (p =0.05), (p=0.01), (p<0.001) and non-significant respectively. S.O.V – source of variation, df – degree of freedom, GY – grain yield, CD – cob diameter, CL – cob length, PHH – plant height at harvest, SDR – *Striga* damage rating, D50 – days to 50% flowering, DMAT – days to maturity, G- genotype, Blk – block, SC10 – *Striga* count at 10 WAP, SC12 – *Striga* count at 12 W. A. P and SC 14 - *Striga* count at 14 W   AP

a.   *Striga* **Damage Rating (SDR)**

Table 9 showed that genotype 8338-1 had significantly higher SDR (4.67 eq.) followed by 9022-1 (4.33 eq.), while 1001-3STR, 1113-3STR and SC 627 had the lowest (2 eq. each). Genotype 8338-1 was not significantly different from 0501-2STR, 0804-7STR and 9022-13, but was significantly different from the remaining genotypes. Genotype 9022-13 gave the next highest SDR (4.33 eq.). It was not significantly different from 0501-2STR, 0804-7STR, Oba Super 1 and 8338-1, but was significantly different from 0501-1STR, 1001-3STR, 1109-21STR, 0601-6STR, 1113-13STR, 1113-2STR, 1113-3STR, PHB 30G19 and SC 627. The genotypes with the lowest SDR were 1001-3STR (2 equivalent), 1113-3 (2 equivalent) and SC 627 (2 equivalent). These genotypes were not significantly different from each other. They were all significantly different from 0501-2STR, Oba Super 1, 9022-13, 8338-1 and 0804-7STR.

Table 9:- Means for measured parameters of genotypes evaluated at Lundazi under natural *Striga* infestation during 2013/14 season

GENOTYPE	GY (T/Ha)	CD (cm)	CL (cm)	D50 FlOW	DMAT	PHH (cm)	SDR	SC10 W.A.P	SC12 W.A.P	SC14 W.A.P
0501-1STR	12.42	4.25	15.37	67	139	200.77	3.00	1.099	1.633	1.633
0501-2STR	10.16	4.48	17.23	68	141	201.97	3.67	1.277	1.439	1.536
0601-6STR	10.89	4.68	15.43	67	139	205.17	2.33	1.237	1.542	1.664
0804-7STR	10.06	4.53	15.23	69	143	205.10	4.33	1.099	1.099	1.191
1001-3STR	10.32	4.50	15.63	68	141	203.23	2.00	1.311	1.583	1.691
1109-21STR	11.68	4.74	16.60	68	141	207.67	2.33	1.277	2.003	1.928
1113-13STR	14.94	4.70	15.17	68	141	200.50	3.00	1.099	1.315	1.315
1113-2STR	12.98	4.85	16.43	67	141	205.90	2.33	1.328	1.477	1.608
1113-3STR	13.74	4.71	15.83	67	139	204.53	2.00	1.194	1.246	1.364
8338-1	8.91	4.71	15.87	69	139	200.33	4.67	2.149	3.060	3.060
9022-13	9.38	4.65	13.93	69	143	204.33	4.33	1.846	2.625	2.625
Oba Super 1	11.95	5.00	14.63	69	143	193.33	3.33	1.802	2.850	2.856
PHB 30G19	11.75	5.23	17.83	66	137	202.23	2.67	1.717	2.337	2.337
SC 627	12.42	5.20	17.70	67	139	200.43	2.00	1.337	1.576	1.576
Mean	11.54	4.73	15.92	67.71	140.43	202.54	3.00	1.412	1.842	1.886
s.e.d	1.448	0.1015	0.819	1.054	2.107	4.650	0.62	0.3712	0.4479	0.4188
L.S.D	2.976	0.2087	1.683				1.275		0.9206	0.8610
C.V	10.5%	1.2%	1%	1.1%	1.1%	2.5%	10.9%	20.5%	23.3%	22.7%

Where GY is grain yield, CD is cob diameter, CL is cob length, D50Flow is days to 50% flowering, DMAT is days to maturity, PHH is plant height at harvest, SDR is *Striga* damage rating, W.A.P is weeks after planting, SC is *Striga* count, l.s.d is least significant difference, C.V is coefficient of variation and s.e.d is standard errors of differences of means, KG/Ha –kilogram per hectare, cm- centimeter

b. ***Striga* Counts (*Striga* plants per maize plant)**

Table 9 showed that genotype 8338-1 had significantly (p<0.001) higher *Striga* plants per maize plant (3.06 plants plant^{-1}), followed by Oba Super 1 (2.86 plants plant^{-1}), while 0804-7STR (1.191 plants plant^{-1}) had the lowest *Striga* counts. The *Striga* counts ranged between 1.191 plants plant^{-1} and 4.67 plants plant^{-1}. The best top five performers i.e. those with lower *Striga* counts were 0804-7STR, 1113-13STR, 1113-3STR, 0501-2STR and SC 627; while those with highest numbers were 8338-1, 9022-13, Oba Super 1 and PHB 30 G19. Genotypes Oba Super 1 and 8338-1 were not significantly different from each other, 9022-13 and PHB 30G19, but were significantly different from 0501-1STR, 0501-2STR, 0601-6STR, 0804-7SR, 1001-3STR, 1109-21STR, 1113-13STR, 1113-2STR, 1113-3STR and SC 627. Genotype 9022-13 was significantly different from all the other genotypes except 1109-21, Oba Super and 8338-1and PHB 30G19. No significant differences were observed among 0501-2STR, 0501-2STR, 0601-6STR, 0804-7STR, 1001-3STR, 1109-21STR, 1113-13STR, 1113-2STR, 1113-3STR and SC 627. The genotype 0804-7STR (1.191 plants plant^{-1}) was significantly different from 8338-1, 9022-13, Oba Super 1 and PHB 30G19, but was not significantly different with the remaining genotypes.

c.   Cob diameter

Table 10 showed that PHB 30G19 had significantly bigger cob diameter (5.3cm equivalent), followed by SC 627 (5.2 cm equivalent), while 0501-1STR (4.25cm equivalent) had a smallest. Genotype PHB 30G19 was significantly different from all the other genotypes except SC 627. The genotype SC 627 gave the next highest cob diameter (5.2 cm equivalent). It was not significantly different from Oba Super 1 and PHB 30G19 but was significantly different from all the remaining genotypes. The genotype 0501-1STR was significantly different from all genotypes.

d.   Cob length

Table 9 showed that genotype PHB 30G19 had a significantly higher cob length (17.83 cm equivalent), followed by SC 627 (17.7 cm equivalent), while 9022-13 (13.93 cm equivalent) had the lowest. Genotype PHB 30G19 was significantly different from 0501-1STR, 0601-6STR, 0804-7STR, 1001-3STR, 1113-13STR, 1113-3STR 8338-1, 9022-13 and Oba Super 1. Genotype SC 627 was not significantly different from 0501-2STR, 1109-21STR, PHB 30G19 and 1113-2STR, but was significantly different from all the other genotypes. Genotype 9022-13 was significantly different from 0501-2STR, 1109-21STR, 1113-2STR, PHB 30G19, 1001-3STR, 1113-3STR, 8338-1 and SC 627.

e.   Grain yield

Table 9 showed that genotype 1113-13STR recorded the highest grain yield (14, 939 kgha^{-1} equivalent) followed by 1113-3STR (13,737 kgha^{-1} equivalent), while 8338-1 (8, 907 kgha^{-1} equivalent) recorded the least yield. The susceptible genotypes 8338-1 and 9022-13 gave the lowest yield. Genotype 1113-13STR was significantly different from 0501-2STR, 0602-6STR, 0804-7STR, 1001-3STR, 1109-21STR, 8338-1, 9022-13, Oba Super 1 and PHB. Genotype 1113-3STR was significantly different from 0501-2STR, 1001-3STR, 0804-7STR, 8338-1 and 9022-13. The genotype 8338-1 (8, 907 kgha^{-1} equivalent) was significantly different from 0501-1STR, SC 627, 1113-2STR, 1113-13STR and 1113-3STR.

4.1.2.3 Across Location

The ANOVA showed significant differences among genotypes for days to 50% flowering, days to maturity, *Striga* count at 12 WAP, *Striga* count at 14 WAP, and grain yield (Table 10).

Table 10:- Analysis of variance of measured parameters of genotypes evaluated across location under natural *Striga* infestation during 2013/14 season

S.O.V	df	GY MS	CD MS	CL MS	PHH MS	SDR MS	D50 MS	DMAT MS	SC10 MS	SC12 MS	SC14 MS
E	1	1.5E+09	145.334	106.4	56027.3	3.592	85.6	342.23	1.924	9.113	1.769
Block	4	1.3E+07	0.251	2.138	912.8	5.232	8.81	35.22	0.592	1.314	1.294
G	13	5.09E+06	0.455	8.728	130.9	3.230	7.72	30.88	0.177	0.909	0.905
G X E	13	4.78E+06**	0.066^{ns}	1.768^{ns}	173.3^{ns}	1.268^{ns}	6.35*	25.40*	0.152^{ns}	0.375*	0.320*
Error	52	1.86E+06	0.051	1.145	110.3	1.240	1.89	7.56	0.105	0.193	0.165
Total	83										

* and ns indicate significant ($p < 0.05$) and non-significant. S.O.V – source of variation, df – degree of freedom, GY – grain yield, CD – cob diameter, CL – cob length, PHH – plant height at harvest, SDR – *Striga* damage rating, D50 – days to 50% flowering, DMAT – days to maturity, E- environment, G- genotype, SC10 – *Striga* count at 10 WAP, SC12 – *Striga* count at 12 WAP and SC 14 - *Striga* count at 14 WAP

a.   Days to 50% flowering

Table 11 showed that Oba Super 1 required more days to attain 50% flowering (68 days equivalent). It was followed by 0804-7STR and the genotype that required the least days to attain 50% flowering was 0601-6STR. Oba Super 1 was significantly different from 0601-6STR, 1001-3STR, 1109-21STR, 1113-3STR and 8338-1, but was not significantly different from all the remaining genotypes. The genotypes that gave the lowest days to 50% flowering were 1001-3STR (65.5 days equivalent) and 0601-6STR (64 days equivalent). They were both not significantly different from each other but were both significantly different from 0501-2STR, 1113-2STR, 0804-7STR, 1113-13STR, SC 627, 9022-13 and Oba Super 1. Genotype 0601-6STR was significantly different from 0501-1STR, 1113-3STR, 8338-1, 1109-21STR and PHB 30G19 but 1001-3STR was not.

b.   *Striga* Counts (*Striga* plants per maize plant)

There were highly significant differences ($p<0.01$) among locations, genotypes and their interactions (G X E) for *Striga* count. The mean square value for location was higher than genotype by environment interaction (Table 10). *Striga* count ranged between 1.359 plants/plant and 2.446 plants/plant. The mean *Striga* count was 1.741 plants/plant. The genotypes 1113-13STR (1.36) and 0501-2STR (1.36) recorded the lowest *Striga* count, followed by 0804-7STR (1.41), and the highest was in Oba Super 1 (2.45). The best top five performers i.e. with the lowest number of *Striga* were 1113-13STR, 0501-2STR, 0804-7STR, 1113-2STR and 1113-3STR, and those with the highest numbers were Oba Super 1, 8338-1, 9022-13 and PHB 30G19.

Table 11:- Means for measured parameters of genotypes evaluated across locations under natural *Striga* infestation during 2013/14 season

Genotype	GY (T/ha)	CD (cm)	CL (cm)	D50% Flow	DMAT	PHH (cm)	SDR	SC10 W.A.P	SC12 W.A.P	SC14 W.A.P
0501-1STR	7.87	2.91	14.75	67	139	184	3	1.099	1.366	1.658
0501-2STR	6.77	3.14	16.12	67.50	140.00	173.6	3.33	1.188	1.269	1.362
0601-6STR	7.31	3.57	13.82	64.00	133.00	175.7	2.80	1.168	1.320	1.568
0804-7STR	6.43	3.22	14.35	68.00	141.00	175.9	4.00	1.099	1.099	1.410
1001-3STR	6.86	3.37	13.88	65.50	136.00	175.9	2.83	1.205	1.341	1.686
1109-21STR	7.40	3.34	15.63	66.17	137.33	184.2	2.50	1.188	1.551	1.661
1113-13STR	8.68	3.23	13.25	67.50	140.00	169.8	3.67	1.099	1.207	1.359
1113-2STR	8.22	3.59	15.20	67.41	139.82	181.6	2.48	1.209	1.281	1.483
1113-3STR	8.67	3.34	14.92	65.83	136.67	180.5	2.83	1.146	1.172	1.491
8338-1	5.64	3.29	14.67	65.67	136.33	174.1	4.67	1.624	2.216	2.440
9022-13	5.97	3.43	13.37	67.33	139.67	170.9	4.50	1.473	1.953	2.180
Oba Super 1	7.71	3.65	13.78	68.00	141.00	178.9	3.00	1.517	2.294	2.446
PHB 30G19	6.85	3.86	15.83	66.78	138.56	171.4	2.38	1.414	1.756	2.128
SC 627	7.16	3.90	17.58	67.18	139.36	177.6	2.88	1.225	1.348	1.500
Mean	7.25	3.42	14.80	66.70	138.41	176.7	3.21	1.261	1.512	1.741
s.e.d	0.7873	0.1302	0.618	0.794	1.587	6.06	0.643	0.1873	0.2539	0.2342
l.s.d	1.5798			1.593	3.185				0.5095	0.4699
C.V	13.5%	3.9%	2.6%	1.2%	1.1%	4.6%	19.1%	16.3%	20.3%	17.5%

Where GY is grain yield, CD is cob diameter, CL is cob length, D50Flow is days to 50% flowering, DMAT is days to maturity, PHH is plant height at harvest, SDR is *Striga* damage rating, W.A.P is weeks after planting, SC is *Striga* count, l.s.d is least significant difference, C.V is coefficient of variation and s.e.d is standard errors of differences of means

c.   Days to maturity

Significantly the highest number of days to maturity was recorded for genotype Oba Super 1 (141 days equivalent) and 0804-7STR (141 days equivalent) while the lowest number of days to maturity was recorded for genotype 0601-3STR (133 days equivalent) (Table 11). Oba Super 1 and 0804-7STR were both significantly different from 0601-6STR, 1001-3STR, 1109-21STR, 1113-3STR and 8338-1 except for all the remaining genotypes. Genotypes 0501-2STR and 1113-13STR had the next longest days to maturity of 140 days equivalent. They were significantly different from 0601-6STR, 1001-3STR, 1113-3STR and 8338-1 but were not significantly different from all the remaining genotypes. The genotypes that gave the lowest days to maturity were 1001-3STR (136 days equivalent) and 0601-3STR (133 days equivalent). They were not significantly different from each other but were both significantly different from 0501-2STR, 0804-7STR, 1113-13STR, 1113-2STR, 9022-13, SC 627 and Oba Super 1. Genotype 1001-3STR was not significantly different from 8338-1, 1113-3STR, 1109-21STR, PHB 30G19 and 0501-1STR but 0601-6STR was (Table 11).

d.   Grain yield

Table 11 showed that 1113-13STR had significantly higher grain yield (8, 680 kgha^{-1} equivalent) followed by 1113-3STR (8, 672 kgha^{-1} equivalent), while the least yielding was 8338-1 (5, 644 kgha^{-1} equivalent). Genotype 1113-13STR was significantly different from 0501-2STR, 0804-7STR, 1001-3STR, 8338-1, 9022-13 and PHB 30G19. Genotype 1113-3STR was significantly different from PHB 30G19, 9022-13, 8338-1, 0501-2STR, 0804-7STR and 1001-3STR. The genotype 8338-1 (5, 644 kgha^{-1} equivalent) was significantly different from 0601-6STR and 1109-21STR 0501-1STR, Oba Super 1, 1113-2STR, 1113-13STR and 1113-3STR. A 9% increase in grain yield was observed.

4.1.3 Relationship among characters

The correlation studies revealed that grain yield was positively correlated to cob diameter, cob length, days to 50% flowering, plant height and days to maturity but negative correlation with SDR (Table 12). The associations were highly significant (p<0.01). The SDR was also significantly correlated to plant height, cob diameter and cob length, while days to maturity were positively associated with cob diameter, cob length and plant height.

Table 12:- Correlation between grain yield and different variables of maize across locations

	SC10 W.A.P	SC12 W.A.P	SC14 W.A.P	PHH	GY	CD	CL	SDR	D50FLOW	DMAT
SC10 W.A.P	-	0.85***	0.82***	0.34***	0.196	0.37***	0.10	0.21	0.17	0.17
SC12 W.A.P	-	-	0.93***	0.41***	0.296**	0.48***	0.16	0.17	0.24*	0.24*
SC14 W.A.P	-	-	-	0.19	-0.056	0.25*	- 0.025	0.24*	0.09	0.09
PHH	-	-	-	-	0.86***	0.88***	0.60	-0.37***	0.36***	0.36***
GY	-	-	-	-	-	0.908***	0.55***	-0.290**	0.40***	0.40***
CD	-	-	-	-	-	-	0.62***	-0.2189	0.39***	0.39***
CL	-	-	-	-	-	-	-	-0.2495*	0.27**	0.27**
SDR	-	-	-	-	-	-	-	-	-0.01	-0.01
D50FL	-	-	-	-	-	-	-	-	-	1**
DMAT	-	-	-	-	-	-	-	-	-	-

SC – *Striga* Count, WAP – week after planting, PHH – Plant height at harvest, GY – grain yield, CD – Cob diameter, CL – cob length, SDR – *Striga* damage rating, D50FL – days to 50% flowering and DMAT – days to maturity

The relationship between grain yield and the *Striga* -resistance traits were examined to determine how well the genotypes could withstand infestation, as a *de facto* measure of resistance.

A comparison of *Striga* numbers and grain yield under *Striga* -infested environment was illustrated in Figure 4. It was observed in Figure 4 that the higher the *Striga* numbers the lower the grain yield of maize. It was observed in the susceptible genotypes 8338-1 and 9022-13. However, genotypes such as Oba Super 1 and PHB 30G19 gave high *Striga* numbers similar to the susceptible ones but there yields were much better (these were tolerant).

A comparison of SDR and grain yield under *Striga* -infested environment is illustrated in Figure 5. It can be seen that genotypes with a high SDR gave lower yields as compared to those that had lower SDR. The susceptible genotypes (8338-1 and 9022-13) had SDRs above 4 and they gave the lowest yields.
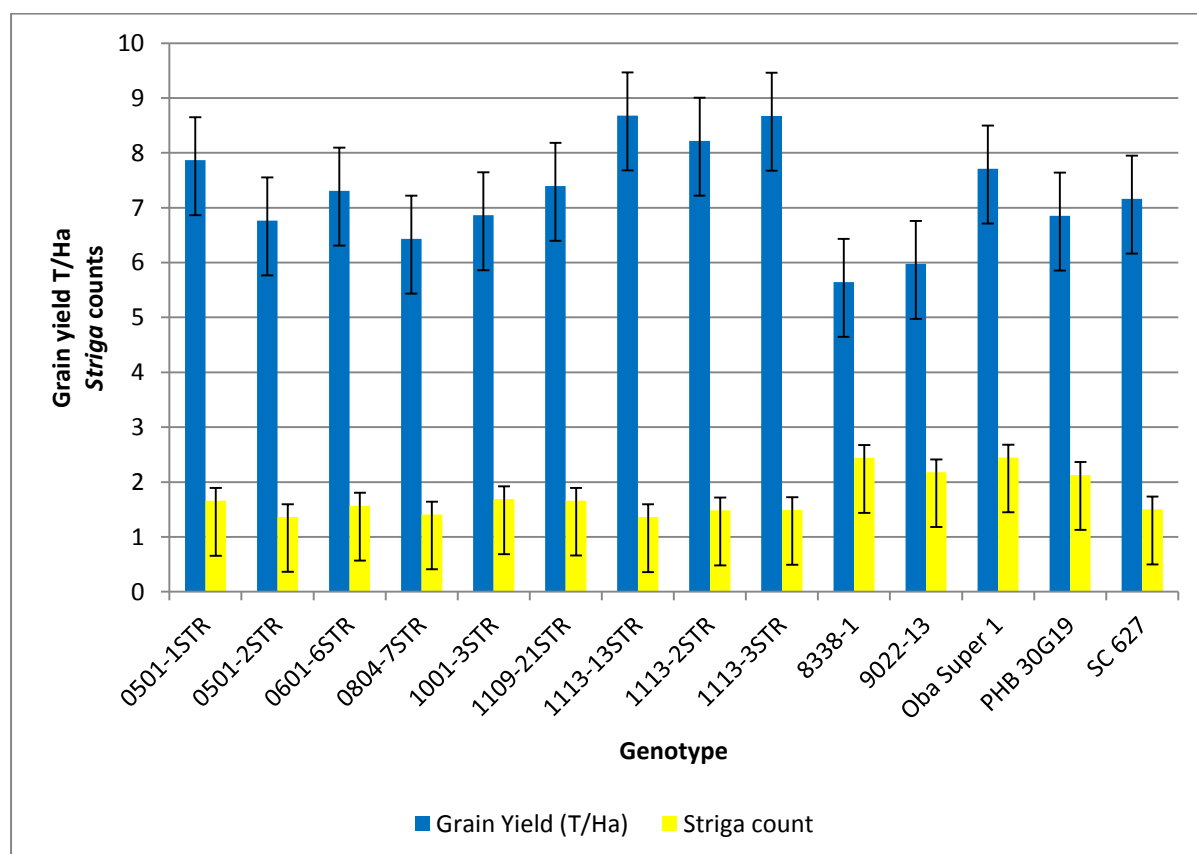

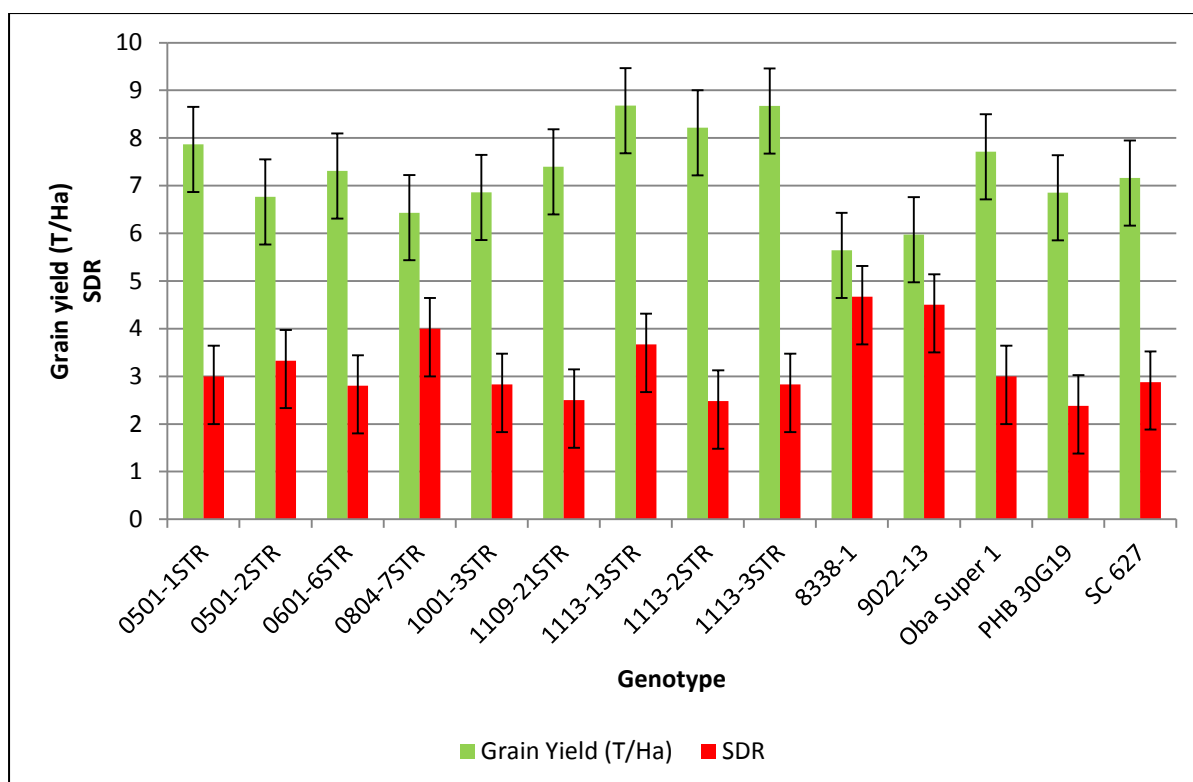**Fig 4:** *Striga* **numbers and effect on the grain yield of maize**

Fig 5: Reaction of maize genotypes to *Striga asiatica*

4.2   Laboratory experiment

Genotype 1113-3STR had the least *Striga* counts per well-plate (1.26) (Table 14). This was, however, not significantly different from the control (distilled water, 1.28) and SC 627 (1.34) but was significantly different from the positive control (GR24), 1113-13STR (1.45) and 1113-2STR (1.40). Genotype SC 627 was significantly different from the positive control (GR24) but was not significantly different from the other three genotypes and the negative control. Genotype 1113-2STR was not significantly different from 1113-13STR (which had the highest *Striga* count), SC 627 and the negative control (distilled water) but was significantly different from the positive control (GR24) and 1113-3STR (Table 14).

Table 13:- Analysis of variance of *Striga* count for the laboratory experiment

S.O.V	df	SC MS
Treatment	5	0.055284**
Error	24	0.007161
Total	29	

* indicate significant p= 0.05, SC – *Striga* count

Table 14:- Means for *Striga* count for the laboratory experiment

Genotype	*Striga* count
1113-13STR	1.45
1113-2STR	1.397
1113-3STR	1.264
SC 627	1.335
Negative Control (distilled Water)	1.281
Positive Control (GR24)	1.542
Mean	1.377
s.e.d	0.0605
l.s.d	0.1249
C.V	7%

It was observed that the *Striga* count for genotypes 1113-13STR, 1113-2STR and SC 627 was higher than that of negative control (distilled water) by 13%, 9% and 5% respectively and lower than that of the positive control (GR24) by 6%, 10% and 15% respectively. In genotype 1113-3STR it reduced by 1% that of water. Numerically, the *Striga* numbers were similar to that of control (distilled water) and most well-plates had no *Striga* germinated.

CHAPTER FIVE - DISCUSSION

5.1   Performance of maize under *Striga* infestation

Firstly, Olupot *et. al*., (2003) also found similar results where they found variations in the flowering patterns of the sorghums in *Striga* –infested environments but no significant differences under non-infested environments were observed. These differences observed for days to 50% flowering in Katete could be attributed to dry spell that was experienced for most part of the growing season. Water is key in nutrient uptake and an important component in various processes of the plant e.g. photosynthesis (O'keefe and Schipp, 2009). In the *Striga* infested environment, genotypes had delayed flowering as compared to the *Striga*-free environment. In actuality, there was a 1.4%, 2% and 4.5% delay in flowering at Katete, across environments and in Lundazi, respectively. This delay could be attributed to the fact that stressed environments induced delayed flowering in maize. Furthermore, *Striga asiatica* induces stress leading to impaired photosynthesis (by limiting stomatal conductance and sensitizes infested plants to photo-inhibition) (Johnson, 2005, Elzein and Broschel, 2004) while at the same time robbing the plant of water and nutrients (CDFA, 2006; Gurney *et. al*., 2001), which are important in the initiation of flowering (O'keefe and Schipp, 2009). Therefore, with a reduction in these elements, the initiation of flowering will be delayed, hence, causing a delay in flowering (O'keefe and Schipp, 2009). Karaya *et. al*., (2012a) found a 5-day delay in susceptible maize genotypes. Showemimo, (2006) observed a 9% delayed days to 50% flowering for pre-flowering stress under *Striga*-infested conditions. Kim *et. al*., (1997) while testing several maize cultivars under different nitrogen levels also reported delayed flowering.

Genotypes were not significantly different for days to maturity under *Striga*-free environment but were significantly different under *Striga* infestation when considered across all environments and in particular at Katete. It was observed that days to maturity were delayed by 1.2% and 2.9% in Katete and across all environments, respectively. The observed differences among genotypes for days to maturity under *Striga* infestation manifested genotypic differences in reaction to stress from *Striga* (Olupot, 2003). *Striga* competes with the maize crop, hence, causing reduced assimilate supply and water uptake causing the crop to have a delayed days to maturity (Rich and Ejeta, 2008). Maturity of maize is affected by

competition from other plants, water stress, assimilate supply and temperature (Okeere and Schipp, 2009), which *Striga* exerted in the *Striga* infested environment.

The relationship between days to maturity and *Striga* count was a low, positive significant correlation (r= 0.24*, r^2 = 0.06) at 12WAP. This means that *Striga* count had a very minimal influence (of less than 1%) on days to maturity. High *Striga* count results in high infestation subjecting the crop to high stress due to resultant competition for water and nutrients (Ransom and Odhiambo, 1995). Genotype 0501-2STR with 140 days had fewer *Striga* emergence than 0601-6STR (133 days). Also, genotype 113-13STR with 140 days had fewer *Striga* emergence compared to Oba Super 1 with 141 days. However, the opposite was observed by Ransom *et. al*., (1997) with genotypes with fewer days to physiological maturity had less parasite emergence unlike those with more days to physiological maturity (attributed to the longer vegetative growth phase, to which *Striga* growth pattern is synchronised).

Plant height was reduced by 10.3% for across environments as a result of *Striga*. Furthermore, stunting of plants was observed in Katete, where plant height was reduced by 23.4% but no stunting was observed in Lundazi generally. The differences in plant height were due to differences in varietal responses to *Striga* between the two locations and differences in prevailing weather conditions (rainfall, temperature) at the time. Effects of *Striga* affected the normal processes in the plant such as photosynthesis (Johnson, 2005), nutrient uptake, water uptake and transport which are essential in stem elongation. Yagoub *et. al*., (2014) and Makoko and Sibuga, (2003) observed that plant grown in *Striga* infested environments were stunted. Showemimo (2006) also showed that *Striga* infestation reduced plant height of sorghum by 13.7% while Vasey (2005) reported that *Striga* infestation in wheat severely lowered plant height (24%). Further, Sinebo and Drennan (2001) observed that *Striga* reduced sorghum stem height by 22% at 38 DAP and by 34% at 64 DAP. Olupot *et. al*., (2003) reported that sorghum plant height was significantly affected by *Striga* since the infested environment had significantly shorter plants compared to the non-infested environment. Hence, as seen from the outcomes of this study and corroborated by others, *Striga* infestation resulted in stunted shoots and alteration in the whole plant allometry.

The relationship between plant height at harvest and SDR was moderate, negative and highly significant correlation (r = -0.4***, r^2 = 0.16). This means that the reaction to *Striga* though moderate contributed to the reduction of plant height by 16%.

Genotypes were not significantly different for cob length and cob diameter under *Striga* infestation when considered across all environments. That was also observed under the *Striga*-free environment. However, significant differences were observed for both variables in each of the individual environments. Generally, cob diameter was reduced by 21% in the *Striga* infested environment when considered across locations while cob length increased by 6%. Environment stress (i.e. lack of water, lack of nutrients) affects the vegetative stage (where initiation of flowering, ear initiation and stem elongation, occur) and the kernel production stage. Plants become stunted and the cob length and cob diameter reduce (Okeere and Schipp, 2009). *Striga asiatica* competes with the host plant for nutrients, water, and so on hence affecting the above mentioned stages resulting in stunted plants and reduced cob (in length and diameter) and kernels. A reduction in cob diameter means the kernels are also reduced in size and number, thereby, reducing yield (Okeere and Schipp, 2009). The simple correlation of cob diameter and grain yield revealed that cob diameter influenced yield under *Striga* with a high, positive and highly significant correlation ($r = 0.91^{***}$, $r^2 = 0.83$). The correlation between cob length and yield revealed a moderate, positive and highly significant correlation ($r = 0.55^{***}$, $r^2 = 0.30$). Cob length and cob diameter were also related and the analysis revealed moderate, positive and highly significant correlation ($r = 0.62^{***}$, $r^2 = 0.38$). Plant height was also related to cob diameter and cob length, with a high, positive and highly significant correlation ($r = 0.88^{***}$, $r^2 = 0.72$) for cob diameter and a moderate, positive and non significant correlation ($r = 0.6$, $r^2 = 0.36$) for cob length. This means that the 72% and 36% of the total variation in cob diameter and cob length respectively was a result of a relationship with plant height. When cob diameter and cob length were related to SDR, the both gave a weak but negative and significant correlation ($r = -0.22^*$ [$r^2 = 0.05$] for cob diameter) and ($r = -0.25^*$ [$r^2 = 0.06$] for cob length). This means that the number of symptoms to *Striga*/reaction to *Striga* caused variations in the cob diameter and cob length by 5% and 6% respectively.

The current study results also revealed that genotypes were not significantly different for SDR under *Striga* infestation when considered across environments, however genotypic differences were observed in Lundazi .These differences manifested genotypic differences in reaction to *Striga*. The SDR is a score which uses the symptoms manifested by the genotype. The symptoms that *Striga* causes include stunting, wilting and chlorosis (Sand *et. al*., 1990; Agrios, 2005). These symptoms tell us that many processes such as water uptake, nutrient uptake and photosynthesis are negatively affected (Agabawi and Younis, 1965; O'keefe and

Schipp, 2009). The numerical differences observed were used as a basis for distinguishing the different genotypes into the following categories: Genotypes that had a score of between 2.4 and 4 (0501-1STR, 0501-2STR, 0601-6STR, 1113-3STR, 0804-7STR, 1001-3STR, 1109-21STR, 1113-2STR, 1113-13STR, Oba Super I, PHB 30G19 and SC 627) were considered resistant on the Likett scale as propounded by Kim (1994). Only two genotypes scored above 4 (8338-1 and 9022-13) and these were considered susceptible on the Likett scale. It was seen that 9022-13 which was resistant to *Striga hermonthica*, was susceptible to *Striga asiatica*. This could have been due to instability of resistance to *Striga* spp. in the genotype, in that, the genotype responded differently to the two *Striga* spp. / strains. Vasudeva Rao *et. al.*, (1983) coined this after they observed a resistant sorghum cultivar to Striga asiatica being resistant to *Striga asiatica* from three locations and susceptible to *Striga asiatica* from one location. This showed differences in reaction to different *Striga* strains. Genotype 8338-1 was susceptible to both *S. hermonthica* and *S. asiatica*. In this study, it was found that all genotypes possessing *Striga hermonthica* resistance were also resistant to *Striga asiatica* except 9022-13. Adetimirin *et. al.*, (2000) using the Likket scale was able to categorise genotypes in a similar manner.

A moderate, negative and highly significant correlation was observed between SDR and plant height at harvest ($r = 0.37^{***}$, $r^2 = 0.14$). This means that the higher the SDR score, the more stunted the genotype is. Plant height is a direct manifestation of assimilate accumulation from photosynthesis (Okeefe and Schipp, 2009).With the high SDR implying severe impairment of several physiological processes including photosynthesis (CDFA, 2006); assimilate accumulation is reduced resulting in shorter plants. This reaction to *Striga* contributed 14% to the reduction in plant height at harvest.

In addition, genotypes were significantly different for *Striga* count under *Striga* infestation when considered across all environments. Significant differences were also observed at each individual environment. *Striga* emergence (count) directly related to germination stimulants exuded by crop plants (Olupot *et. al.*, 2003; Spallek, 2013). The genotypic differences observed in the present study point to differential production of germination stimulants. Susceptible genotypes like 8338-1 and 9022-13 were found to be similar to those in resistant genotypes like Oba Super 1 (Fig. 1). This is similar to the findings of Karaya *et. al.*, (2012a) and Kim (1994) who also found that *Striga* counts from resistant and moderately susceptible genotypes were not significantly different. Correlation analysis revealed that there were

strong, positive and highly significant relationships between *Striga* count at the different sampling times, i.e. between *Striga* count at 10 WAP and *Striga* count at 12 WAP (r = 0.85***, r^2 = 0.72), *Striga* count at 12 WAP and *Striga* count at 14 WAP (r = 0.93***, r^2 = 0.86) and *Striga* count at 10 WAP and *Striga* count at *Striga* count at 14 WAP (r = 0.82***, r^2 = 0.67).

There was a weak relationship between *S. asiatica* and grain yield, where grain yield. *Striga* infection did not cause reduction effect on maize grain yield and cob length it actually increased by 1%. This could be attributed to the resistance (low stimulant production) of most of the genotypes causing fewer *Striga* seeds to germinate.

Genotypes were significantly different for yield when considered under *Striga* infestation across all environments. There were no significant differences observed among all the genotypes under the *Striga* -free environment. This was also observed by Adetimirin *et. al.* (2000). Differences were seen in the individual environments were significant differences were observed for Lundazi, while non-significant differences were not observed for Katete. Genotypic differences observed for grain yield were attributed to the dry spell and high temperature experienced during most stages of plant growth which may have affected water and nutrient uptake thereby affecting silking, flowering, ear initiation, formation of kernel rows and kernel numbers (Okeere and Schipp, 2009). Generally, it was observed that there was a 9% increase in grain yield in resistant genotypes in the *Striga* infested environment as compared to the *Striga* free environment. This was because the genotypes resistant to *Striga hermonthica* were also resistant to *S. asiatica* and hence not being affected by the parasite and thereby having grain yield gains. In addition, the remarkable differences in grain yield exhibited by the genotypes under *Striga* were not related with the variation for reduction in yield components by the parasite. The susceptible genotypes yield was reduced by 8-9%. On the contrary, observations by Showemimo (2006) and Olupot *et. al.* (2003) revealed a reduction of grain yield in sorghum of up-to 45%. Adetimirin (2000) also observed differences in grain yields when genotypes were grown under *Striga* infested environment. In addition, genotypes 9022-13 and 8338-1 were also among the genotypes Adetimirin (2000) used and observed that the genotypes were susceptible to *Striga hermonthica* and grain yields were reduced with 8338-1 recording a much reduced yield as compared to 9022-13, which was also the case in this study.

The positive correlation against cob diameter and cob length were significant (p>0.05). This suggested a weak relationship between *S. asiatica* and grain yield and yield components. *Striga* infection did not cause reduction effect on maize grain yield. This was attributed to the resistance (low stimulant production) of most the genotypes causing fewer *Striga* seeds to germinate. Eight percent of the variation in grain yield was as a result of reaction of *Striga*. Similar observations were made by Kim and Adetiminin (1997) and Karaya *et. al*., (2012a). Karaya *et. al*., (2012a) reported that the significant and positive correlation between the *Striga* counts with the SDR and the decrease in grain yield of maize indicated that the possibility existed of selecting genotypes with low SDR scores and *Striga* emergence, and with higher grain yields under *Striga* infestation. In addition to what Karaya *et. al*., (2012a) reported, this can also be used in the present study where the yield was increased, to also select genotypes that are both resistant to *Striga hermonthica* and *Striga asiatica* in addition to SDR and *Striga* count.

Arising from the study the following can be inferred: that genotypes have different reactions to *Striga* infestation manifested through differences in duration to flowering with some flowering earlier than others, for example, Oba Super 1 had 68 days to 50% flowering, while 0601-6STR had 64 days to flowering; that genotypes ability to withstand *Striga* infestation as assessed via SDR varied with some being identified as resistant while others were susceptible; that genotypes had differences in the *Striga* germination stimulants produced under *Striga* infestation as seen from the differences in *Striga* numbers in the field with some genotypes having fewer *Striga* numbers than others as observed with as observed with 1113-13STR and 1113-3STR which had fewer *Striga* numbers than 8338-1 and 9022-13 (Fig. 1); Genotypes resistant to *Striga* had fewer *Striga* numbers than the susceptible ones; that genotypes had different reactions to *Striga* infestation manifested through differences in plant height were some were taller than others and that genotypes responded differently to *Striga* infestation with regard to cob length and cob diameter some having bigger cob diameter, longer cob lengths while others had smaller cob diameters, shorter cob lengths. The cob diameters or cob lengths for the susceptible genotypes were similar to those of the resistant genotypes; and, Indeed plant height was greatly influenced by *Striga* infestation;

5.2 Maize resistance to *Striga* infestation

Resistance to *Striga* in maize is manifested through low production of germination stimulants and in the present study through the laboratory experiment genotypes was able to identify to be resistant genotypes.

The genotypes exhibited different for their resistance to *Striga* as manifested by the varying ability to stimulate *Striga* germination. Karaya *et. al.*, (2012b), also observed that genotypes tested had differences in the amount of germination stimulant produced. They also observed that the positive control had the highest *Striga* germinated compared to the genotypes and distilled water. Ejeta and Butler (1993) explained that low production of host plant root exudates compounds that are essential for *Striga* germination has been the best understood mechanism of resistance to *Striga*. These researchers observed that genetic variation in crop genotypes, for signals essential for successful parasitism existed in nature or could be artificially created. These results were also corroborated by field results where the genotypes scored different SDR and also had different *Striga* counts.

The low germination stimulants (lgs) in some of the genotypes, manifested in low *Striga* numbers, could have interrupted or disrupted the germination of *Striga*. Mutengwa (2004) reported that interruption or disruption of one of the signals or resources resulted in the failure of parasitism by the pest. *Striga* resistance mechanisms had been defined on the basis of host dependent developmental processes and the essential signals exchanged between *Striga* and its hosts. Indeed Rich and Ejeta (2008) also reported that maize resistance could be expressed through low stimulation of *Striga* seed germination.

The ranking of resistant genotypes was similar to that obtained in the field (using SDR and the Likett scale), however Mutengwa, (2004) cautioned the complex interactions between host, parasite and environmental may influence germination, attachment and growth of parasite on the roots. Ejeta *et. al.*, (1991) reported that laboratory techniques were efficient in screening for individual resistance mechanisms, however, field screening was the ultimate test to identify *Striga* resistance and high yielding genotypes for some targeted environments. The three (top performers) selected genotypes which were identified to be resistant in the field also showed resistance in the laboratory. The genotypes were able to effectively interact with the parasite (by reducing its germination and growth) and environment, thereby producing high yields. However, Karaya *et. al.*, (2012b) observed that IITA inbred lines

exhibited higher germination percent although they had shown to be *Striga* resistant in the field which was contrary to what the current study observed.

CHAPTER SIX - CONCLUSION

It was evident from the study that genotypes had different reactions to *Striga* infestation manifested through differences in morphological and physiological attributes which ultimately resulted in differences in grain yield, with some having higher grain yields than others. Based on the SDR, ≈ 90% of the genotypes resistant to *Striga hermonthica* were identified to be resistant to *Striga asiatica*. The genotypes identified to be resistant had low SDR, low *Striga* counts and high maize grain yield. The highest yielders were 1113-13STR, 1113-3STR and 1113-2STR.

The mechanism of resistance observed in the current study is probably due to the production of low germination stimulants that inhibited the progression of the *Striga* life cycle at germination.

The genotypes can be tested for another season in the field, along with testing them in the screen house under artificial infestation and the laboratory for other mechanisms of resistance at haustorial development, attachment and penetration, and other stages of the life cycle of *Striga* in rhizotrons would shade more insights in the *Striga* resistance in maize.

The maize genotypes resistant to *S. asiatica* identified may be used as parents in the *S. asiatica* maize improvement programmes in Zambia in particular and across Southern Africa generally.

The study did add to the body of knowledge on the genotypes resistant to both *Striga asiatica* and *Striga hermonthica.*

REFERENCES

AAFT, 2006. Empowering African farmers to eradicate *Striga* from maize crop lands, The African Agricultural Technology Foundation, Nairobi, Kenya.

Adetimirin, V. O., M. E. Akenova and S. K. Kim, 2000. "Effects of *Striga hermonthica* on yield components in maize." Journal of Agric. Sci., 135: 185 - 191.

Agabawi, K. A and A. E. Younis, 1965. "Effect of Nitrogen application on growth and content of *Striga hermonthica* Benth and Sorghum vulgare, Lur. growth per forage." Plant soil, 23:295-304.

Agrios, G. N. (ed.), 2005. Plant Pathology, 5th Edition, Elsevier Academic Press.

Aigbokhan, E. I., D. K. Berner and L. J. Musselman, 1998. "Reproductive ability of hybrids of *Striga aspera* and *Striga hermonthica*." Phytopathology., 88: 563 – 567.

Aigbokhan, E. I., D. K. Berner, L. J. Musselman and Mignouna, H. D., 2000. "Evaluation of variability in *Striga aspera*, *Striga hermonthica* and there hybrids using morphological characters and random amplified polymorphic DNA markers." Weed research, 40: 375 – 386.

Akobundu, I. O., (1987). Weed Science in the Tropics: Principles and Practices, John Wiley and Sons, Chichester.

Amusan I. O., P. J. Rich, A. Menkir, T. Housley and G. Ejeta, 2008. "Resistance to *Striga hermonthica* in a maize inbred line derived from *Zea diploperennis*." New Phytol., 178: 157–166.

Animal and Plant Health Inspection Service (APHIS), 2000. Witch weed: A Parasitic Plant, United States Department of Agriculture Fact sheet: Plant Protection and Quarantine.

Awad, A., D. Sato, D. Kusumoto, H. Kamoka , Y. Takauchi and K. Yoneyama, 2006. "Characterisation of strigolactones, germination stimulants for root parasitic *Striga* and *Orobanche*, produced by maize, millet and sorghum."Plant growth regulation, 48: 221 – 227.

Battisti, D. S., and R. L. Naylor, 2009. "Historical warnings of future food Insecurity with unprecedented seasonal heat." Science, 323: 240 - 244.

Berner, D. K., Winslow, M. D., Awad, A. E., Cardwell, K. F., Mohan Raj, D. R., and Kim, S. K., (1997), *Striga* Research Methods- A Manual, Second Edition, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Berner, D.K., J. G. Kling and B. B. Singh, 1995. "*Striga* Research and Control: A Perspective from Africa." Plant Diseases, 79 (7): 652 - 660.

Berner, D. K., F. O. Ikie and E. I. Aigbokhan, 1994. Some control measures for *Striga hermonthica* utilizing critical infection period on maize and sorghum, Fourth eastern and southern Africa Regional Maize Conference.

Besserer, A., G. Bécard, A. Jauneau, C. Roux and N. sejalon-Delmas, 2008. "GR 24, a synthetic analog of strigolactones, stimulates the mitosis and growth of Arbscular Mychorrhzal fungus *Gigaspora rosea* by boosting its energy metabolism." Plant physiology, 148: 402 - 413.

Bouwmeester, H. J., R. Matusova, S. Zhongkui and M. H. Beale, 2003. "Secondary metabolites signalling in host - parasitic plant interactions." Plant biology, 6: 358 – 364.

Cairns J. E., K. Sonder, P. H. Zaidi, N. Verhulst, G. Mahuku, R. Babu, S. K. Nair, B. Das, B. Govaerts, M. T. Vinayan, Z. Rasid, J. J. Noor, P. Devi, F. San Vicente and B. M. Prasanna, 2012. "Maize production in a changing climate: impacts, adaptation and mitigation strategies." Adv. Agron., 114: 1–58.

CDFA (California Department of Food and Agriculture), 2006. Witchweed *Striga asiatica (L.)* Kuntze, Noxious Weed Index. (http://www.cdfa.ca.gov/phpps/ipc/weedinfo/*Striga* .htm)

Chang, M., 1986. "The haustorium and the chemistry of host recognition in parasitic angiosperms." Journal of Chemical Ecology, 12 (2):561-579.

CIMMYT and IITA, 2010. Maize- Global alliance for improving food security and the livelihoods of the resource-poor in the developing world. Draft proposal submitted by CIMMYT and IITA to the CGIAR Consortium Board, El Batan, Mexico.

Cramer, H., 1976. Weed Control (In. Minjas, A N. and Jana, R. K. (ed.)) Proceedings of a workshop on resource efficient farming methods for Tanzania May 16-20, 1983.

Central Statistical Office (CSO) Zambia, 2014. The National food balance sheet for the 2013/2014 agricultural marketing season. (http://www.zamstats.gov.zm/2014)

Coe, E.H., 2001. "The origins of maize genetics." Nature Reviews Genetics. 11 (2): 898 – 905.

De groote, H., L. Wangare, F. Kanampiu, M. Odendo, A. Daillo, and H. Karaya, 2008. "The potential of a herbicide resistant maize technology for *Striga* control in Africa." Agric. Syst., 97:83-94.

Donahue, R. L., R. W. Miller and J. C. Shickluna (ed.), 1983. Soil: an introduction to soils and plant growth, 5th edition, Prentice hall, New Jersey, U. S. A.

Dorr, I., 1996. New results on interspecific bridges between parasites and their hosts, Advances in parasitic plants research, Seville, Junta de Andelucia.

Dorr, I., and R. Kollmann, 1995. "Symplastic sieve element continuity between Orobanche and host." Bot. Acta., 108: 47-55.

Du Plessis, J., 2003. Maize Production in South Africa, Department of Agriculture, South Africa.

Elzein, A., and J. Kroschel, 2004. "*Fusarium oxysporum* Foxy 2 shows potential to control both *Striga hermonthica and S. asiatica*." European Weed Research Society Weed Research, 44: 433-438.

Ejeta, G., 2007. "Breeding for *Striga* resistance in sorghum: Exploitation of an intricate host-parasite biology." Crop Sci. 47:S216-S227.

Ejeta, G., and L. G. Butler, 1993. "Host- parasite interaction throughout the *Striga* life cycle, and their contributions to *Striga* resistance." African Crop Science Journal, 1 (2): 75-80.

Ejeta, G., L. G. Butler and A. G. Babiker, 1991. New approaches to the control of *Striga*, *Striga* research at Purdue university, Research bulletin RB- 991, Agricultural Experiment Station, Purdue University, IN, U.S.A.

Enujeke, E. C., 2013. "Effects of variety and spacing on yield indices of open-pollinated maize Asaba area of Delta State." Sustainable Agriculture research, 2(4):1-11.

FAO, FAOSTAT (2008).

FAO, FAOSTAT (2011).

FAO, FAOSTAT (2012).

Fernandeź, G., 1992. "Residual analysis and data transformations: important tools in statistical analysis." HortScience, 27 (4): 297 – 300.

Forum for Agricultural Research in Africa (FARA), 2009. Patterns of change in maize production in Africa: Implications for maize policy development, FARA, Accra, Ghana.

Frost D. L., A. L. Gurney, M. C. Press and J. D. Scholes, 1997. "*Striga hermonthica* reduces photosynthesis in sorghum: the importance of stomatal limitations and a potential role for ABA?" Plant Cell Environm., 20: 483 – 492.

Gianessi, L., and A. Williams, 2011. Herbicides in Africa, Outlook on Pest Management pp 211-215.

Gomez, A. K and A. A. Gomez, 1984. Statistical procedures for agricultural research, 2nd Edition, John Wiley and Sons, New York, USA.

Goodman, M., and S. Taba, 2007. Global Strategy for ex-situ conservation and utilization of maize germplasm, North Carolina State University, U.S.A.

Grant, R. F., B. S. Jackson, J. R. Kiniry, and G. F. Arkin, 1989. Water deficit timing effects on yield components in maize. Agron. J., 81: 61-65.

Gurney, A. L., A. Taylor, A. Mbwaga, J. D. Scholes, and M. C. Press, 2002. "Do maize cultivars demonstrate tolerance to the parasitic weed *Striga asiatica?*" *European Weed Research Society Weed Research*, 42: 299 - 306.

Gurney, A. L., D. Grimanelli, F. Kanampiu, D. Hoisington, J. D. Scholes, and M. C. Press, 2003. "Novel sources of resistance to *Striga hermonthica* in *Tripsacum dactyloides*, a wild relative of maize." New Phytologist, 160: 557 - 568.

Guillaume, B., 2008. "GR24, a synthetic analog of *Striga*lactones, stimulates the mitosis and growth of arbuscular mycorrhizal fungus Gigaspora rosea by boosting its energy metabolism." Plant physiology., 148 (1): 402 – 413.

Harper, R. M., 1944. "Preliminary report on weeds of Alabama University, Alabama." Bulletin of Geological Surveys, 53: 275.

Hassan, R., J .Ransom, and J. Ojiem, 1994. The spatial distribution and farmer's strategies to control *Striga* in maize: Survey results from Kenya, Fourth Eastern and Southern Africa Regional Maize Conference, pp. 250 – 254.

Haussmann, B. I. G., D. E. Hess, H. G. Welz, and H. H. Geiger, 2000. "Improved methodologies for breeding *Striga* resistant sorghum." Field crops Research, 66: 195 – 211.

Hess, D. E., G. Ejeta, and L. G. Butler, 1992. "Selecting sorghum genotypes expressing a quantitative biosynthetic trait that confers resistance to *Striga*." Phytochemistry, 31:493 - 497.

Heisey, P. W., and G. O. Edmeades, (999. Maize Production in Drought- Stressed Environments: Technical Options and Research Resource Allocation. Part 1 of CIMMYT 1997/1998 World Facts and Trends.

Holm, L. G., J. V. Panchu, J. P. Herberger, and D. L. Plucknett, 1991. A geographical atlas of world weeds, Kruger publishing company, Malabar, U.S.A.

Hood, M. E., J. M. Condon, M. P. Timko and J. L. Reopel, 1998. "Primary haustorial development of *Striga asiatica* on host and non-host species." Phytopathology, 88 : 70 - 75.

IITA, 2009. Maize, Ibadan, Nigeria. (http://old.iita.org/cms/maize_project/2014)

IITA, 2014. About *Striga* and Alectra, International Institute of Tropical Agriculture, Ibadan, Nigeria. (http://www.iita.org/web/*Striga* /2014)

IITA, 2010. Grant proposal information: Achieving sustainable control for poor farmers in Africa, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Japan Association for International Collaboration of Agriculture and forestry, 2008. The Maize in Zambia and Malawi, Excerpt Edition, JAICAF, Tokyo, Japan.

Johnson, A., 2005. Witchweed, New South Wales.

Karaya, H., Kiarie, N., Muga, S., Kanampiu, F., Ariga, E., and Nderitu, J., 2012a. "Identification of new maize inbred lines with resistance to *Striga hermonthica* (Del.) Benth." J. Crop Prot., 1(2): 131 - 142.

Karaya, H., K. Njoroge, S. Mugo, F. Kanampiu, E. Ariga and J. Nderitu, 2012b. "Determination of levels of *Striga* germination stimulants for maize gene bank accessions and elite inbred lines." International Journal of Plant Production, 6(2): 209 - 223.

Keyes, W. J., J. V. Taylor, R. P. Apkaran and D. G. Lynn, 2001. "Dancing together, controls in parasitic plant development." Plant physiology, 127 (4): 1508 – 1512.

Kim, S. K., V. O. Adetirimin, A. Y. Akintunde, 1997. "Nitrogen effects on *Striga hermonthica* infestation, grain yield, and agronomic traits of tolerant and susceptible maize hybrids." Crop Science, 37: 711 - 716.

Kim, S. K. and V. O. Adetimirin, 1997. "Responses of tolerant and susceptible maize varieties to timing and rate of nitrogen under *Striga hermonthica* infestation." Agronomy Journal, 89, 38 - 44.

Kim. S. K., 1994, "Genetics of maize tolerance and *Striga hermonthica*." Crop Science, 34: 900 – 907.

Klingman, G. C., F. M. Ashton and L. J. Noordhoof, 1982. Weed Science: Principles and Practices, Second edition, John Wiley and Sons, New York, USA.

Kureh, I., U. F. Chiezey and B. D. Tarta, 2000. "On-station verification of the use of soya bean trap crop for the control of *Striga* in maize." Afr. Crop. Sci. J., 8(3): 295 – 300.

Lagoke, S. T. O, V. Parkinson and R. M. Agunbiade, 1991. Parasitic weeds and control methods in Africa (S. K. Kim (ed.)) In: Combating *Striga* in Africa, Proceedings of an International Worshop organized by IITA, ICRISAT, and IDRC, 22 – 24, August, 1988, IITA, Ibadan, Nigeria.

Little, T. M., and F. J. Hills, 1977. Agricultural experimentation: Design and Analysis, John wily and Sons, Toronto, Canada.

Llaca, V., M. A. Campbell and S. Deschamps, 2011. "Genome diversity in maize." Journal of botany, 1-10, doi:10.1155/2011/104172

Matata P. Z., B. M. Gama, A. Mbwaga, M. Mpanda and D. A. Byamungu, 2011. "Effect of *Sesbania sesban* Fallows on *Striga* Infestation and maize yield in Tabora Region of Western Tanzania." Academic Journals, J. Soil.Sci. Envi Mgt., 2(10): 311 - 317.

Makoko, R. B., and K. P. Sibuga, 2003. "Preliminary screening of sorghum (sorghum bicolour) genotypes for tolerance and resistance to *Striga asiatica*." African Crop Society Conference Proceedings, 6: 126 - 132.

Mashingaidze, A. B., 2004. Improving weed management and crop productivity in maize systems in Zimbabwe, Ph.D Thesis, Waageningen University, Wageningen, The Netherlands.

Maurice, C. R., M. H. Beale, and R. Matusova, 2005. "The strigolacetone germination stimulants of the plant-parasitic *Striga* and Orobanche spp. are derived from the carotenoid pathway." Plant Physiology, 139 (2): 920 - 934.

MCcann, J. C., 2005. Maize and grace: Africa's encounter with new world crop, Harvard University Press, MA. Pp 1500 – 2000.

Ministry of Agriculture, Food and Fisheries, 1997. Zambia Seed Technology Handbook, Revised Edition, Berlings, Sweden.

Mohamed, K. I., and J. L. Musselman, 2006. Taxonomy of agronomically important *Striga* species and Orobanche species, University of New York, New York, USA.

Musselmann, L. J., 1987. "Taxonomy of witchweeds." Parasitic weeds in Agriculture 1: 3 – 12.

Mutengwa, C.S., 2004. The search for molecular markers, parental characterisation and inheritance studies of witchweed [*Striga asiatica* (L.) Kuntze] in sorghum [Sorghum bicolour (L.) Moench], Ph.D thesis, University of Zimbabwe, Harare, Zimbabwe.

Mwila, G.P., D. Ng'uni, and A. Phiri, 2008. Country report on the state of plant genetic resources for food and agriculture, Zambia.

Nikrent, D. L., and J. L. Musselman, 2004. "Introduction to parasitic flowering plants." The Plant Health Instructor, DOI 10 1094/PHI-1-2004-0330-01.

O'brien, D., 2011. World corn supply – demand trends: An at risk position for MY 2011/12, Kansas State University, U. S. A.

Ogborn, J. E. A., 1987. *Striga* control under peasant farming conditions, Parasitic weeds in Agriculture, Vol. 1, CRC Press, Bocxa Raton, Florida, USA.

O'keefe, K and A. Schipp, 2009. Procrop: Maize growth and development, NSW department of primary industries, New South Wales.

Olupot, J.R., D.S.O. Osini, Oryokot, B. Gebrekidan, 2003. "The effectiveness of *Celosia argentia* (*Striga* chaser) to control *Striga* on sorghum in Uganda." Crop Protection, 22: 463 - 468.

Oswald A and J. K. Ransom, 2004. "Response of maize varieties to *Striga* infestation." Crop Prot., 23: 89 – 94.

Parker, C., 2009, "Observations on current status of Orobanche and *Striga* problems worldwide." Pest Management Sci., 65: 453 - 459.

Parker, C., and C. R. Riches, 1993. Parasitic weeds of the world: Biology and control, CAB International, Walingfed, UK.

Ransom J. K., G. D. Odhiambo, G. Abayo and A. Oswald, 1997. An update on *Striga* control research in Africa. In: Adipala E; Tusiime G; Okori P, (eds). 1997, Proceedings of the 16th Biennial Weed Science Society Conference For Eastern Africa, Kampala, Uganda.

Ransom, J. K and G. D. Odhiambo, 1995. "Effect of corn (Zea mays L.) genotypes, which vary in maturity length on *Striga hermonthica* parasitism." Weed Technology, 9: 63 - 67.

Reda, F., L. G. Butler, G. Ejeta, and J. K. Ransom, 1994. "Screening of maize genotypes for low *Striga asiatica* stimulant production using the 'agar gel technique." African Crop science Journal, 2: 173 - 177.

Rich, P.S., and G. Ejeta, 2008. "Towards effective resistance to *Striga* in African maize." Plant Signaling and Behaviour, 3(9): 618 - 621.

Runo, S., S. Macharia, A. Alakonya, J. Machuka, N. Sinha, and J. Scholes, 2012. "*Striga* paratisizes transgenic hairy roots of Zea mays and provides a tool for studying plant- plant interactions." Plant methods, 8: 20.

Sand, P., Robert E., and Randy W. 1990. Witchweed Research and Control in the United States, Weed Science Society of America, Champaign, Ilinois.

Shetto, R. M., and Kwiligwa, 1990. Weed control systems in maize based on animal drawn cultivators, ILRI, Food and Agricultural Organization.

Showemimo, F. A., 2006. "Effect of *Striga hermonthica* on yield and yield components of sorghum in Northern Guinea Savanna of Nigeria." Journal of Plant Sciences, 1: 67 - 71.

Sinebo, W., and D. S. H. Drennan, 2001. "Vegetative growth of sorghum and *Striga hermonthica* in response to nitrogen and the degree of host root infection." European Journal of Plant Pathology, 107: 849 - 860.

Singh, B. B. and A. M. Emechebe, 1997. Advances in research on cowpea *Striga* and Alectra. IITA, Ibadan, Nigeria.

Singh, R. J., and P. P. Jauhar, 2005. Genetic resources engineering and crop improvement: Gain legumes, Vol. 1, CRC Press, Bocxa Raton, Florida, USA.

Siwale, J., K. Mbata, J. Mcrobert, and D. Lungu, 2009. "Comparative resistance of improved maize genotypes and landraces to maize weevil." African Crop Science Journal, 17: 1 - 16.

Smale, M., J. Hartell, P. W. Heisey, & B. Senauer, 1998. "The contribution of genetic resources and diversity to wheat production in the Punjab ofPakistan." American Journal of Agricultural Economics, 80(3), 482 – 493.

Soladoye, M. O., A. A. Osipitan, M. A. Sonibare, and E. C. Chukwuma, 2010. "From 'vagabonds' to ethnobotanical relevance: Weeds of the campus sites of Olabisi Onabanjo University, Ago-Iwoye, Nigeria." Ethnobotanical leaflets 14: 546 - 558.

Songolo, H. L., and P. L. Pauwelyn, 1998. Practical manual for soil science, 3rd edition, University of Zambia, Lusaka, Zambia.

Spallek, T., M. J. Mutuku, and K. Shirasu, 2013. "The genus *Striga*: A witchweed profile." Molecular Plant Pathology, 10:1 - 9.

Teshome R. G., 2013. Integrating Sorghum [*Sorghum bicolor* (L.) Moench] Breeding and Biological Control Using *Fusarium oxysporum* Against *Striga hermonthica* in Ethiopia. Ph.D. Thesis, University of Kwazulu Natal.

The Bulletin, 2003. Farmers acclaim *Striga* resistant maize varieties, International Institute of Tropical Agriculture, Ibadan, Nigeria.

Thomson, L. M., 1966. "Weather variability, climate change and grain production." Science, 188: 535 - 541.

Thomas, W. L., 1956. Man's role in changing the face of the earth. An international symposium sponsored by Wenner Gren Foundation for Anthropological Research, University of Chicago Press, Chicago, United States of America.

United States Department of Agriculture, 2003. Witchweed: A Parasitic Pest. Columbia, USA.

Vasudeva Rao, M. J., V. L. Chidley, K. V. Ramaiah and L. R. House, 1983. "Breeding sorghum resistance to Striga asiatica (L) Kuntze at ICRISAT center. In: Proceedings of the second international workshop on Striga, pp. 61 − 76."

Vasudeva Rao, M. J., 1985. Techniques for Screening Sorghums for Resistance to *Striga*, ICRISAT Information Bulletin No. 20, India.

Vasey, R. A., Scholes, J. D., and Press, M. C., 2005. Wheat (Triticum aestivum) is susceptible to the parasitic angiosperm *Striga hermonthica*, a major cereal pathogen in Africa, Phytopathology 95 (11): 1294-1300.

Vernon, R. and J. M. H. Parker, 1983. "Maize-weed competition experiments: Implications for tropical small farm weed control research." Experimental Agriculture 19: 341 - 347.

VSN International, 2013, GenStat, 16th edition, VSN International, Hemel Hempstead, UK.

Waruru, M., 2013. Deadly *Striga* weed spreading across Eastern Africa. (http://www.scidev.net/en/sub-suharan-africa/news/deadly-*Striga*-weed-spreadingacross-eastern-africa.as)

Westwood, J. H., J. Yoder, M. P. Timko, and C. W. dePamphilis, 2010. "The evolution of paratism in plants trends." Plant Sci., 15: 227 - 23.

Witcombe J. R., P.A. Hollington, C. J. Howarth, S. Reader and K. A. Steele, 2008. "Breeding for abiotic stresses for Sustainable Agriculture." Philos Trans R Lond Biol. Sci., 27; 363 (1492):703-16.

Xie, X. N., K. Yoneyama, D. Kusumoto and Y. Takeuchi, 2006. Germination stimulants for root parasitic plants produced by tobacco. In: 11th IUPAC international congress of pesticide chemistry.

Yagoub, S. O., M. M. Hassan, M. E. Abdel Gani, and A. Babiker, 2014. "Screening sorghum for resistance to *Striga hermonthica* (Del.) Benth." Nova Journal of Medical and Biological Sciences, 2(4): 1 - 7.

Yao, Q., Yang, K., Pan, G., and Rong, T., 2007. "Genetic diversity of maize (*Zea mays* L.) landraces from southwest China based on SSR data." *Journal of Genetics and Genomics*, 34(9):851-860.

Yokota, T., H. Sakai, k. Okuno, K. Yoneyama and Y. Takeuchi, 1998. Determination and quantification of strigolactones. In Joel D.M (ed) 8th international parasitic symposium, the International Parasitic Plant Society, Durban, South Africa, pp. 9.

Zhongkui, S., R. Matusova and H. Bouwmeester, 2007. Germination of *Striga* and chemical signalling involved: A target for control methods. In: Ejeta and Gressel (ed): Integrating new technologies for *Striga* control − towards ending the witch hunt, World Publishing C., New Jersey, U.S.A.

Zhongkui, S., 2008. Biosynthesis of germination stimulants of parasitic weeds *Striga* and *Orobanche*, P. h. D Thesis, Wageningen University, The Netherlands.

(http://www.biology-online.org/dictionary/genotype/12.01.17)

(http://www.mathsbit.com/2016)

(www.necz.org/2013)