IDENTIFICATION OF MAIZE (*ZEA MAYS* L.) GENOTYPES RESISTANT TO *STRIGA HERMONTHICA* (DEL.) AND DETERMINATION OF GENETIC BASIS FOR RESISTANCE

BY

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DECLARATION

Student:

This thesis is my original work and has not been previously submitted for a degree in Maseno University or in any other University. The work herein has all sources of information supported by relevant references.

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DEDICATION

This work is dedicated to my late father Mark Mbogo Akech and to my late beloved mother, Wilfrida; the late Jullen Anyango, my wife Sarah Wamboi, Daughters Quinta Okoth, Brenda Okoth, Anne Wamboi, Anita Atieno and my son Gabby Okoth.

ABSTRACT

The obligate root hemi-parasite, *Striga hermonthica* (Del.) Benth., native to sub-Saharan Africa causes serious economic constraint to cereal production. There has been limited study to understand the genetics of *Striga* tolerance or resistance in maize in Kenya and the information on mechanisms of resistance to *Striga* in maize in very limited. The use of maize (*Zea mays* L.) genotypes that support reduced *Striga hermonthica* emergence can form an important basis for developing *Striga* resistant cultivars. The objective of this study was to contribute to the knowledge of gene action controlling *Striga* resistance and to improved yield in maize. 28 maize inbred lines sourced from IITA and Maseno University and 9 Maseno university experimental hybrids were evaluated in western Kenya in 2011 and 2012 growing seasons. A generation means analysis was performed using a resistant and a highly susceptible maize inbred line selected from inbred line screening. Highly significant differences (P <0.001) were detected among the inbred lines and hybrids for grain yield, emerged *Striga* counts and *Striga* damage rating. A highly significant and negative correlation coefficient was observed between emerged *Striga* and yield as well as between *Striga* damage ratings and yield. Inbred lines MSMP1/P2, TZSTR154, TZSTR133, TZSTR139, TZSTR166 and a resistant check 9450 were identified as the most resistant lines as they consistently performed well in *Strig*a-infested environments. These inbred lines could be used for breeding *Striga* resistant maize varieties. Maseno experimental hybrids, EH14 and EH12 recorded much better grain yields and stability compared to commercial varieties under *Striga* infestation and in *Striga* free fields. National performance trials conducted by KEPHIS confirmed their high yield and yield stability and were released for commercialization. Maseno hybrids had parental lines previously selected from maize landraces from western Kenya, thus suggesting that they are potential sources of *Striga* weed tolerance genes. Generation means analysis results showed significant differences among generations for emerged *Striga*, *Striga* damage rating and maize growth including Plant and Ear height. Most of the additive, dominance, additive x additive, additive x dominance and dominance x dominance effects were significant indicating the importance of the additive, dominance and epistatic modes of gene actions in controlling emerged *Striga*, *Striga* damage rating, plant and ear height. Most components conferring *Striga* tolerance behaved in a qualitative manner. Dominance effects had higher mean values over additive effects. Significant dominant genetic effects (d) for *Striga* emergence and *Striga* damage rating suggested preponderance of non-additive genetic effects in the inheritance of *Striga* tolerance. The results also reveal the involvement of duplicate epistasis where the dominance estimate and dominance x dominance interaction had opposite signs. The presence of duplicate type of gene interaction confirms the importance of dominance gene effects. The identified maize inbred lines with good levels of resistance and different resistance mechanisms can facilitate pyramiding of several resistant alleles to obtain more durable and stable polygenic resistance to *Striga hermonthica* in maize.

TABLE OF CONTENS

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BC$_1$	Backcross to resistant Parent
BC$_2$	Backcross to susceptible Parent
CIMMYT	International Maize and Wheat Improvement Centre
F$_1$	First filial generation
F$_2$	Second filial generation.
F$_3$	Third filial generation
FAO	Food and Agricultural Organization of the United Nations.
IITA	International Institute of Tropical Agriculture
KEPHIS	Kenya Plant Health Inspectorate Services.
LSD	Least significant difference
NPT	National Performance Trials
P$_1$	Resistant Parent
P$_2$	Susceptible Parent.
SDR	*Striga* damage rating.
t/ha	Tons per hectare.

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE:INTRODUCTION

1.1 Background Information

Maize (*Zea mays* L.) in its various processed forms is an important food crop for majority of people living in the developing world (FAO, 1998). It is the third important cereal crop in the world, after rice and wheat (Poehlman, 1979); mainly used as human food, animal feed and extensively in industrial products, including production of biofuels (Saleh *et al.,* 2002). Maize is currently produced on nearly one hundred million hectares in 125 developing countries (FAOSTAT, 2010). In parts of Africa, maize alone contributes over 20% of food calories (Shiferaw *et al.*, 2011). Maize is known to contribute 15% of protein and 20% of calories derived from food crops in the world's diet (National Research Council, 1988) and accounts for about 40-50% of both calories and proteins consumed in the east Africa region (FAOSTAT, 2010). It has high potential as nutritive food and is a good source of high quality edible oil (Serna-Saldivar *et al.*, 1994; United Nations, 2000).

Maize is the main staple food of Kenya, averaging over 80 percent of total cereals (FAO, 1998). Maize production in Kenya is a highly relevant activity due to its importance as it is a dominant food crop (Mantel and van Engelen, 1997). It is wholly produced under rain fed conditions. The total land area under maize production in Kenya is about 1.6 million hectares with 70-90% belonging to small-scale farms (FAO, 1998). However, maize production has lagged behind and its production capacity has not kept pace with surging demand for food. The low yields recorded in the country are attributed to abiotic and biotic constraints such as drought incidences, pests, diseases and most importantly the parasitic weed, *Striga* (Mantel and van Engelen, 1997)

Striga hermonthica (Del.) Benth., is a menacing parasitic weed that belongs to the family Scrophulariaceae and constitutes one of the greatest biotic constraints to food crop production, undermining the struggle to attain food security and economic growth in Sub-Saharan Africa (Sauerborn, 1991). *Striga*, a widely acknowledged scourge, is considered a more serious agricultural problem than insects, birds or plant diseases (Ejeta and Butler, 1993). It has been given the common name of "witchweed" because it attaches itself to the roots of the host plant depriving the host of water and nutrients leading to reduced yield and even death to the host plant (Plate 1).

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Plate 1. *Striga hermonthica* parasitizing maize in a field at Nyahera in Kisumu County (Peter Mbogo, 2016)

There are five species of *Striga* that cause significant damage to crops. These are: *Striga hermonthica* (Del.) Benth, *Striga asiatica* (L.) Kuntze, *Striga aspera* (Willd.) Vatke, *Striga forbesii* Benth. and *Striga gesnerioides* (Willd.) Vatke. The first four species parasitize cereal crops, for example, maize, sorghum, millet, upland rice and sugarcane, with *Striga hermonthica* being the most serious in sub-Saharan Africa (Kim *et al.*, 1994). *Striga asiatica* is a more widespread species in southern Africa, India and the United States of America (Parkinson, 1985; Musselman *et al.*, 1991). *Striga aspera* is present in the mid-altitude areas of west Africa (Kim, 1991). *Striga gesneroides* occurs mainly in West Africa and attacks cowpea (*Vigna unguiculata* (L) Walp) and other legumes (Aggarval, 1985; Musselman, 1987; Hess *et al.*, 1992; Kim *et al.*, 1997). In Kenya, the most serious species affecting cereals is *Striga hermonthica*, where it infests approximately 158,000 hectares of land, while *Striga asiatica* (L.) Kuntze is currently of minor significance, but identified as a potential threat to future cereal crop production in Busia and coastal counties (Ransom *et al.*, 1990).

Striga (Witch weed) is becoming increasingly important, particularly in Africa where population pressure has necessitated more intensive cultivation of the staple cereal crops and where few, if any, quarantine measures are in place to arrest its spread to non-infested areas (Pieterse and Pesch, 1983). Most importantly, it mostly affects the livelihoods of poor subsistence farmers in cereal-based agricultural systems in Africa (Weed Busters, 2003). Traditionally, African cropping systems included prolonged fallow, rotations, and intercropping, which were common practices that kept *Striga hermonthica* infestations at tolerable levels (Badu-Apraku *et al.*, 2006). Recently however, prevailing scarcity of land as a result of population increase has minimized the length of fallow periods and rotations. Continuous mono-cropping with no fallow in turn has led to a gradual increase in populations of *Striga* species, which have become a serious threat to cereal production (Ariga, 1996). It is important to note that areas that have *Striga* problems are also characterized by low productivity, low moisture, minimal use of organic or inorganic fertilizer as well as non-pesticide use and improved seeds (Abayo *et al.*, 1996; De Groote *et al.*, 2005).

In Kenya, *Striga* species seriously affects crop production in Kisumu, Siaya, Homa bay, Migori, Busia, Kakamega, Vihiga, Bungoma, Kwale, Kilifi and Mombasa counties (PASCON) 1993). The main cereals cultivated as food crops in the affected areas are sorghum (*Sorghum bicolor* L. Moench), maize, millet *(Pernisetum glaucum* (L) R. Br. and upland rice (*Oryza sativa* L.).

1.2 Statement of the Problem

The witchweeds *Striga hermonthica* (Del.) Benth and *Striga asiatica* (L.) Kuntze decimate maize (*Zea mays* L.), millets (Pennisetum spp.), sorghum (*Sorghum bicolor* (L.) Moench) and upland rice (*Oryza sativa*) throughout sub-Saharan Africa (Kanampiu *et al*., 2003). From the high plateau of east Africa, where peasant farmers struggle to survive on tiny fields of maize, to the arid savannas of northern Nigeria where they rely on sorghum, African farmers are fighting a losing battle against the spreading scourge of *Striga*. Based on Food and Agricultural Organization (FAO) studies, over 100 million Africans lose half their crop production to these flowering, root-attaching parasites (Kanampiu *et al*., 2003). In regions of Kenya alone, 80,000 hectares cropped to maize are severely infested, causing an estimated $ 10 million in annual losses to maize production (Hussein *et al*., 1995). In western Kenya, livelihoods of poor subsistence farmers in the cereal based agricultural systems are threatened, posing a very serious threat to food security. Generally there has been limited study to understand the genetics of *Striga* tolerance or resistance in maize in Kenya and the information on mechanisms of resistance to *Striga* in maize in very limited (Ejeta, 2007a). While several studies have been conducted to characterize mechanisms of resistance to *Striga* in other crops, including cowpea (*Vigna unguiculata*; Riopel and Timko, 1995), sorghum (Hess *et al.*, 1992; Arnaud *et al.*, 1999; Mohamed *et al.*, 2003; Rich *et al.*, 2004), and rice (Gurney *et al.*, 2006), information on mechanisms of resistance to *Striga* in maize is still very limited. This study would address the highlighted gaps.

1.3 Justification

Maize is a cereal crop of great dietary and socioeconomic significance in sub-Saharan Africa. It accounts for 56% of total harvested area of annual food crops and 30-70% of total calorie consumption (Shiferaw *et al.*, 2011). In East Africa maize accounts for about 40 to 50% of both calories and proteins consumed in the region (FAOSTAT, 2010). The high incidence and rapid spread of *Striga hermonthica* in the region poses a great threat to food security for millions of people if no suitable measures to manage the parasitic weed are put in place. *Striga* has recently been reported to extend to areas where it has not previously been present (Ahmed *et al*., 1987). Hence, *Striga* represents one of the largest single biological barriers to increased maize production in infested areas of Kenya and it has become an increasing challenge to breeders and agronomists. Yield losses of up to 100% in *Striga* affected maize growing areas undermine the efforts to have sustainable food security in the region. This implies that the *Striga* problem, if not addressed, the negative impacts on food security can be devastating for the affected country and for the region broadly. Developing maize germplasm resistant/tolerant to *Striga* has been a major goal of maize breeders around the world. Attempts to produce high yielding, stable, adaptable and locally acceptable resistant cultivars have had limited success (Ogborn, 1987; Parker and Riches, 1993; Ramaiah, 1987; Rubiales, 2003). A few tolerant varieties developed in West and East Africa however still lack good yields and adaptation to local environmental constraints. Previous work done at International Institute of Tropical Agriculture (IITA) and International Maize and Wheat Improvement Center (CIMMYT) have identified some maize genotypes with potential tolerance/resistance to *Striga*. However these genotypes have not been widely tested under *Striga* prone lake Victoria region of Kenya. The current popular maize varieties in Kenya have also not shown total resistance to *Striga* in the field. The major challenge therefore is to develop methods or varieties that will help small-scale resource poor farmers control *Striga* effectively within a sustainable and profitable farming system (Dogget, 1988). Hence there is a need to develop, evaluate and identify high yielding and stable maize varieties with *Striga* resistance.

The response to *Striga* resistance/tolerance is variable under different growing conditions due to different intensity of the weed (Oswald and Ransom, 2004). Genotypes' interaction with environmental factors (location, year of planting, soil type, level of technology used, etc.) is an important consideration for plant breeders. The effects that genotypes and environments exert on GEI are statistically non-additive, indicating that differences in yields among genotypes will depend on the environment (Yue *et al*., 1997). Consequently, selection procedures based on the mean yield of genotypes in a given environment are less efficient. Eberhart and Russel (1966) recommended growing of varieties in adequate number of environments, covering a full range of possible environmental conditions, so that useful information is available regarding stability.

There is need to study GEI and stability of different maize cultivars at different locations in Kenya, *Striga* and non *Striga* areas to find out if genotypes significantly interact with the environments. There are no published results and information concerning GEI for maize genotypes under *Striga* infestation and *Striga* free field conditions in Kenya to date. Therefore, it is necessary to evaluate the maize genotype's differential response in multi-environment trials and assessing their genotype-by-environment interaction (GEI) and stability across environments.

Identifying source germplasm with different resistance mechanisms can facilitate combining several resistance genes to obtain more durable and stable polygenic resistance to *Striga* in cereals (Ejeta *et al.*, 2000; Menkir, 2006).

1.4 Objectives

1.4.1 General Objectives

To contribute to the knowledge of gene action controlling *Striga* resistance and to improved yield in maize.

1.4.2 Specific Objectives

1. To evaluate diverse maize inbred lines and hybrids for performance in yield components and yield under *Striga hermonthica* infestation in western Kenya.
2. To determine the genetic parameters for yield and other traits under *Striga hermonthica* infestation using analysis of Generation Means.

1.5 Hypotheses

1. There are no performance differences between different maize inbred lines and hybrids under *Striga hermonthica* infestation.
2. Resistance to *Striga hermonthica* is not due to additive gene action.

CHAPTER TWO: LITERATURE REVIEW

2.1 Maize Taxonomy and Global Importance

Maize (*Zea mays* L.) is a diploid (2n=20) belonging to the family Poaceae (Grass family). There are five species in the genus *Zea* (*Z. mays, Z. perennis, Z. nicaraguensis, Z. luxurians* and *Z. diploperennis*) but *Z. mays* are the only cultivated species. The others are wild grasses commonly referred to as teosintes and are native to Mexico and Central America (Doeblay, 1990). Maize is predominantly an outcrossing species, the reason for its exceptional genetic diversity, making it highly adaptable and responsive to selection pressure. Maize is the third most important cereal grain in the world that provides nutrients to humans and animals (FAO, 1998). It plays a significant role in the nutrition of millions of people around the world and its importance is widely recognized. Maize arrived in Africa through various introductions as long ago as 500 years ago (McCann, 2005).

Since then, maize has become the number one crop in the continent in both the cultivated area and total grain production (FAO, 2008). In East Africa, maize production, processing and utilization provides vital employment and income generation activities for a large cross section of people (Twumwasi-Afriyie *et al.*, 2001). Globally, maize production has increased from the year 1979 to 1981 period, mainly as a result of increases in land area planted, genetic improvements on varieties grown, more efficient and advanced technological field practices as well as proper agronomic practices (FAO, 1988). Developing countries have more land area under maize compared to the developed countries though maize yields in developing countries have increased only slightly since 1981 (FAO and INPhO, 1998). Perhaps owing to its exotic origin, maize shows greater susceptibility to abiotic and biotic stresses common in the continent hence the slight increases in maize yields. One of the major biotic constraints to maize production is *Striga* (witchweed) which takes up water and nutrients from its host and also causes toxicity (Pieterse and Pesch, 1983; Musselman, 1987; Stewart, 1990).

2.2 *Striga* Botany

The genus *Striga* belongs to the dicotyledonous family, Scrophulariaceae (order Tubiflorae) with about fifty species, all of which are parasitic on other plants, the most troublesome being the obligate parasites (Musselman, 1980). However, the genus is now classified in the family Orobanchaceae although earlier authors placed it in the family Scrophulariaceae (Gethi *et al.*, 2005). Of these, only a few are economically important (Ramaiah *et al.*, 1983, Raynal-Rogues, 1991). The genus is characterized by opposite leaves, irregular flowers with a corolla divided into a tube and spreading lobes, herbaceous habit, small seeds, and parasitism (Musselman, 1987). *Striga hermonthica*, which is the most important in Kenya, has pink to white flowers and is found throughout the tropics and sub-tropics of the old world and Australia (Pieterse and Pesch, 1983).

Parasitic plants have evolved from several families of the angiosperm (Parker and Riches, 1993). Seven of the families contain species that are parasitic weeds with the most damaging being in the family's Scrophulariaceae (*Striga*), Orobanchaceae *(Orobanche*) and Convolvulaceae (*Cuscuta*), (Odhiambo, 1998). In the case of *Striga,* current estimates put the number of species in this genus at between 25 and 60 (Dogget, 1988; Ejeta *et al.*, 1992; Musselman, 1980 and Pieterse and Verkleij, 1991).

There are at least two distinct patterns of breeding within the genus. The first is allogamy which is well developed in *Striga hermonthica*. In fact, this species is an obligate out-crosser (Safa *et al*, 1984) exhibiting sporophytic incompatibility. It is thus dependent upon insect vectors, which include bee flies (Diptera- Bombyliidae), and Lepidoptera in West Africa (Musselman *et al.*, 1983), and Lepidoptera in Sudan (Musselman and Hepper, 1986). *Striga asiatica* and *Striga gesnerioides*, on the other hand are inbreeders which have a well-developed system of autogamy (Musselman *et al*, 1982). Here no pollen vector is needed, the pollen is picked up by the elongating style and fertilization ensues. The likelihood of any cross pollination is small as the pollen is sticky and forms a plug on the bifid stigma, which effectively forms a barrier to any foreign pollen. In *Striga gesnerioides*, at least, the barriers to outbreeding are mechanical, because crosses between strains of *Striga gesnerioides* have been successful (Musselman *et al.*, 1982).

2.3 *Striga* Ecology and Distribution

The genus *Striga* is basically tropical and subtropical in distribution, usually occurring between latitudes 30°N and 30°S. It extends south of 30°S in Natal, South Africa growing on sugarcane, and grows at 34°N in the Carolinas (United States). It tends to prefer light and sandy soils, whereas *Striga hermonthica* in East Africa is more common on heavy soils.

Striga species occur in many areas of tropical Africa, Asia and some parts of America with the greatest diversification in Africa (Raynal-Rogues, 1991). *Striga hermonthica* is widespread in most parts of Africa with distribution extending from northern tropical Africa of Ethiopia and Sudan, the savannah areas of West Africa and through Eastern Africa (Parker and Riches, 1993). These areas are also known to be the origin of sorghum and pearl millet which are readily infected by the witchweed (Ejeta, 2007). They are found to a limited extent in open savannah, with large populations in agricultural fields under cereal production (Odhiambo, 1998). Three species causing the greatest damage in Africa: *Striga asiatica* and *Striga hermonthica* are mainly found on grains, such as sorghum, corn, pearl millet, rice and others, while *Striga gesneroides* parasitizes legumes such as cowpea and peanuts. The occurrence of the economically important *Striga* species is reported from 59 countries (Sauerborn, 1991). These are mainly countries of West and East Africa as well as Asia. According to Mboob (1989) *Striga* is distributed in more than 40% of the arable land south of the Sahara.

There are nine *Striga* species found in Kenya (Table 1). The predominant species considered to be dangerous is *Striga hermonthica* which is found in the densely populated western parts of the country around the lake Victoria basin (Figure 1) (Dogget, 1965; MacOpiyo *et al.*, 2010). This is where it parasitizes the major cereal crops: maize, sorghum, rice and finger millet. *Striga asiatica* is predominantly found in the coastal region infecting upland rice (Gethi *et al.*, 2005) and exists sporadically in Isiolo, Busia and Naivasha (Mohamed *et al.*, 2001). The species that is adapted as a pest of legume crops, *Striga gesneriodes*, has a wide geographical distribution in Kenya compared to the other species. It occurs as far as Kilifi (coastal province of Kenya) spreading to Homa hills (Nyanza province, western Kenya) infecting cowpea.

Table 1: *Striga* distribution and occurrence in Kenya

Striga Species	Host Plants	Occurrence Area
S. asiatica	Maize, rice, sorghum, pearl millet, finger millet, sugar cane, wild grasses	Kilifi, Isiolo, Mathews range, Alupe, Daka Chom,Kiunga
S. bilabiata	Wild grasses	Naivasha, Chyulu hills, Rumbia, Kahawa, Mathews range
S. elegans	Wild grasses	Nairobi, Loitokitok, Laikipia, Rumuruti
S. forbesii	Sorghum, rice, maize, sugar cane	Narok, Mara plains, Kipini, Chyulu hills, Uasin Gishu plateau, Trans Nzoia
S. gesnerioides	Cow pea	Kilifi, Buna, Homa hills, Rongo, Nairobi, Naivasha
S. hermonthica	Maize, rice, sorghum, pearl millet, finger millet, sugar cane, wild grasses	Alupe, Chulaimbo, Miwani, Bungoma, Kendu Migori, Kuria, Nyamira, Siaya, Homabay
S. latericea	Sugar cane, wild grasses	Samburu, Mariakani, Kwale, Voi, Machakos Sultan Hamud, Kilifi, Mwea
S. lutea	Wild grasses	Kwale, Shimba hills, Embu, Chyulu hills
S. pubiflora	Sugar cane, wild grasses	Kwale, Shimba hills, Voi

Source: Khan *et al.,* 2008

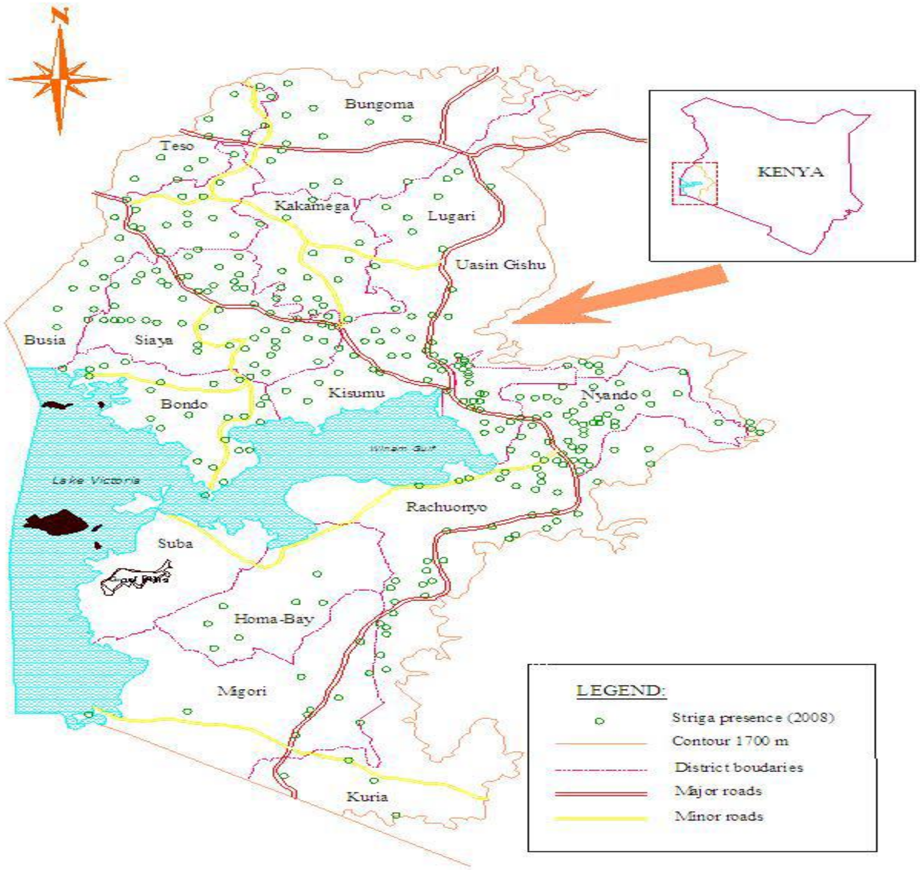

Figure 1: *Striga* distribution in western Kenya.

Source: De Groote *et al.*, 2008.

2.4. Biology, Life Cycle and Mechanism of Parasitism of *Striga*

The life cycle of *Striga* is shown in Figure 2. Each *Striga* plant can produce 100,000 seeds which are viable for up to 20 years (Fig.2a). Following a period of pre-conditioning seeds germinate in response to germination stimulants present in host root exudates (Fig.2b). Elongation of the *Striga* radical is accompanied by the production of hydrogen peroxide by the meristem. When the radical comes into contact with the host cell surface it serves as a peroxidase co-substrate, oxidatively releasing simple benzoquinone xenognosins from host cell walls. Perception of these haustorial initiation factors (HIF) initiates haustoriogenesis leading to the formation of the functional attachment organ (Fig.2c). The haustorium attaches to the host root by means of sticky haustorial hairs (Fig.2d). Cells located centrally beneath the haustorium divide to form a wedge and penetrate through the host root cortex and endodermis. Parasite cells then form intrusions into the xylem vessels of the host. This is illustrated by the longitudinal view of the parasite on the host root and the cross section through the host vascular tissue. No direct connections to host phloem cells have been observed in *Striga*–host associations (Fig.2e). Once xylem continuity with the host has been established the parasite haustorium undergoes further differentiation and cotyledon leaves are formed one to two days later. Leaf pairs are initiated along the growing stem initiating a period of intense metabolic interaction between the host and parasite (Fig.2f). The *Striga* shoot emerges above ground and flowers and sets seed approximately six weeks later (Fig.2g).

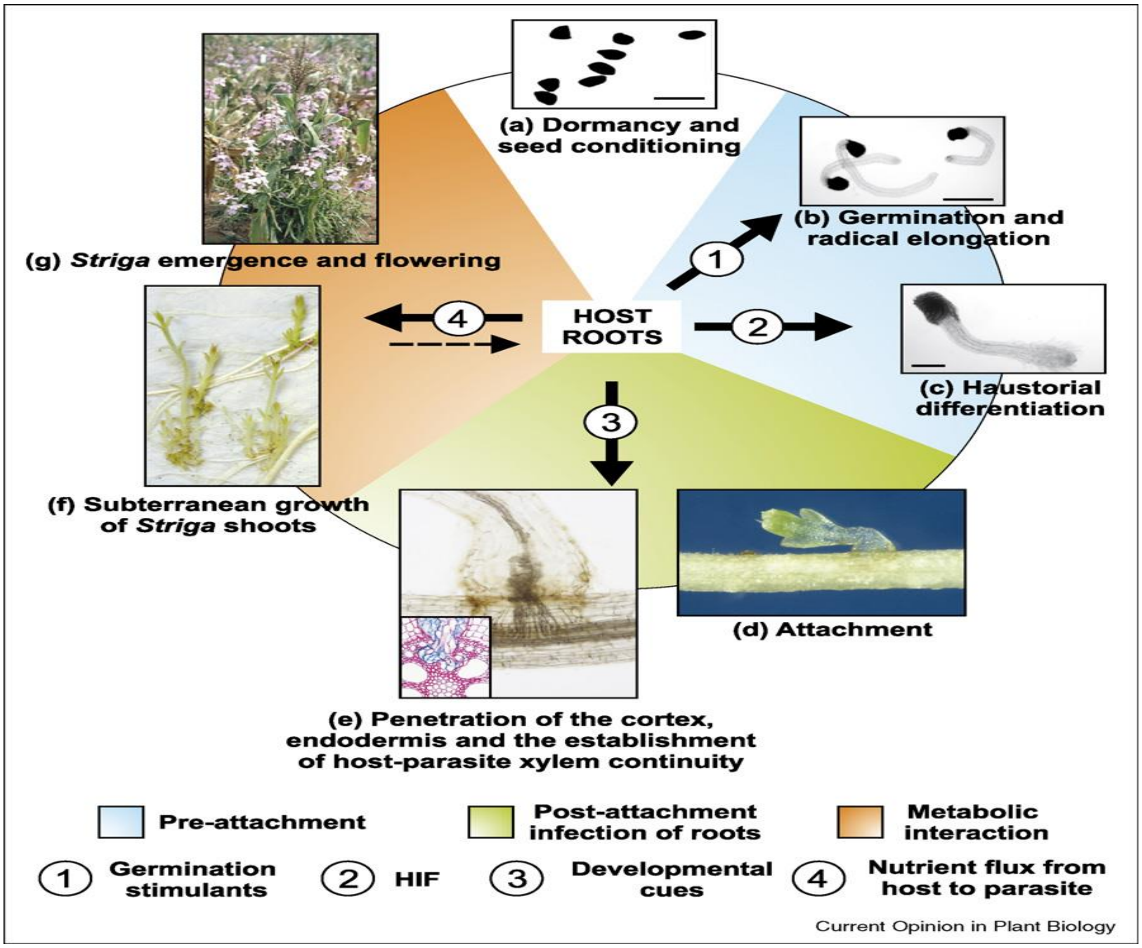

Figure 2: The life cycle of *Striga.*

Source: (Bouwmeester *et al*., 2003). The scale bar in (a–c) is 250 mm.

2.4.1 *Striga Hermonthica* Seed

Striga seeds are tiny, some 0.30 mm long and 0.15 mm broad, larger or smaller according to species. Estimates of seed production in the literature may be as high as 40,000 seeds per plant of *Striga hermonthica,* and over 90,000 seeds per plant of *Striga asiatica.* They can remain viable for many years under dry conditions; estimates vary from six months to 14 years according to climatic conditions (Yoder and Scholes, 2010). Most of the seeds, perhaps 80% occur in the top 30 cm of soil, and may give 20-50% germination. Some seeds occur down to a depth of 150 cm and seeds from this depth may show over 95% germination (Andrews, 1945; Robinson and Kust, 1962).

2.4.2 Striga Seed Conditioning and Germination

Striga seed requires a period of after-ripening (Fig.2a) before they can germinate (Valance, 1950; Ejeta and Gressel, 2007), and so cannot germinate at the end of the rainy season in which it is produced. The seed requires a period of pre-treatment after it has imbibed water, lasting perhaps one to five weeks. It is therefore not ready to germinate until the rains begin and the host plants have had time to start growing. This requirement is an excellent adaptation for S. *asiatica* and S. *hermonthica* to the semi-arid tropics (Doggett, 1984). The pre-treated seed requires a stimulant produced by the host plant before it can germinate. The majority of the seeds within 2 mm of the host root receive sufficient stimulant to germinate, so few seedlings are wasted through being too far away from a host root. Much of the seed which has imbibed water enters a period of "wet dormancy" if it is not stimulated to revert to their original condition, and need pre-treatment again before they become responsive to the germination stimulant (Saunders, 1933; Vallance, 1950; 195la, 1951b; Reid and Parker, 1979; Cardoso *et al*., 2011).

Another very conspicuous feature of the germination behavior of the seed of the different root-parasitic species is the fact that germination will only take place after seeds have been exposed to moisture for some time (Visser, 1989). This survival mechanism helps build a seed bank of *Striga* seed in tropical soils (Ejeta *et al.*, 1992). The period of conditioning for *Striga* may last some seven to fifteen days under optimum moisture and temperature conditions (Ramaiah *et al.*, 1983). After this period the seeds are able to respond to a germination stimulant exuded by roots of a host or non-host (Dogett, 1988). During conditioning the seed becomes progressively more sensitive to the stimulant, where after wet dormancy results in decreased germination (Visser, 1989; Parker, 2009; Cardoso *et al*., 2011)). At favorable temperatures of around 30^0C, seed germination occurs within 24 hours. Numerous natural and synthetic compounds have been reported to induce *Striga* germination (Brown, 1965; Cardoso *et al*., 2011) of which Strigol is the best known.

2.4.3 Haustorial Initiation and Attachment

A weak chemotrophic influence appears to assist the parasite in making contact with the host root and on contact; the tip of the radicle transforms itself into a haustorium, apparently due to a chemical secretion from the host root known as the haustorial initiation factor (Ramaiah *et al.*, 1983). Simple compounds, such as 2, 6-dimethoxybenzoquinone (Lynn and Chang, 1990) are active as haustorial initiation factors in *S. asiatica*, but the natural signal produced by the host has not been identified (Ejeta *et al.*, 1992). In addition to chemical signals a thigmotrophic response is required for *Striga* to produce morphologically normal haustoria (Wolf and Timko, 1991).

The radicle of the *Striga* seedling grows towards the host root and secretes enzymes that assist in its penetration of the host root (Kuijit, 1991). At the point of contact, the tip of the radical of the *Striga* seedling swells, forming a papilla, which penetrates between the celas of the cortex and flattens against the host endodermis. The haustorium forms a vascular bridge that provides the parasite with direct access to host-plant nutrients (Saunders, 1933; Okonkwo and Nwoke, 1978; Ba, 1987; Riopel and Baird, 1987). The ability of the endodermis to bar penetration by the parasite may differ according to genotype. Once a link is established with the host xylem and phloem, the parasite draws its supplies from the host (Ramaiah *et al.*, 1983; Ejeta *et al.*, 1992). In general, penetration is completed within 48-72 hours after contact with a host root (Hood *et al.*, 1998). Although *Striga* does turn green above ground; there is continued movement of carbohydrates, minerals and water from host to parasite. Growth hormones are also important (Rogers and Nelson, 1962; Ramaiah and Parker, 1982). *Striga* spp., also produces adventitious roots (or secondary haustoria) (Musselman, 1980), which penetrate the host root along with the primary haustorium, (Ejeta *et al.*, 1992). These roots attach themselves to the same root to which the primary haustorium is attached or more frequently, to another nearby host root (Pieterse and Pesch, 1983).

2.4.4 *Striga* Parasitism and Development (Host Parasite Interaction)

Once established, the parasite becomes a metabolic sink for the carbohydrates produced in the host, thus depriving the host of some of its photosynthates (Ramaiah *et al.*, 1983). The *Striga* seedling then grows parasitically underground for approximately 4-6 weeks, during which time it wholly depends upon the host for food and water and apparently causes its most severe damage to the host plant (Pieterse and Pesch, 1983). On emergence from the ground, the *Striga* plants develop green leaves that produce their own photosynthates; however, there is continued flow of carbohydrates, water and minerals from the host (Ramaiah *et al.*, 1983). The period from conditioning to emergence above ground varies with the temperature and the host crop. Emergence occurs earlier in maize than sorghum while *Striga hermonthica* emerges earlier than S. *asiatica* (Ransom and Odhiambo, 1992).

Damage from *Striga* far exceeds what might be expected based on the biomass of the parasite. The interference with movement of nutrients and moisture through the root system coupled with metabolic toxicants, cause devastating effects on the host crop, often leading to severe yield losses (Eplee, 1983). Studies at the University of Reading, United Kingdom, have also shown that as a result of *Striga* infestation, growth inhibitors such as abscisic acid and fernasol in the host are increased, and growth promoters such as cytokinins and gibberellins decreased (Ramaiah *et al.,* 1983). Stewart and Press (1990) also summarized the growth inhibiting effects of *Striga* species on its host and speculated that a toxin produced by the parasite is responsible for the symptoms. In cereals such as maize and sorghum, *Striga hermonthica* causes stunting, drought like leaf wilting, chlorotic lesions and leaf rolling even under high moisture condition (Graves *et al.,* 1989). Usually damage to the crop in the form of a 'bewitched' and chlorotic whorl is apparent before tassel formation on heavily infested plants prior to the emergence of the *Striga* flower stalks (Abayo *et al.,* 1998). Under severe infestation by *Striga hermonthica*, there may be no yield and the host plant may be killed (Andrews, 1945).

The biology and survival mechanism of *Striga* make it very difficult to control with the normal weed control practices available to most small-scale farmers. In Africa, the *Striga* problem is further excercebated because *Striga hermonthica* plants especially, have a great capability of survival under African conditions of low input farming (Kim and Ademetrin, 1997).

2.5 Economic Significance of *Striga* Parasitism on Crops.

A conservative estimate of crop losses because of *Striga* species in Africa is 40% representing loss of cereals worth US $ 7 billion annually (Mboob, 1986; Aly, 2007; Ejeta, 2007). In infested areas, yield losses due to *Striga* damage are often significant, ranging from 40-90% (Lagoke *et al.,* 1991; Ejeta *et al.,* 1993; Gressel *et al.,* 2004). More recently, infestation caused losses of 30-50% to Africa's agricultural economy on 40% of its arable land has been reported (Amudavi *et al.,* 2007; Hearne, 2009). In India, some 25,000 tons of sorghum grain is lost annually in the state of Andhra Pradesh alone (Doggett, 1988). Within Sub-Saharan Africa, Doggett (1984) estimated a 20-95% total yield loss for sorghum and millet in East Africa; while in countries such as Ethiopia and Sudan, losses of 65-100% are common in heavily infested fields (Ejeta *et al.*, 2000). Farmers have reported losses of between 20-80%, and are eventually forced to abandon highly infested fields (Atera and Itoh, 2011). Because of *Striga* spp infection, maize yield dropped in Sub-Saharan Africa from the world average of 4.2 to 1.3 kilo-ton/ha (Kanampiu *et al.*, 2002). In Nigeria losses of 10-91% with an average loss of 35% in sorghum and maize yields have been attributed to *Striga hermonthica* (Parkinson, 1985). Sauerborn (1991) estimated yield loss from all *Striga* spp. as 24% in six West Africa countries. In Cameroon 15-20% of overall production was affected by *Striga* species and the losses in certain cases were as high as 50-90% (Lagoke *et al.*, 1991). Interestingly, *Striga* extracts are rich in secondary metabolites and find broad use in traditional medicine, especially as a result of their antimicrobial activity (Koua and Babiker, 2011)

In regions of Kenya alone, 80,000 hectares cropped to maize are severely infested, causing an estimated $ 10 million in annual losses to maize production (Hussein *et al.*, 1995). However, the total area in Kenya affected by *Striga* is estimated at between 300,000 and 500,000 hectares, and occurs in the most populous parts of the country (PASCON, 1993). A survey of 83 farms done in Western Kenya revealed that 73% of the farms are infected with *Striga hermonthica* (Woomer and Savala, 2009). The average yield loss due to *Striga* is 1.15, 1.10 and 0.99 tons/ha for maize, sorghum and millet, respectively (MacOpiyo *et al.*, 2010). However, the damage can reach as high as 2.8 tons per hectare in maize and sorghum in some locations with high *Striga* densities (Andersson and Halvarsson, 2011). The loss represents 12.3% of the 2.4 million metric tons of maize that Kenya produces annually. This translates to about 39.6 kg maize loss per capita, amounting to about 20% of a typical person's annual food requirement (Evans *et al.*, 2013).

Table 2: *Striga* caused loss of revenue[1] in Africa

	Actual (million US$)	**Potential (million US$)**
Corn (76)[2]	140	1513
Millet (73)	82	676
Sorghum	89	760
Total	311	2949

Source: Sauerborn 1991b

1 data in FOB (freight on board) prices, FAO1988

number in parenthesis=FOB price (US$/ton)

2.6 *Striga* Control and Management Strategies.

There are several methods for the control of parasitic weeds including *Striga* (Parker and Riches 1993; Verkleij and Kuiper 2000; Kroschel, 2001; Joel *et al.*, 2006). The existing *Striga* control methods have given no conclusive and consistent feasible results for the peasant farmers, due to its high fecundity and the mismatch between technologies and the farmers' socio-economic conditions. *Striga* control has proved elusive in Kenya and Africa in general due to diversity of farming/cropping systems. It has therefore been almost impossible to develop one single *Striga* control package that can be extended throughout the region (PASCON, 1993). For any control option to be effective it has to take into consideration the high number of *Striga seeds* produced (ranging from tens to hundreds of thousands of *Striga* seeds), the large number of *Striga* seed bank in many of the soils where *Striga is* a problem, and the long dormancy period (up to 20 years) of *Striga* seeds (Ikie *et al*., 2006).. *Striga* seed banks are also particularly high in many of the soils of the resource-limited subsistence agricultural systems of Africa where the parasite is prevalent. However, several potential current control options available include;

a) Methods which lead to the depletion of *Striga* from the soil, such as trap crops, catch crops, ethylene gas, strigol analogues, methyl bromide fumigation and others.

b) Methods which limit and/or reduce *Striga* reproduction, such as hand weeding before flowering, herbicides, seed hardening, resistant varieties, fertilizers, irrigation, shading-intercropping, or mulching or high crop density, biological control, resistance of the host crop, chemical, biological and cultural practices.

2.6.1 Biological Control

There is scanty data on the kinds of organisms that could be considered in a potential biological control program for *Striga* (Musselman, 1983). Research at the International Institute of Tropical Agriculture (IITA) has however found that biotic agents cause pre-reproductive wilting of *Striga* plants (PASCON, 1993). In addition to wilts, several diseases of fungal and bacterial etiology have been identified on *Striga hermonthica*, causing symptoms such as tip die back, stem and leaf lesions, and floral necrosis (Berner *et al.*, 1993). However, a lot still need to be learned about ecological requirement, quantitative damage and host specificity. The most promising control agents are the gall forming insects (S*micronyx* species), the borers (Lepidopterus) and weevil species (Ariga, 1996).

Several fungal and bacterial pathogens of *Striga hermonthica* have also been identified and have been tested for feasibility in field control (Nzioki *et al.*, 2016). The most promising fungi are in the genera *Sclerotium* and *Fusarium* while the most promising bacteria are in the genera *Pseudomonas* and *Xanthomonas* (Berner *et al.*, 1993). *Fusarium oxysporium Schlecht* (Foxy 2 & PSM197) has proved to be highly virulent against *Striga* weed, (Schaub *et al.,* 2006). Applied as granular mycoherbicides, they cumulatively reduced emerged *Striga* plants per plot by 75.3%, *Striga* dry weight by 74.4%, *Striga* flowers by 83.6% and plant crop infested by 64.8% compared to controls in field trials conducted in Nigeria (Schaub *et al.,* 2006). Biological control could give a lasting effect as it is relatively cheap and does no harm to the environment. It could be a very attractive method for solving the *Striga* problem (Pieterse and Pesch, 1983) and especially with regard to the small-scale cash strapped African farmer. However, a lot still remains to be done in seeking a lasting biological control solution that farmers in Africa could easily apply in the management and control of *Striga* infestations.

2.6.2 Chemical Control (Herbicides)

The use of herbicides in *Striga* control saves on labor costs (Ariga, 1996) and herbicides such as Trifluralin (Treflan), (2,6-dinitro-N-N-dipropyYl-4-(triflouryethyl), benefin, fluchloralin and pendimethalin (Anon, 1983; Ross and Lembi, 1985) have been found to give good control of *Striga.* Dicamba was found to be effective against *S. asiatica* in the USA (Eplee and Norris, 1987). Dicamba is a systemic herbicide applied to the crop foliage about 35 days after emergence. Dicamba efficacy was tested in Kenya and it was noted that for it to be effective; the time of application should coincide with the peak of *Striga* germination and attachment (Odhiambo *et al.,* 1993). However, it is not cost effective, as it does not provide persistent and continual control (Abayo *et al.*, 1998). Several other herbicides and combinations of herbicides have been shown to give good control of *Striga* (Abayo *et al.*, 1996; Babiker *et al.*, 1996).

In recent decades, some chemicals have become available for parasitic weed control (Gracia-Torres, 1998) although only a few are able to control the parasitic weed selectively (Goldwasser and Kleifield, 2004). The use of herbicides against parasitic weeds is however generally restricted because of the negative effects on host crops. Many like 2,4-D and related compounds such as MCPA, which kill *Striga* without damaging the grassy host, cannot be used in mixed cropping with broad leaf crops (Pieterse and Pesch, 1983). 2, 4-D is an herbicide that is sprayed directly on the parasites during the growing season. The farming systems in most small-holder situations are such that there are a variety of cropping practices such as intercropping, mixed cropping and relay cropping. These practices limit the choice of herbicides that can be used to control weeds without injuring the crops. The few herbicides that are available have a narrow range of activity, are expensive and therefore out of the scope of the ordinary farmer (Verkleij and Kuiper, 2000). Herbicide control for *Striga* in Africa still has a long way to go owing to the economic status of most of the farmers where *Striga* is a problem and the lack of technological know-how to implement the control strategy.

A mutation for herbicide resistance in maize has been exploited as a *Striga* control technology in East Africa (Kanampiu *et al.*, 2003). The germplasm used in this technology is resistant to the imidazolinone group of the acetolactate synthase (ALS) inhibiting family of herbicides. Seed treatment of imidazolinone resistant (IR) maize with herbicide (registered as *Strigaway*^{TM}), combining low doses of imazapyr (<30 g/ha) to maize gave effective control of *Striga* in the early stages of parasitic attachment to maize seedlings. The herbicide is taken up by the maize plant, slowly moves through the soil, killing *Striga* and forming a localized protective zone around the growing maize roots (Kanampiu *et al.*, 2002). Imazapyr as a seed treatment was reported to increase harvest index by 17% when corn plants in *Striga* infested soils were kept insect and disease free by using insecticides and fungicides (Abayo *et al.*, 1998). Complete control could be achieved at affordable cost ($ 5 ha^{-1}) to farmers in subsistence conditions. The *Ua-Kayongo* (*Striga* Killer) technology has been commercialized in Kenya and adopted by local seed companies (De Groote *et al*., 2008).

New formulations such as slow release which ensures longer duration of imazapyr herbicide release to the plant and soil are being developed (Kanampiu *et al*., 2009). This however lowers the initial transient phytotoxicity effects seen in Imidazolinone Resistant (IR) germplasm treated with herbicide (Gressel, 2009). A major challenge on the use of ALS-inhibiting herbicides is the threat of imminent evolution of *Striga hermonthica* biotypes with resistance to this herbicide group (Gressel *et al.*, 1996; Tranel and Wright, 2002; Hearne 2009). Resistant *Striga hermonthica* biotypes could dominate in a few years unless additional management practices are employed to prevent the rapid build-up of resistance (Gressel *et al.*, 1996, Abayo *et al.*, 1998, Kanampiu *et al.*, 2001, Chaudhry, 2008). The farmers are also given instructions when handling the treated seed such as hand washing to prevent herbicide carry-over to non-herbicide resistant maize or other crop seed. Another drawback with the technology is the low plant population attributed to its deleterious effects (Personal field experience). In order to use the IR seed, farmers need to purchase coated seed on annual basis otherwise any saved seed will be susceptible to *Striga* (De Groote *et al*., 2008). Another broader indication in access to germplasm is cash constraints (18 % of farmers stated cash flow limitations as one of the reasons for non-adoption of IR technologies) (Manyong *et al.,* 2008).

2.6.3 Soil Fertility Improvement and Direct Fertilizer Effects.

There are strong indications that the use of higher rates of nitrogen fertilizers reduce *Striga* incidence and damage and therefore often recommended for inclusion in integrated control programs (Verkleij *et al.,* 1993; Ibginnosa, 1996; Kim *et al.,* 1997; Kureh *et al.,* 2006). Field studies have reported that increasing the supply of nitrogen fertilizer reduced the infection of *Striga* and increased the host yield (Agabawi and Younis, 1965; Bebawi, 1981; Farina *et al.,* 1985). Similarly, the addition of nitrogen fertilizers reduced *Striga* emergence in fertile soils but increased emergence on infertile soils (Dogget, 1988). A repeated application of N is more effective in depressing *Striga* performance and stimulating host growth than a single initial application (Mumera and Below, 1993; Yaduraju *et al.,* 1979). Though it is generally accepted that nitrogen fertilizer reduces the severity of *Striga* on maize, the mechanisms are not well documented (Kureh *et al.,* 2003). Various investigations on the inhibiting effect of nitrogen fertilizers on development of *Striga* suggest that the effect could be related to germination after observing that in vitro urea and also ammonium sulphate decreased the number of germinating seeds and the length of the radicals (Pesch and Pieterse, 1982). Parker (1984) proposed that the effect could be related to the host's partitioning of resources between the root and shoot. He found that the root/shoot ratio increased as a result of *Striga* attack but this effect was significantly reduced in the presence of ammonium nitrogen. Raju *et al.,* (1990) showed that host plants produce a smaller quantity of stimulant in the presence of nitrogen fertilizers. Pieterse and Verkleij (1991) also emphasized that although it is uncertain how nitrogen inhibits *Striga* development under field conditions, three effects have irrefutably been shown in vitro. First, an inhibitory effect caused by ammonium-nitrogen on germination and radicle length in *Striga*. Second, an inhibitory effect of ammonium-nitrogen and nitrate-nitrogen on stimulant production by the host crop. Third, a toxic effect caused by ammonium nitrogen on *Striga* development following attachment. Verkleij *et al.,* (1993) concluded that N-fertilizer could be bringing about an effect on the early development. However, it is evident that wherever *Striga* is a problem it is likely that there is some nutrient deficiency in the soil that needs to be addressed (Jamil *et al*., 2012). Increased incidence of *Striga* in tropical countries has been attributed to a decline in soil fertility and intensity of land use (Vogt *et al*., 1991).

Most small-holder farmers in developing countries who produce cereals for home consumption cannot afford the price of artificial inorganic fertilizers, and moreover, the availability and distribution of those fertilizers is not guaranteed (Ariga, 1996). If mineral fertilizers are not available, then alternative means of improving soil fertility have to be considered, whether by farmyard manure or use of leguminous crops (Zerihun, 2016). The use of leguminous crops has been identified as one of the methods available to improve soil fertility when most of the residues are returned or left in the fields (Odhiambo, 1998).

2.6.4. Agronomic Control

Agronomic control options involving rotation, trap cropping, catch cropping, hand pulling and hygienic procedures of various sorts all have been shown to help reduce *Striga* infestations (Ndung'u *et al*., 2000; Emechebe *et al*., 2004; PROSAB, 2004). According to Berner *et al.*, (1995), a central focus of approach to management of cereal crops in the *Striga* zone in Africa still remains the inclusion of legume crops in cereal rotation or mixtures. Some of the agronomic options available include:

2.6.4.1 Manual Weeding (Hand Pulling)

Hand pulling is the most common control measure used by small-scale farmers but it is only effective where the *Striga* population is low (Ransom *et al.,* 1990). It has been shown to reduce *Striga* incidence (Doggett, 1988), but the critical time for hand pulling is usually a major problem for farmers (Oswald, 2005). The method is less effective because much of the damage to the host occurs while the parasite is still underground (Oswald, 2005). The farmers allow the parasite to flower and set seed before uprooting the stems. Due to the high fecundity of *Striga*, their efforts become of little significance. Removing mature *Striga* plants from infested fields will reduce only the amount of seeds but not increase the host yield in the short term (Rady, 2007). The methods of disposal of the uprooted *Striga* such as placement on the roads and footpaths instead of burning make seeds find their way back into their farms. Weeding out the parasite requires a prohibitive amount of labor once *Striga* is fully established (Parker, 1983).

2.6.4.2. Catch Cropping

Striga “Catch crops" are crops that are parasitized by *Striga* but which are destroyed before the parasite sets seed (Oswald, 2005) Catch crops are usually planted at high densities than is normal for crop production in order to induce greater germination of *Striga* seeds (Oswald *et al.,* 1997). After the parasite has germinated and emerged, the catch crop is harvested or destroyed before the parasite sets seeds (Pieterse and Pesch, 1983). The crop can be used as forage or ploughed into the soil to improve soil fertility. In this way reproduction is prevented as no *Striga* seeds return to the soil (Odhiambo, 1998). Sudan grass (*Sorghum halapense* L.) has been identified as an effective "catch crop" for *Striga hermonthica* (Pieterse and Pesch, 1983, Oswald *et al.*, 2004.). However, catch (parasite-susceptible) cropping is rarely used by small-scale farmers to control *Striga* because the technique is not well known and should be adapted to a specific cropping system (Oswald *et al.*, 1999). Catch cropping can have useful effects where the parasite soil infestation level is very low (Rady, 2007).

2.6.4.3. Crop Rotation with "Trap Crops"

A wide range of rotations can be effective in reducing *Striga* numbers in the soil and increasing yields in subsequent cereal crop (Odhiambo and Ransom, 1994; Sauerborn *et al.*, 2000; Oswald and Ransom 2001; Schulz *et al.*, 2003; Ahonsi *et al.*, 2004; Hess and Dodo, 2004). Crop rotation is a farming system in which different crops are grown in alternate seasons in a given field to improve crop performance (Sanginga *et al.*, 2001). This method of crop production is intended to help improve soil fertility and prevent the build-up of dangerous pests and diseases (Odhiambo, 1998; Sanginga *et al.*, 2001). 'Trap crops' or 'false host' are non-host crops that offer the advantage of stimulating germination of *Striga* or root parasites without themselves being parasitized (Visser *et al*., 1987; Khalel, 1992). Usually in the case of *Striga* the system involves growing of a trap crop in one year or season followed by maize or any other cereal. The trap crops cause suicidal germination by stimulating *Striga* seeds to germinate and help in the reduction of *Striga* seed bank in the soil. A long-term approach therefore, in the control of *Striga* in Africa is rotation of resistant cereal varieties with trap crops previously selected for high *Striga* seed germination stimulation (Ariga, 1996). Scientists are identifying locally acceptable trap crops, mainly legumes, which stimulate *Striga* germination and improve soil fertility to fit into farming systems (Oswald, 2005). Major trap crops recommended for use against *Striga* include cotton (*Gossypium hirsutum* L.), cowpea, (*Vigna unguiculata*), soybean (*Glycine max* L.), groundnut (*Arachis hypogeae* L.) and sunflower (*Helianthus annus* L.). Carsky *et al.*, (2000), reported that *Striga hermonthica* incidence in maize after soybean, compared to maize after sorghum was reduced from 3.2 to 1.3 *Striga* plants per maize plant, resulting in greatly improved yields. In Ghana and Nigeria, Sauerborn *et al.,* (1999) and Schulz *et al.,* (2003) achieved 30% and 50% respectively, seed bank reduction, after one year rotation with trap crops that included soybean, cowpea, sunflower and cotton.

2.6.4.4. Mixed Cropping (Intercropping)

Inter-cropping cereals with legumes and other crops is a common practice in many parts of Africa and reportedly reduced *Striga* infestation (Kroschel, 2001). The practice is popular in the semi-arid zone because food production is diversified, risk of crop failure reduced, and resources for crop growth utilized more efficiently, than with sole-cropping (Carsky *et al.,* 1994). Inter-crop yields also represent an additional gain in land productivity (Oswald *et al.*, 1996). Intercrop cultivars which produce *Striga* germination stimulant abundantly but which fail to produce haustorial initiation factor for *Striga* would be useful in *Striga* control (Butler, 1995). Careful selection of those cultivars with enhanced *Striga* germination stimulant production would play a major role in diminishing the *Striga* seed population in the soil (Ejeta, 2007b).

The most encouraging reports on the benefits from mixed cropping on reducing incidence of *Striga* include those from Salle *et al.,* (1987) who observed reduced *Striga hermonthica* in pearl millet when they interplanted four rows of groundnut to each one of millet. Carson (1988) also found that the density of emerged *Striga* plants, and soil temperature were reduced when sorghum was associated with groundnuts. He also found that groundnut planted within sorghum rows had a much greater effect in reducing *Striga hermonthica* than did interplanting with alternate rows. The fodder legumes *stylosanthes*, *mucuna* and *desmodium* as intercrops were found to reduce *Striga* infestations and to improve maize yields (Ndung'u *et al.,* 2000). *Desmodium* as an intercrop in maize is used in a highly effective *Striga* and stem borer control technology known as “push and pull” (Khan *et al.,* 2008). Farmers have come to appreciate intercropping as it ensures growing of much needed cereals and legumes and at the same time achieve some level of productivity (Gethi, 2004). Parker, (1991) suggested that shading and reduced temperature of the emerged parasite could be the most important effect from intercropping. Nitrogen fixed and released by some intercrops like cowpea (Eaglesham *et al.*, 1981) is also thought to contribute to *Striga* suppression in inter-cropping since the amount of available nitrogen apparently affects *Striga* density (Pieterse and Verkleij, 1991). Intercropping maize with cowpea and sweet potato has been reported to reduce the emergence of *Striga* in Kenya (Oswald *et al.,* 2002).

2.6.5. Breeding for *Striga* Resistance/Host Plant Resistance

Host plant resistance provides an important part of the solution to *Striga* problem to the resource poor farmer (Kim, 1991). The best long-term strategy and the most economically feasible and sustainable approach to minimize the yield loss due to *Striga* infestation in cereals is to use resistant crop varieties (Ramaiah, 1986; Cubero and Hernandez, 1991; Ejeta *et al.,* 1991; DeVries, 2000; Verkleij and Kuijper, 2000; Haussmann and Hess, 2000; Badu-Apraku *et al.*, 2005; Rich and Ejeta, 2008; Badu-Apraku and Akinwale, 2011) because they do not require additional inputs such as labor and chemicals. It has been reported that genetic resistance reduces *Striga* damage at the subterranean level (Vasudeva Rao *et al.*, 1982). Current breeding practices are primarily focused on improving host resistance levels (Tomilov *et al.,* 2008; Li and Timko, 2009; Yoder and Scholes, 2010). This is because resistance is an effective mechanism to reduce parasite infection and reproduction rates thereby protecting the current crop and lowering the parasite pressure in the forthcoming growing seasons (Rodenburg *et al.,* 2006). A maize genotype that combines superior levels of resistance/tolerance to *Striga* is a promising breeding strategy and has been proposed for *Striga* resistance/tolerance breeding in many studies (Kim, 1991; Devries, 2000; Hausmann *et al.,* 2001; Pierce *et al.,* 2003; Rodenburg *et al.,* 2006). Reports of genetic resistance to *Striga* have been documented in rice [*Oryza sativa*] (Harahap *et al.,* 1993; Bennetzen *et al.,* 2000; Gurney *et al.,* 2006; Jamil *et al.,* 2011), sorghum [*Sorghum bicolor* (L.) Moench] (Maiti *et al.,* 1984; Hess *et al.,* 1992; Vogler *et al.,* 1996; Arnaud *et al.,*1999; Mohamed *et al.,* 2003; Rich *et al.,* 2004; Haussmann *et al.,* 2004; Noubissie *et al.,* 2012), pearl millet [*Pennisetum glaucum*] (L.) R. Br] (Kountche *et al.,* 2013), cowpea (*Vigna unguiculata*) (Riopel and Timko, 1995) and maize [*Zea mays* L.] (Adetimirin *et al.,* 2000; Gethi and Smith, 2004; Menkir, 2006; Amusan *et al.,* 2008; Karaya *et al.,* 2014).

Resistance to *Striga* is controlled by relatively few genes with additive effects (Vasudeva Rao *et al.,* 1982). Considerable variability in resistance to *Striga hermonthica* has been shown in maize. The early maturing variety, Katumani, has been shown to support less *Striga* (Ransom, 1996). Mumera and Below (1996), suggested that identification of *Striga* resistant genotypes should focus on the ability of the ear sink to successfully compete with *Striga* for assimilates. Screening of wild relatives for resistance to a parasitic plant is also a promising approach to detect and transfer novel resistance mechanisms to crops such as those identified in *Tripsacum dactyloides* and in some *Viciae* species (Gurney *et al* ., 2003; Sillero *et al* ., 2005).

The uses of varieties, which are tolerant and resistant to *Striga* species, have been recommended as the most practical approach for resource-poor small-holder farmers (Ramaiah, 1987; Kim, 1991). According to the definition of "resistance" and "tolerance"(Ejeta *et al.*, 1991; Parker and Riches, 1993), a crop genotype that, when grown under *Striga* infestation supports significantly fewer *Striga* plants and produces higher yield than local farmers' susceptible cultivar is designated "resistant". "Tolerant" genotypes stimulate germination of *Striga* seeds and support as many *Striga* plants as do susceptible genotypes, without showing a concomitant reduction in grain production or overall plant productivity (Parker and Riches, 1993). Tolerance is so far the only genetic resource for resistance against *Striga* in maize (Cardoso *et al*., 2011).

Breeding for *Striga* resistance or tolerance should be linked with other favorable traits such as high yield and drought resistance (Spallek *et al*., 2013). Promising results were obtained when both traits, *Striga* and drought resistance were combined by classical breeding (Spallek *et al*., 2013). This effort was internationally recognized when Professor Gebisa Ejeta received the World Food Prize in 2009 (http://worldfoodprize.org). Some *Striga* resistant sorghum varieties that have been identified include S35, CS-54, CS-95, Framida (red), and SRN-39 (PASCON, 1993). SRN-39, exhibits broad-based resistance across *Striga* species and strains, is drought resistant and has good food attributes (PASCON, 1993). This variety has been officially released for commercial cultivation by farmers in *Striga* endemic areas of Sudan (Ejeta *et al.*, 1992). The landrace N13 (*S. bicolor* subspecies *bicolor* race durra) has a resistance mechanism that was described in detail by Maiti *et al.*, 1984. It resists *Striga* by cell-wall thickening as well as depositing silica (Maiti *et al*., 1984). Though resistance in maize is still elusive, some progress has been made in this area due to resistance in wild varieties of maize like teosinte (Odhiambo, 1998). Even though resistance in maize has not been documented, field observations and surveys indicate that some maize genotypes grown by farmers are tolerant to *Striga* and are thus able to give some yield even under a high *Striga* infestation (Frost, 1995). Some tolerant maize varieties include 9022-13, 9021-18 and 7044-15 for West and Central Africa (PASCON, 1993). A maize genotype (B37), which was found to be a low stimulant producer, has also been identified (Ejeta *et al.*, 1992).

The International Institute of Tropical Agriculture (IITA) has employed recurrent selection and inbreeding to develop lines that support less emerged parasites thus reducing parasite seed reproduction and the subsequent buildup of seed bank in the soil in the savannas (Kim, 1991; Berner *et al.*, 1995; Kling *et al.*, 2000; Haussmann *et al.*, 2000; Menkir *et al.*, 2007). In Kenya, work done by Odongo (Odongo, 1997) identified some local maize land races, for example, “Rachar” and “Nyamula” as having some resistance/tolerance to *Striga.* KSTP94 which is a variety developed from land races from the farmers in *Striga* infested areas in Lake Victoria basin has been developed and selected for its tolerance to *Striga* infection. Studies conducted have identified KSTP94 to be superior to available maize hybrids and it has been selected for further improvement (Ndung'u, 2003). National performance trials in Kenya indicate that GAF4 developed by KALRO-Kibos was able to yield 5.12 tons per hectare compared to H513, a commercial susceptible hybrid that yielded 0.75 tons per hectare (Ngesa *et al*, 2010). In West Africa continued research at IITA based on symptomatology is trying to identify not only tolerant maize genotypes, but also genotypes whose resistance is due to other resistance mechanisms or a combination of these (Berner *et al.*, 1995). The continuous efforts at IITA in breeding for resistance has culminated in the development of open pollinated resistant varieties, inbred lines and hybrids adapted to the lowlands of West and Central Africa (Menkir *et al.,* 2007).

It has been reported that resistance reactions have been manifested in laboratory co-culture in a cultivated maize inbred line, ZD05, developed through long term breeding effort at the International Institute for Tropical Agriculture (IITA) (Amusan *et al.,* 2008). The inbred was selected for its field resistance to *Striga hermonthica* and has in its pedigree *Zea diploperennis* and tropical maize germplasm (Menkir, 2006). It had fewer /reduced number of emerged *Striga* than a susceptible inbred. However the underlying mechanism of the resistance exhibited was not characterized. Observations in the laboratory indicated that there were fewer *Striga* attachments and any *Striga* that did attach onto the roots died and rarely developed growth stages attained on the susceptible maize. These manifestations of resistance have been reported in wild relatives of maize, *Zea diploperennis* (Lane *et al.,* 1997) and *Tripsacum dactyloides* (Gurney *et al.,* 2003). Much less is known about the molecular basis of host resistance acting at this stage, normally referred to as post attachment resistance (Cissoko *et al*, 2011). Microscopic examination of incompatible interactions e.g. the blocking of parasite growth in the host cortex, at the endodermis, and before or after, connection to the host vasculature have recently been reported (Yoshida and Shirasu, 2009; Yoder and Scholes, 2010). These reports of true resistance reactions shows that durable resistance in *Zea mays* appears likely and this is effective when expressed early in the parasitic life cycle, since *Striga* causes much damage during establishment (Frost *et al.,*1997). This also means that resistance manifested in the progenitors can be transferred to cultivars. These points to potential gains to be made through plant breeding using carefully selected procedures.

2.6.6 Genetic Stability Studies in Maize under *Striga* Stress

The response to *Striga* weed resistance is variable under different growing conditions due to different intensity of the weed (Oswald and Ransom, 2004). Therefore, it is necessary to evaluate the genotype's differential response in multi-environment trials and assessing their genotype-by-environment interaction (GEI). In plant breeding programmes, potential genotypes are usually evaluated in different environments (locations and years) before desirable ones are selected (Rea *et al*., 2002). Genotype x environment (G x E) interaction is associated with the differential performance of materials tested at different locations and in different years, and influences selection and recommendation of cultivars. Highly stable genotypes are desirable (Rea *et al*., 2002). At CIMMYT, regional trials are used to evaluate new maize germplasm in multiple environments (locations and years) because of differential genotypic responses to different environments (Makumbi *et al*., 2015). The objective of the multi-environment trials is to identify high yielding adapted varieties for release in the respective countries (Makumbi *et al*., 2015) *Striga* resistant/tolerant varieties, developed by CIMMYT, are tested in multi-environment trials across the *Striga* endemic areas of eastern and central Africa (Makumbi *et al*., 2015)

2.6.6.1 Genotype and Environment (G X E) Interactions

The performance of genotypes can vary from one environment to another, so genotypes that are superior in one environment may not be superior in other environments, resulting in genotype × environment interaction (GE) (Makumbi *et al*., 2015). The interactions of genetic and non-genetic factors on phenotypic expression is called G × E interaction which is widely present and substantially contributes to the non-realization of expected gain from selection(Makumbi *et al*.,2015). Presence of G x E reduces the correlation between phenotype and genotype, making valid inferences more complicated in plant breeding (Comstock and Moll, 1963; Crossa, 1990; Kang, 1993; Annicchiarico, 1997; Epinat-Le Signor *et al*., 2001). A population which can adjust its genotypic or phenotypic state in response to environmental fluctuations in such a way that it gives high and stable economic returns, can be termed as “well buffered” (Singh and Singh, 1980). G × E interaction certainly plays an important role in the evaluation and execution of breeding programmes.

Allard and Bradshaw (1964) have critically reviewed this phenomenon and brought out its implications in applied plant breeding. Thus, G × E interaction is important in the expression of quantitative characters, which are controlled by polygenic systems and largely influenced by environmental changes. Significant GE has been reported in CIMMYT maize regional trials (Setimela *et al*., 2005, 2007; Windhausen *et al*., 2012). Similarly, G x E’s have been reported in evaluation of maize and sorghum varieties for *Striga* control in Sub Saharan Africa (Haussman *et al*., 2001) In a study to evaluate maize varieties for resistance to *Striga*, Menkir *et al*. (2012a) reported significant cultivar × environment interactions for grain yield and the number of emerged *Striga* plants under *Striga*-infested and *Striga*-free conditions. In other studies significant G x E’s have been reported for several traits in maize under *Striga* infestation. (Menkir *et al*., 2012b; Badu-Apraku and Lum, 2007, 2010; Badu-Apraku *et al*., 2007), Also, Haussmann *et al.* (2001), reported significant G x E’s for sorghum grain yield, emerged *Striga* plants, and flowering traits in sorghum. In contrast, a study by Badu-Apraku and Lum (2007) revealed no significant G x E for maize grain yield under *Striga* infestation.

The process of identification of stable maize genotype is difficult because of G × E interaction (Nguyen *et al*., 1980). Plant breeders have been unable to fully exploit the differences in breeding stable genotypes even though they have observed genetic differences for adaptability (Kalpande *et al*., 2017). This has been largely due to the problem of defining and measuring phenotypic stability. Various attempts were made to characterize the behaviors of genotypes in response to varying environments (Farshadfar *et al*., 2003). Plaisted and Peterson (1959) developed a method to characterize the stability of yield performance when several varieties were tested at number of locations within one year. A combined analysis was computed for each pair of varieties, n (n-1)/2 pairs for 'n' varieties and estimate of σ^2 v was obtained from each variety. The variety with the smallest mean value is the one that contributes the least to variety × location interactions and thus considered the most stable genotype in the tests. Statistical approach of Finlay and Wilkinson (1963) has proved useful for measuring the phenotypic stability in the performance of genotypes. They considered linear regression slope (b_i) as a measure of stability. The technique compares the performance of a set of cultivars grown at many sites for each variety. Varietal mean yield over all environments and regression coefficients are used to classify the cultivars specially adapted as poor, better yielding environments and for general adaptability. They indicated average phenotypic stability by a regression coefficient of unit ($b_i = 1.0$). A cultivar with $b_i < 1.0$ has above average stability, $b_i > 1.0$ has below average stability and $b_i = 0$ has absolute phenotypic stability which means a constant gain in all environments. The ideal cultivar is one that possesses genetic potential in highest yielding environment and maximum phenotypic stability. The regression analysis proposed by Finlay and Wilkinson (1963) was improved upon by Eberhart and Russell (1966). They introduced one more parameter, deviation from regression ($S^2\ d_i$) which accounts for unpredictable irregularities in the response of genotypes to varying environments. Eberhart and Russell (1966) observed that the corn hybrids with a regression coefficient less than 1.0 usually had mean yields that were below average. Accordingly they suggested that a desired variety should have high mean value, regression coefficient equal to 1.0 and variance due to regression as small as possible. Thus they modified the regression technique, which enables partitioning of G × E interaction of each variety into two parts (b_i), the variation due to response of variety to varying environmental indices (sum of squares due to regression) and the unexplainable deviation from the regression on the environmental index. They defined both the linear (b_i) and non linear ($S^2\ d_i$) components as stability parameters. Mechanism of stability falls into the four categories as follows:

1. Genetic heterogeneity
2. Yield component compensation,
3. Stress tolerance
4. Capacity to recover rapidly from stress.

2.6.6.2 Statistics and Genetics of G × E interactions

Many statistical tools are available for analysis of Genotype x Environment interactions. These are, combined ANOVA, stability analysis and multivariate methods (Adu *et al*., 2013)

Combined ANOVA is more often used to identify the existence of G x E interactions in multi-environmental experiments. However, the main drawback of this analysis method is that it assumes homogeneity of variance among environments that are required to determine genotypic differences. Although this analysis allows the determination of the components of variance arising from different factors (genotype, environment and the G x E interaction), it does not allow exploration of the response of the genotypes in the non-additive term: the G x E (Zobel *et al.*, 1988; Gauch, 1992).

Stability analysis provides a general solution for the response of genotypes to environmental changes. In this way, Yates and Cochran (1938) proposed linear regression analysis, which has been widely used and revised by a number of authors (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966; Lin and Thompson, 1975; Becker and León, 1988; Crossa, 1990). This analysis, involves regressing the average of the genotypes on an environmental index (the average yield of all the genotypes evaluated in each environment), thus providing a stability index. However, the analysis has several limitations and criticisms from both the biological and statistical points of view (Crossa, 1990). The biological problem appears when only a few very low and very high yielding locations are included in the analysis, and the fit is determined by the genotype behavior in a few extreme environments (Crossa, 1990). The main statistical problem is that the average of all genotypes evaluated in each environment is not independent of the average of each genotype in a particular environment (Freeman and Perkins, 1971). The other statistical drawback is that the errors associated with the slopes of the genotypes are not statistically independent (Crossa *et al.*, 1990). The last problem is the assumption of a linear relationship between interaction and environmental means, when the actual responses of the genotypes to the environments are intrinsically multivariate (Crossa *et al.*, 1990).

Multivariate analysis has three main purposes: (i) to eliminate “noise” in the data set (for example, to distinguish systematic and non-systematic variation); (ii) to summarize the information and (iii) to reveal a structure in the data (Crossa *et al.*, 1990; Gauch, 1996). Models based on principal components analysis, such as AMMI and Site regression (SREG), are linear-bilinear models with an additive component (the main effect of the environment or genotypes) and a multiplicative component (the G x E interaction). AMMI is a combination of ANOVA for the main effects of the genotypes and the environment together with principal components analysis (PCA) of the genotype-environment interaction (Zobel *et al.,* 1998; Gauch, 1996). AMMI models are usually called AMMI (1), AMMI (2) and so on up to AMMI (n), depending on the number of principal components used to study the interaction. Graphic representations are obtained using biplots (Gabriel, 1971) that allow (1) the observation, in the same graph, of the genotypes (points) and the environments (vectors), and (2) the exploration of patterns attributable to the effects of G x E interaction. In the biplot, the angles between the vectors that represent genotypes and environments show the interaction, and the distances from the origin indicate the degree of interaction that the genotypes show throughout the environments or vice versa. Site regression analysis, SREG (Cornelius *et al.,* 1996; Crossa and Cornelius, 1997; Crossa *et al.,* 2002), also called GGE (Genotype Main Effect plus Genotype-Environment Interaction), is a linear-bilinear model that removes the effect of location and expresses the answer only as a function of the effect of genotypes and the G x E interaction. This model is recommended when the environments are the main source of variation in relation to the contributions of the genotypes and the G x E interaction with respect to the total variability (Balzarini *et al.,* 2005). As a difference with AMMI model, this technique allows the detection of G x E interactions in terms of the crossover effect resulting from great changes in the ranking of the genotypes across the environments (Yan *et al.,* 2000). Yan *et al.* (2000) used GGE biplot graphics to visualize patterns and interactions without environmental effects. These authors point out that usually the first principal component (1PC) represents responses of the genotypes that are proportional to the environments, which are associated with the G x E interaction. The second principal component (2PC) provides information about cultivation locations that are not proportional to the environments, indicating that those are responsible for the G x E crossover interaction. This technique, at the same time, allows the determination of mega-environments, which means, parts of the cultivation area of a species that show homogeneous environmental conditions and where the performance of certain genotypes is similar through the years (Gauch and Zobel, 1997). In each mega-environment, the effects of the genotype-location interaction are limited or negligible (Yan and Hunt, 2002).

2.6.6.3 Additive Main Effects and Multiplicative Interaction (AMMI) and GGE Bi-Plot Analysis

Genotype × environment interactions have been investigated through use of statistical tools such as the additive main effects and multiplicative interaction (AMMI) analysis (Gauch and Zobel, 1988; Crossa *et al.*, 1990) and genotype main effect plus genotype × environment interaction (GGE) analysis (Yan *et al.*, 2000). All these analytical methods provide an insight into the extent of G x E present in a particular study. Genetic correlations can be used to quantify the importance of G x E (Falconer, 1952) and have been used in G x E studies (Eisen and Saxton, 1983; Cooper and DeLacy, 1994). AMMI helps agronomists and breeders to understand or model complex data sets, especially the interactions; to estimate yields more accurately, even with less data; to make better selections; and to design more efficient yield-trial experiments. The Additive main effect and multiplicative interaction (AMMI) model proved to be a powerful tool in diagnosing genotype by environment interaction (GEI) patterns. AMMI analysis provides a biplot graphical representation to summarize information on main effects, genotype, environment and interactions (PAC1) of both genotypes and environments simultaneously (Kempton, 1984). Genotypes with first principal component axis value close to zero shows general adaptation to the tested environment. A large PCA1 score reflects more specific adaptation to environments with PCA1 scores of the same sign. AMMI analysis can also be used to determine stability of the genotypes across locations using the PCA (principal component axis) scores and AMMI stability value (ASV). Moreover the GGE (genotype plus genotype by environment interaction) analysis is an effective method which is based on principal component analysis (PCA) to fully explore multi-environment trials (METs). GGE analysis, partitions G + GE into principal components through singular value decomposition of environmentally centered yield data (Yan, 2001).

2.6.7 Generations Means Analysis

The breeding method to be adopted for genetic improvement of the crop depends mainly on the nature of gene action involved in the expression of the quantitative traits (Azizi *et al.*, 2006). To formulate an efficient breeding program for developing weed tolerant/resistant varieties, it is essential to understand the mode of inheritance, the magnitude of gene effects and their mode of action (Farshafar *et al.*, 2001; Sharma, 1998). Many scientists have developed genetic models for the estimation of different genetic effects (Gamil and Saheal, 1986; Kearsy and Pooni, 1996). However, the majority of these genetic models are basically additive-dominance models or simply additive models.

Generation mean analysis (GMA) is a genetic design that is used to characterize the inheritance of a relevant trait by identifying the types of gene action conditioning the target trait when crossing two parental inbred lines having contrasting expression of the trait (Mather and Jinks, 1995). Studies on the inheritance are necessary so as to determine the gene action controlling resistance so that an appropriate breeding procedure can be developed (Singh and Chaudhry, 1993). In studies of pest, weed and disease resistance, it is important to identify susceptible and resistant parents before the crosses are made (Singh and Chaudhry, 1995). This is important in GMA as it is based on the assumption that the parental values will be significantly different and the genes for resistance are located in the resistant parent. In comparison to the other mating designs, GMA has several advantages such as its small sized experiments that allow for certain levels of precision and errors to be reduced when working with means rather than with variances (Singh and Chaudhry, 1993). The epistatic or non-allelic interactions are largely ignored so as to have a simplified interpretation of genetic variation (Singh and Chaudhry, 1995). However, it has now been established that such inter-allelic interactions are of frequent occurrence in the control of trait-expansion for continuous variation. Thus, inferences drawn from additive models are likely to be based to an unknown extent. That is why, Jinks *et al.,* (1969) suggested that it is no longer possible to justify the use of a biometrical genetic analysis which does not have a built in test for epistasis. To be on the safe side, it is therefore, rather essential to test the presence or absence of non-allelic interaction (Sharma, 1998; Kearsey and Pooni, 1996; Singh and Chaudhry, 1995; Farshadfar, 1998). More than one procedure is available to test the deviation from additive models, i.e. to detect epistatic effects. These are: Wr-Vr test for additivity (Hayman, 1954), the triple test cross test (Kearsey and Jinks, 1968), the test of epistasis (Jinks *et al.,*1969), computation of interaction per se (Jinks and Jones, 1958) and scaling test (Mather, 1949; Hayman,1954; Jinks and Jones, 1958). Phenotypic mean is consummated by additive (a), dominance (d) and interaction effects (i) of genes in point. The interaction effect is again of two kinds: (1) complementary (aa) and duplicate (ad and dd) at digenetic level.

The analysis of generation mean provides the opportunity first to detect the presence or absence of epistasis (by scaling test) and when present, it measures them accurately whether it is complementary (additive x additive) or duplicate (additive x dominance) and (dominance x dominance) at the digenic level (Farshadfar *et al.*, 2008). It also determines the components of heterosis in terms of gene-effects and some other statistics such as potence ratio, level of dominance, number of effective factors, etc. (Kearsy and Pooni, 1996; Singh and Narayanan, 1993; Farshadfar, 1998; Farshadfar *et al.*, 2001).

As mentioned by Kearsy and Pooni (1996), generation mean analysis is a useful technique in plant breeding for estimating gene effects (additive and dominance) and their disgenic (additive x additive; Additive x dominance; Dominance x dominance) interactions responsible for inheritance of quantitative traits. According to Sharma and Sain (2003) generation mean analysis help us in understanding the performance of the parent used in the crosses and potential crosses to be used either for heterosis exploitation or for pedigree selection.

CHAPTER THREE:MATERIALS AND METHODS

3.1 Experimental Sites

Field experiments were conducted at Maseno University, Nyahera and at the Kenya Sugar Research Foundation (KESREF) Kibos respectively. The three sites are situated in Western Kenya and are traditionally used for *Striga* Research. The National performance trials organized by Kenya Plant Health Inspectorate Service (KEPHIS) were conducted at KESREF-Kibos, Nyahera, Alupe, Busia, Ndori, Homa bay, Rarieda and Luanda. The sites have a bimodal type of rainfall where the first peak falls between March and June whereas a second peak falls between October and January. The sites lie at or near the equator meaning that there is no significant variation in day length.

Maseno University site lies along the Equator at latitude 0^o, longitude 34^o 30'E and at an altitude of 1515 meters above sea level. The soils at Maseno are well drained, extremely reddish brown and friable clay. The soils vary in color, consistence and texture. They are classified as dystric nitisols. It experiences mean minimum and maximum temperatures of 15.4^0C and 29.9^oC respectively with an annual rainfall of between 1100 mm-1500 mm (Jaetzold *et al.,* 1982). The site is *Striga* free and was used for hybrids evaluation, inbred lines increase and making crosses to form new hybrids for further testing.

Nyahera, a natural *Striga* hot spot, lies at latitude E 34^0 53.452', longitude N 0^0 35.977' at an altitude of 1490 meters above sea level. The soils are well drained loam on a gentle sloping land. The average annual rainfall is 1650 mm per annum (Jaetzold *et al.*, 1982).

The Kenya Sugar Research Center site at Kibos, lies at 0^0 04'S, 34^0 48, elevation 1214 meters above sea level. Kibos has a tropical climate with a mean daily temperature of 23^0C and an average annual rainfall of 1250 mm per annum. The soils are dark grey in color, normally deep and cracks when dry. The soil type is clay and not well drained (Jaetzold *et al.*, 1982). Kibos is located in Kisumu County in western Kenya and the location is widely used for Sugarcane and *Striga* research with well-established *Striga* laboratory and *Striga* sick field plots in place.

Alupe research sub-station is located in Busia county Western Kenya. Its geographical coordinates are 0^{o} 29´ North latitude and 34^{o} 08´East longitude. It has an elevation of 1190 meters above sea level with a maximum and minimum temperature of 28^{o}C and 16^{o}C respectively and annual average rainfall of 1775 mm. The soils are ferro-orthic acrisols with a sandy clay texture, which are shallow to moderately deep and well drained (Oswald and Ransom, 2004).

Busia County receives a mean annual rainfall of 1500 mm in 2 seasons a year. The annual mean maximum temperature ranges from 26° to 30°C and the annual mean minimum temperature varies between 14° and 18°C. The altitude varies from 1130 to1375 meters above sea level. It lies in an area with alluvial soils at an altitude of 1135–1200 m above sea level.

Ndori is located in Bondo district at 0^{o} 02´N, 34^{o} 20´ E at an altitude of 1170 meters above sea level, with a mean annual rainfall of 1200 mm.

Homa Bay is situated at 0.52° South latitude, 34.45° East longitude and 1166 meters elevation above the sea level. The average annual temperature is 22.5 °C. The average annual rainfall is 1226 mm. Soils are mainly acrisols, ferralsols, and vertisols of a sandy to clay texture, highly acidic and of low organic matter.

Rarieda lies on the northern shores of Lake Victoria within latitudes 0.0^0 02`N and 0.0024^0 S and Longitudes 34.00^0’ E at an altitude of 1350m. It has hot and moderately wet climate.

Luanda, situated at Vihiga County in western Kenya, lies at Latitude 0.0240^0 N, longitude 34.5874^0 E. The site is at an altitude of 1501meters above sea level. The annual mean maximum temperature ranges from 23° to 30°C and the annual mean minimum temperature varies between 16° and 18°C. The soils are classified as dystric nitisols.

3.2 Materials

Maize inbred lines from IITA and Maseno University were evaluated under *Striga* infestation in the 2010 and 2011 (Table 3). Hybrids from the IITA and Experimental maize hybrids from Maseno university together with commercial hybrid checks (DK8031, PhB3253 and H513) were also evaluated under *Striga* and *Striga* free conditions at Nyahera and Maseno in western Kenya in 2011 and 2012 growing seasons (Table 4 and Table 5). Experimental design was a randomized complete block design with three replications. Each plot consisted of four rows of 5 meters long, spaced at 0.75 meters apart with 0.25 meters between plants within a row. Two exceptional hybrids, EH12 and EH14 were submitted to the National performance Trials (NPT) for further evaluation in eight *Striga* infested locations.

3.2.1 Experiment I: Maize Inbred Lines Screening

This was conducted during the short rainy season, September to December 2010 and long rains season, April to August 2011 at Nyahera. The inbred lines evaluated were obtained from either International Institute of Tropical Agriculture (IITA) or Maseno University. The list of inbred lines screened under *Striga* infestation during short rains season of 2010 and Long rains season of 2011 are shown in Table 3.

Table 3: List of maize Inbred lines screened under *Striga* infestation at Nyahera in the short rains season 2010 and long rains season 2011.

Inbred	Source
ABR*¶	Maseno University
GF4/S1S2*¶	Maseno University
M211¶	Maseno University
MSMP1/P2*¶	Maseno University
TZSTR132¶	IITA
TZSTR133¶	IITA
TZSTR136¶	IITA
TZSTR139¶	IITA
TZSTR149¶	IITA
TZSTR150*¶	IITA
TZSTR151¶	IITA
TZSTR153¶	IITA
TZSTR154*¶	IITA
TZSTR155¶	IITA
TZSTR166*	IITA
TZSTR167*	IITA
TZSTR168*	IITA
TZSTR170*	IITA
TZSTR179*	IITA
TZSTR182*	IITA
TZSTR184*	IITA
TZSTR185*	IITA
TZSTR186*	IITA
TZSTR187*	IITA
5057*¶(susceptible check)	IITA
1368*¶(Tolerant check)	IITA
1383*	IITA
1398¶	IITA
9540*¶	IITA

Key:*Maize inbred lines evaluated short rains 2010 ¶ Maize inbred lines evaluated long rains 2011 *¶ Maize inbred lines evaluated both short rains 2010 and long rains 2011.

3.2.2 Agronomic Practices.

Land preparation was done using a disc plough and harrowed before planting. A pre marked twine and hoes were used to mark planting stations. Plantings were done on the 24th of

September 2010. The inbred lines were planted in two row plots of 5 meters spaced at 0.75 meters apart with 0.25 meter spacing between plants within the row. Within a row, two seeds were planted per hill and thinned to one plant after emergence to attain a population density of 53,333 plants ha^{-1}. A compound fertilizer was applied at the rates of 60kg N, 60kg P per hectare at the time of sowing. Additional 60kg N ha^{-1} was applied as top dressing 4 weeks later. Hand hoe weeding was carried out prior to *Striga* emergence and thereafter weeds were hand pulled.

3.2.3 *Striga* Inoculation

The *Striga* infestation method developed by IITA Maize Program (Kim, 1991; Kim and Winslow, 1991) was used. The *Striga* seeds used were collected from fields at the end of the growing season and mixed with finely sieved sand in the ratio of 1:99 by weight. About 5000 germinable seeds of *Striga* were used in each hill for infestation.

3.2.4 Agronomic Traits Measured

Emerged *Striga* counts and host damage ratings were made at eight and 10 weeks after crop emergence in the *Striga* infested plots. *Striga* damage was scored per plot using the scale of 1-5 where 1 = no damage, indicating normal plant growth and high level of tolerance, and 5 = complete collapse or death of the maize plant, that is, highly sensitive/intolerant. Husk was removed and field weight of the ears per plot was measured using a measuring balance. Moisture tester was used to determine the amount of moisture in the grain. Grain yield was calculated in kilogram per hectare and was estimated based on 80% shelling percentage and adjusted to 15% moisture. Grain yield under *Striga*-infested environment was calculated as follows:

$$\mathrm{GY} = fwt\ X\ \frac{(100 - m)}{85}\ X\ \frac{10000}{(\beta\ x\ \phi)}\ X\ 0.8$$

where,

GY = grain yield (kg ha^{-1}),

fwt = field weight of harvested ears per plot (kg),

m = grain moisture content at harvest

10,000= land area per hectare (m^2),

β = land area per plot (0.75 m x 0.4 m),

ϕ = number of hills/plot (11) and 0.80 = 80% shelling percentage.

Other traits recorded wherever possible included plant and ear heights measured using a ruler as the displacement from the base of the plant to the height of the first tassel branch and the node bearing the upper ear respectively.

3.2.5 Data analysis

Analysis of variance (ANOVA) was performed using CIMMYT Alpha software (Banziger and Vivek, 1997) and significant means separated using Least Significant Differences (LSD).The variance of *Striga* counts has been found to increase with the mean, therefore a log transformation {log (counts+1)} was used to reduce heterogeneity of variance before analysis of variance was done

3.3 Experiment II: Maize Hybrids Evaluation

3.3.1 Plant Materials

The maize hybrids evaluated were obtained from IITA and Maseno University. The list of materials evaluated is shown in Table 4 and Table 5 respectively.

Table 4. List of eighteen maize hybrids evaluated under *Striga* infestation at Nyahera in 2010 short rains season.

Hybrid	Source
0502-5 STR	IITA
0602-1STR	IITA
0602-3STR	IITA
0602-8STR	IITA
0501-STR	IITA
0501-2STR	IITA
0501-6STR	IITA
0601-6STR	IITA
0702-1STR	IITA
0702-2STR	IITA
9022-13	IITA
8338-1	IITA
KSCH513	Kenya Seed Company
EH10T	Maseno University
EH11S	Maseno University
EH12	Maseno University
PHB3253	Pioneer Seed Company
EH21	Maseno University

Table 5. List of nine maize genotypes evaluated under *Striga* and *Striga* free conditions at Nyahera and Maseno University respectively in 2011 and 2012.

Cultivars	Source
EH21S	Maseno University
EH11M	Maseno University
DK8031	Monsanto Seed company
EH21H	Maseno University
EH11S	Maseno University
EH14	Maseno University
H513	Kenya Seed Company
EH12	Maseno University
PHB3253	DuPont Pioneer

3.3.2 Agronomic Practices

All agronomic practices were done in similar way as described in section 3.2.2. *Striga* inoculation was done in a similar way as previously described in section 3.2.3. For *Striga* free environment data was also recorded for days to 50% silking, and days to 50 % anthesis. These were estimated as the number of days from planting to when 50% of the plants had emerged silks and had shed pollen respectively. The Anthesis Silking Interval was calculated as the difference between days to 50% silking and 50% anthesis. Plant aspect was recorded on a scale of 1-5 based on overall plant type, where 1= excellent plant type and 5 = poor plant type. Ear aspect was based on a scale of 1-5, where 1 = clean, uniform, large and well filled ears and 5 = ears with undesirable ears.

3.3.3 Data Analysis

Analysis of variance (ANOVA) was performed on plot means for grain yield and other measured traits using CIMMYT Alpha software (Banziger and Vivek, 1997) and significant means separated using Least Significant Differences (LSD). The ANOVA was conducted separately for data collected from *Striga*-infested and non-infested environments for the selected traits of the cultivars. The variance of *Striga* counts has been found to increase with the mean, therefore a log transformation {log (counts+1) was used to reduce heterogeneity of variance.

Simple linear Correlation analysis was also applied in order to assess the relationship between *Striga* resistance parameters (*Striga* emergence, *Striga* damage rating) and maize performance parameters (Grain yield).

Based on the results of ANOVA indicating significant G x E for GY in the trials, Additive Main effect and Multiplication interaction (AMMI) statistical analysis (Crossa *et al*.,1990) was used to asses G x E and stability of genotypes. The genotypes were treated as fixed effects whereas the season and G x E were treated as random effects. The AMMI analysis uses principal component analysis (PCA) to decompose the multiplicative effects (G x E) into a number of interaction principal component axes (IPCA). The AMMI biplot was developed by placing both the genotype and environment means on the X-axis and the respective PCA axis Eigen vectors on the y-axis (Vargas and Crossa, 2000). The biplot display of Principal component analysis scores plotted against each other provides visual inspection and interpretation of the genotype x environment interaction components.

3.4 Experiment III: Generation Means Analysis

3.4.1 Plant Materials

A cross between *Striga* resistant inbred line MSMP1/P2 and susceptible 5057 inbred lines of corn derived from Experiment I was used to generate progeny generations for field evaluations.

F_1, F_2, BC_1P_1 and BC_1P_2 were produced in short rains of 2011 and long rains of 2012. The F_1, F_2, BC_1P_1 (P_1) and BC_1P_2 generations were produced by crossing the parental inbred lines, selfing individual F_1 plants, crossing the F_1 to the susceptible parent and crossing the F_1 to the resistant parent. F_1 generations were selfed to produce F_2 generations by self-pollination of individual plants. F_1 generations were crossed to both parents [susceptible parents (P_1) and resistant parents (P_2)] to produce backcrosses of F_1 for each parents BC_1P_1 and BC_1P_2 generations, respectively. Some of these generations are genetically homogenous (P_1, P_2, F_1) and the rest are segregating (F_2, BC_1P_1, and BC_1P_2). The six generations, P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2 were evaluated under *Striga* sick plots at Nyahera during the short rains of 2012 and long rains of 2013. Seeds were hand sown at one seed per hill. Field evaluations for entries were grown in a randomized complete block design with two replications. The experimental units were four row plots for the P_1, P_2, and F_1 generations, a six row plot for the BC_1P_1 and BC_1P_2 generations, and an eight row plot for the F_2 progeny generation. The length of the rows including 1 meter alleys was 5.1 meters with 0.75 meters between rows. Four, six and eight rows were used to reduce intergenotypic competition between plots of different generations and to sample adequately genotypic variability within generations.

3.4.2 Agronomic Practices

All agronomic practices were done in similar way as described in section 3.2.2. *Striga* inoculation was done in a similar as previously described in section 3.2.3.

3.4.3 *Striga* Severity Assessment

Striga counts and *Striga* damage rating at eight and 10 weeks were recorded per plant for each of the six generations.

3.4.4 Statistical and Genetic Analyses

The statistical package used was Genstat discovery edition (version 4). *Striga* counts were transformed using logarithm to equalize variance. Both logarithmic and untransformed *Striga* count values were used in the analysis and presentation of the results. Adjusted means were analyzed using REM$_{tool}$ software. Since data in a repeated measure are dependent and correlated. REML (Restricted Maximum Likelihood) variance components analysis provides an effective analysis for repeated measurements. It involves the use of mixed models approach to test the significance of week factor, generation factor and interaction between week and generation. Where the difference was significant ($p < 0.05$) treatment means were separated using Least Significant Difference (LSD) test at 5%.

The following genetic effects were estimated using SAS procedures: a = additive effects = dominance effects, ad = additive by dominance effects and aa = additive by additive, and dd = dominant by dominant epistatic effects, following Gamble (1962).

Statistical treatment of data was run as under:

i) Find the total number of observation in each generation (*n*). For greater precision, it is important to base (*n*) on raw data rather than on plot means.

ii)Development of generation means by averaging the generations total (Total/*n*). P_1.P_2, F_1, F_2, BC_1P_1 and BC_1P_2.

iii) Getting the variance and mean variance of each generation. The variance is calculated as usual: Sum of Squares (SS)/ (n-1) Degrees of freedom *(df)* in each generation and mean variance (*V*) can be obtained by dividing *V* by *n*.

iv) Scaling tests to detect the presence or absence of epistasis: Adequacy of scale must satisfy two conditions namely, additivity of gene effects and independence of heritable components from non-heritable ones. The test of first condition provides information regarding absence or presence of gene interactions. The test of adequacy of scales is important because in most of the cases the estimation of additive and dominance components of variances are made assuming the absence of gene interactions. Hayman (1958) and Jinks and Jones (1958) proposed 4 scales: *A*, *B*, *C* and *D* to detect the presence of *j*, *l* and *i* interactions. These scales are computed by linear combination of various means involved in the expectation.

$$A = P_1 + F_1 - 2BC_1P_1$$

$$B = P_2 + F_1 - 2BC_1P_2$$

$$C = P_1 + P_2 + 2F_1 - 4F_2$$

$$D = 2F_2 - BC_1P_1 - BC_1P_2$$

Test of significance: The scales are tested for their significance by t test as,

T (A) = A/SE (A), T (B) = B/SE (B), T(C) = C/SE (C) and T (D) = D/SE (D).

v) If Epistasis is present:

a) Measurement of Six-parameters when backcrosses are available. Generation mean analysis is based on six populations, P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2. Hayman (1958), and Jinks and Jones (1958) developed the six parameter model for the estimation of various components of genetic variance when epistasis is present. According to Hayman (1958) the procedure for estimating the various gene effects is as follows.

m = mean effect = F_2

d = additive effect = $BC_1P_1 - BC_1P_2$

h = dominance effect = $F_1 - 4F_2 - ½P_1 - ½P_2 + 2BC_1P_1 + 2BC_1P_2$

i = additive x additive gene interaction = $2BC_1P_1 + 2BC_1P_2 - 4F_2$

j = additive x dominance gene interaction= $BC_1P_1 - ½P_1 - BC_1P_2 + ½P_2$

l =dominance x dominance gene interaction

$= P_1 + P_2 + 2F_1 + 4F_2 - 4BC_1P_1 - 4BC_1P_2$

Where P_1, P_2, F_1, F_2 BC_1P_1 and BC_1P_2 are the mean values for the character in the P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2 populations respectively.

vi) If epistasis is absent:

a) Application of Jinks and Jone's 3-parameter model of components of means
b) Application of Mather and Jinks' 3-parameter model of variance components.

vii) Number of effective genes (blocks).

The following formula was deployed using both means and variances to calculate *n*; effective factors conditioning a quantitative trait (Mather and Jinks, 1971).

Castle-wright's formula

$$n = \frac{.25(\bar{P}_1 - \bar{P}_2)^2}{8(V_{F2} + V_{F1})}$$

Where

n is the symbol of effective factors conditioning a quantitative trait.

P_1-mean of the resistant parent

P_2- mean of the susceptible parent

V_{F2}-variance of the F_2 population

V_{F1}-variance of the F_1 population

The use of this formula assumes: 1) there is no linkage between pertinent genes; 2) one parent carries only factors for *Striga* tolerance and the other parent carries only factors for *Striga* susceptibility; 3) all genes have equal effects; 4) all dominant factors have the same degree of dominance; and 5) inter-locus interaction is not present. Furthermore, the Castle Wright formula stipulates that effects of all the genes must be additive. Violation of any of these assumptions results in an underestimation of the number of genetic factors.

CHAPTER FOUR:RESULTS

4.1 Maize inbred Lines screening under *Striga* infestation at Nyahera during the short rains of 2010.

4.1.1 Emerged *Striga* Counts

The emerged mean *Striga* counts at eight weeks after crop emergence is presented in Table 6 below. In general, there were significant differences (P < 0.05) amongst the maize inbred lines for emerged *Striga* plants at eight weeks after crop emergence. The emerged *Striga* count at eight weeks after crop emergence ranged from 2.3 to 49.3.The average emerged *Striga* count was 15.9. The inbred line with the highest emerged *Striga* plants and was significantly different from all the rest was the susceptible 5057 with a mean count of 49.3. The tolerant inbred lines 1368 and 1393 had the second and third highest *Striga* count of 40.3 and 24.0 respectively. The other similarly tolerant inbred line that was not significantly different from the tolerant check 1393 was TZSTR153. The maize inbred lines with the lowest emerged *Striga* plants were TZSTR136 and the resistant maize inbred check, 9540 with mean counts of 2.3 and 3.3 respectively. The other maize inbred lines that had lower emerged *Striga* plants and were not significantly different from the resistant check, 9540 and TZSTR136 were TZSTR154, TZSTR139 and TZSTR149.

There were significant differences (P<0.05) amongst the maize inbred lines for emerged *Striga* plants at 10 weeks after crop emergence. The emerged mean *Striga* plants ranged from 2.7 to 50.7 at 10 weeks after crop emergence. The mean emerged *Striga* count was 20.6. The maize inbred lines with the least emerged *Striga* plants included the resistant check 9540, TZSTR136, TZSTR150, TZSTR151; TZSTR139 and TZSTR132. The inbred line with the highest emerged *Striga* was the susceptible 5057. Other noticeable inbred lines with high number of emerged

Striga plants and were not significantly different from the others included TZSTR133, TZSTR153, TZSTR154 and the tolerant check 1368.

4.1.2 *Striga* Damage Rating

The *Striga* damage rating results are presented in Table 6 below. The *Striga* damage rating score for the inbred lines ranged from 1.0 to 3.5 on a scale of 1-5. The inbred lines with the lowest score of 1.0 were the resistant check 9540, TZSTR150 and the tolerant check 1393. The susceptible inbred line 5057 had the highest mean damage rating of 3.5. The tolerant inbred check 1368, TZSTR154 had *Striga* damage rating score of 1.8. The inbred lines TZSTR149, TZSTR155, TZSTR136, and TZSTR151 had Striga damage rating score of 1.3. The rest of the inbred lines, TZSTR133, TZSTR139 and TZSTR153 had *Striga* damage rating score of 1.5. Significant difference (P<0.05) between the most susceptible inbred line, 5057 and the rest of the inbred lines was observed for the *Striga* damage rating at 10 weeks after crop emergence. All the inbred lines except the susceptible inbred line 5057 were not significantly different.

4.1.3 Number of Days to Flowering / 50 Percent Anthesis

The number of days to 50% anthesis is presented in Table 6. Significant differences (P<0.01) were observed amongst the inbred lines for the number of days to 50 percent anthesis. The average number of days to pollen shed was 73.3 while the pollen shed period ranged from 70 to 77 days. The maize inbred lines that flowered early were TZSTR154 and TZSTR155 at 70 days after planting. The maize inbred that took long to flower was 1393 at 77 days after planting. There was a difference of 7 days between the inbred line with the least number of days and the inbred line with the highest number of days.

4.1.4 Plant Height

Differences in mean plant height among the maize inbred lines were significant ($P<0.05$) (Table 6). The plant heights ranged from 110.0 cm to 153.7 cm. The mean plant height for all the maize inbreds was 134.1cm. Maize inbred TZSTR147 had the highest plant height (153.7 cm) whereas 5057 had the lowest plant height of 110 cm.

4.1.5 Ear Height

The mean ear height results are shown in Table 6 below. The mean ear height for the inbred lines was 69.7. Ear heights ranged from 55.0 to 89.7 cm with highly significant differences ($P < 0.001$) amongst the inbred lines observed for this trait.

Table 6. Means of Maize Inbred Lines Evaluated at Nyahera under *Striga* Infestation in 2010 Short Rainy Season.

	SDR (scale 1-5)	**[©]Number of emerged *Striga* plants**		**Days to flowering**	**Plant height**	**Ear height**
Variety	**10 w.a.c.e**	**8 w.a.c.e**	**10 w.a.c.e**		**(cm)**	**(cm)**
TZSTR132	1.3	15.0(1.2)	8.7(1.0)	74.7	149.7	70.0
TZSTR133	1.5	14.3(1.2)	35.0(1.6)	73.0	134.3	72.0
TZSTR136	1.3	2.3(0.5)	3.7(0.7)	71.7	146.7	74.0
TZSTR139	1.5	8.0(1.0)	9.3(1.0)	73.7	114.7	57.0
TZSTR149	1.3	8.7(1.0)	10.3(1.1)	71.0	153.7	89.7
TZSTR150	1.0	7.3(0.9)	5.7(0.8)	73.0	136.0	73.7
TZSTR151	1.3	11.0(1.1)	7.0(0.9)	73.7	144.0	89.7
TZSTR153	1.5	22.7(1.4)	41.7(1.6)	74.3	132.7	71.3
TZSTR154	1.8	6.0(0.9)	24.3(1.4)	70.0	121.7	59.0
TZSTR155	1.3	10.7(1.1)	10.0(1.0)	70.0	136.3	57.7
1368[β]	1.8	40.3(1.6)	30.6(1.5)	74.3	143.0	71.0
1393[β]	1.0	24.0(1.4)	49.3(1.7)	77.0	127.0	69.0
5057[∞]	3.5	49.3(1.7)	50.7(1.7)	75.3	110.0	55.0
9540[¥]	1.0	3.3(0.6)	2.7(0.6)	74.0	127.7	66.7
Mean	1.5	15.9	20.6	73.3	134.1	69.7
LSD $_{(0.05)}$	1.0	29.9	39.8	3.5	24.4	14.7
CV (%)	41.8	30.7	33.8	2.7	10.3	11.9
SEM	0.46	13.8	18.4	1.6	11.3	6.8
P	**	*	**	**	*	***

Key: [©]Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed {$\log_{10}(x+1)$} values of *Striga* counts; w.a.c.e: Weeks after crop emergence. SDR -*Striga* Damage Rating (1-5); ***-highly significant (P < 0.001, **-significant (P<0.01, *-significant (P < 0.05), [β]-Tolerant check, [¥]Resistant check, [∞]Susceptible check, SEM (standard error of mean), ASI-Anthesis silking interval, CV (Co-efficient of variation), LSD (least significant difference).

4.2 Maize Inbred Lines Screening under *Striga* Infestation at Nyahera during the long Rains of 2011

The performance of various traits of Maize inbred lines screened at Nyahera under *Striga* infestation at Nyahera during the long rainy season of 2011 are shown in Table 7.

4.2.1 Grain Yield

Highly significant differences (P < 0.001) were observed among the maize inbred lines for grain yield. The mean grain yields of the maize inbred lines ranged from 0.61 to 4.07 tons per hectare with an overall mean yield of 1.78 tons/ha. The top three highest yielding maize inbred lines under *Striga* infestation were GF4/S1S2, ABR and MSMP/1P2 from Maseno university with yield of 4.07 and 3.18 and 3.14 ton/ha respectively. The latter two were however not significantly different from one another. The highest yielding maize inbred lines were not significantly different from TZSTR155 and TZSTR136. The lowest yielding maize inbred line was TZSTR139 with 0.61 tons/ha. This was however not significantly different from the yield of the susceptible check 5057 at 0.72 tons/ha.

4.2.2 Emerged *Striga* Counts

The mean emerged *Striga* counts among the maize inbred lines are presented in Table 7. The emerged *Striga* count at eight weeks after crop emergence ranged from 0.5 to 4.5 with an overall mean emerged *Striga* count of 1.5. Fourteen inbred lines from IITA and four inbred lines from Maseno University (GF4/S1S2; ABR; MSMP1/P2; M211) had low emerged *Striga* plants and were not significantly different from one another. TZSTR153, TZSTR155 and the tolerant check 1393 also had low *Striga* emergence and were not significantly different. The highly susceptible maize inbred line was 5057 with a mean *Striga* count of 9.8 and was significantly different from the rest of the maize inbred lines.

Table 7. Mean performance of maize inbred lines screened at Nyahera under *Striga* infestation in 2011 Long rains season.

Variety	Grain Yield (t/ha)	©Number of Emerged *Striga* Plants		Days to Flowering	Ear Asp Aspect (1-5)	Plant height (cm)	Ear Height (cm)	Days to Silk	ASI (days)
		8 w.a.c.e	**10 w.a.c.e**						
GF4/S1S2	4.07	1.5(0.4)	4.0(0.6)	61.3	1.0	144.3	49.0	62.7	1.3
ABRABR	3.18	1.8(0.5)	3.3(0.5)	65.3	1.5	127.3	58.3	68.7	3.3
MSMP1/P2	3.14	1.2(0.3)	0.3(0.1)	62.3	1.3	167.0	64.0	65.3	3.0
TZSTR155	2.52	3.2(0.6)	12.7(0.7)	58.0	1.5	119.3	38.3	61.0	3.0
TZSTR136	2.49	0.8(0.3)	2.7(0.3)	59.0	1.5	130.0	60.0	61.3	2.3
TZSTR153	2.11	4.5(0.7)	19.7(1.3)	60.3	1.5	136.7	52.7	62.3	2.0
TZSTR151	1.74	0.8(0.3)	2.7(0.5)	62.7	2.7	129.0	65.3	65.7	3.0
TZSTR154	1.73	0.5(0.2)	1.0(0.3)	59.3	1.8	115.3	45.0	61.3	2.0
1368 $^{\beta}$	1.58	1.5(0.4)	37.7(1.1)	62.3	1.3	114.0	49.7	66.3	4.0
9540$^{¥}$	1.32	0.8(0.3)	2.7(0.3)	61.3	3.0	123.0	55.0	64.3	3.0
TZSTR133	1.29	0.5(0.2)	0.7(0.2)	59.7	1.7	114.3	55.7	63.3	3.7
M211	1.29	1.2(0.3)	2.7(0.3)	56.7	2.5	104.0	41.7	61.0	4.3
TZSTR150	1.22	1.2(0.3)	4.3(0.4)	60.7	1.7	111.3	58.7	64.0	3.3
1393 $^{\beta}$	1.08	3.8(0.7)	17.7(1.2)	67.0	2.7	103.0	46.0	70.3	3.3
TZSTR149	1.07	0.8(0.3)	3.3(0.5)	60.0	1.5	133.0	64.0	63.0	3.0
TZSTR132	0.91	1.5(0.4)	9.0(0.9)	63.0	2.5	143.3	59.0	68.0	5.0
5057$^{\infty}$	0.72	9.8(1.0)	41.3(1.4)	63.7	3.7	93.0	31.3	70.7	7.0
TZSTR139	0.61	0.5(0.2)	1.0(0.2)	64.3	3.2	88.3	36.3	68.7	4.3
Mean	1.78	1.5	9.2	61.5	2.0	122.0	51.7	64.9	3.4
LSD $_{(0.05)}$	1.38	3.7	26.6	2.7	0.9	38.5	18.4	3.5	2.9
CV (%)	45.0	52.5	59.2	3.0	25.0	18.0	21.0	3.0	49.0
SEM	0.66	1.7	12.6	1.3	0.4	18.3	8.7	1.7	1.4
P	***	**	**	***	***	*	**	***	*

Key: $^{©}$Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed $\{\log_{10}(x+1)\}$ values of *Striga* counts, w.a.c.e: weeks after crop emergence, ***-highly significant ($P < 0.001$, **-significant ($P<0.01$,*-significant ($P < 0.05$), $^{\beta}$-Tolerant check, $^{¥}$Resistant check, $^{\infty}$Susceptible check, SEM (standard error of mean), ASI-Anthesis silking interval, LSD (Least significant difference), CV (Co-efficient of variation).

Significant (P <0.05) differences were observed amongst the maize inbred lines for emerged *Striga* plants at 10 weeks after crop emergence. The mean emerged *Striga* count at 10 weeks after crop emergence ranged from 0.3 to 41.3 with a mean of count of 9.2 (Table 7). Thirteen maize inbred lines, four from Maseno university (GF4/S1S2, ABR, MSMP1/P2, M211) and nine inbred lines (TZSTR136, TZSTR151, TZSTR154, 9540, TZSTR133, TZSTR150, TZSTR149, TZSTR132, TZSTR139) from IITA exhibited low emerged *Striga* plants and were not significantly different from one another. TZSTR153 and the tolerant check 1393 were not significantly different either. The highly susceptible maize inbred line 5057 had the highest number of emerged *Striga* plants and was significantly different from all the rest of the inbred lines.

4.2.3 Number of Days to Flowering/50 Percent Anthesis

Highly significant differences (P < 0.001) were observed amongst the inbred lines for the number of days to 50 percent anthesis. The average number of days to pollen shed was 61.5 while the pollen shed period ranged from 56.7- 67 days. The earliest flowering maize inbred line was M211 at 56.7 days after planting and was significantly different from the rest of the inbred lines. The maize inbred that was significantly different from all the rest and was late to flower was the *Striga* tolerant check 1393.

4.2.4 Number of Days to 50 Percent Silk Emergence

Highly significant differences (P<0.001) were observed amongst the maize inbred lines for the number of days to 50 percent silk emergence. The mean number of days to 50 percent silk emergence was 64.9 whilst the silking period ranged from 61.0 to 70.7. The earliest silking inbred line was TZSTR155 at 61 days whereas the late silking maize inbred line was 5057 at 70.7 days

4.2.5 Plant Height

The mean plant heights presented in Table 7 ranged from 88.3 cm to 167.0 cm and were significantly ($P<0.05$) different. The mean plant height for all the maize inbreds was 122.0cm. Maize inbred MSP1/P2 had the highest plant height (167.0 cm) whereas TZSTR139 had the lowest plant height of 88.3 cm.

4.2.6 Ear Height

Mean ear heights ranged from 31.3 to 65.3 cm. The mean ear height for the inbred lines was 51.7 cm with significant differences ($P<0.01$) observed amongst the inbred lines.

4.3 Maize Inbred Lines Screening under *Striga* Infestation at Nyahera during the Short Rains of 2011

The results for the emerged *Striga* counts and growth components, plant height and ear height are shown in Table 8 below.

4.3.1 Emerged *Striga* Counts

There were significant differences ($P<0.01$) amongst the maize inbred lines for emerged *Striga* plants at eight weeks after crop emergence (Table 8). The average emerged *Striga* count was 0.4. The emerged *Striga* count at eight weeks after crop emergence ranged from 0 to 4.7. All the maize inbred lines except 5057, TZSTR168, TZSTR184, TZSTR187, TZSTR154 and

TZSTR182 had zero emerged *Striga* count. The highly susceptible maize inbred line with the highest emerged *Striga* plants was the susceptible check 5057 with a mean count of 4.7 and was significantly ($P<0.05$) from the all the rest of the maize inbred lines.

Significant differences ($P < 0.05$) were observed amongst the maize inbred lines for emerged *Striga* plants at 10 weeks after crop emergence (Table 8). The mean emerged *Striga* count was 3.5. The highly resistant/tolerant maize inbred lines with zero emerged *Striga* were the resistant check 9450, TZSTR166 and TZSTR167. Other noticeable inbred lines with fewer attached *Striga* were TZSTR182, TZSTR185, TZSTR186, TZSTR170, tolerant check 1368, TZSTR154 and MSMP1/P2. The susceptible maize inbred line, 5057 had the highest emerged *Striga* with a mean of 11.3.

Table 8: Means of Maize Inbred Lines Evaluated at Nyahera under *Striga* Infestation in 2011 Short Rainy Season

	$^{\copyright}$**Number of Emerged *Striga* Plants**		**Plant height (cm)**	**Ear Height (cm)**
Variety	**8 w.a.c.e**	**10 w.a.c.e**		
ABR	0.0(0.0)	5.0(0.8)	139.3	100.0
GF4/S1S2	0.0(0.0)	8.3(1.0)	95.3	61.7
MSMP1/P2	0.0(0.0)	4.0(0.7)	73.0	40.0
TZSTR170	0.0(0.0)	1.7(0.4)	77.7	52.7
TZSTR185	0.0(0.0)	0.7(0.2)	99.0	54.0
5057$^{\infty}$	4.7(0.8)	11.3(1.1)	25.7	10.0
TZSTR168	0.7(0.2)	3.7(0.7)	97.3	40.0
TZSTR184	1.3(0.4)	9.0(1.0)	103.3	60.0
TZSTR187	1.3(0.4)	4.0(0.7)	81.7	38.7
TZSTR186	0.0(0.0)	1.0(0.3)	96.0	36.7
9540$^{¥}$	0.0(0.0)	0.0(0.0)	93.0	37.0
1368$^{\beta}$	0.0(0.0)	2.0(0.5)	88.3	51.7
1383$^{\beta}$	0.0(0.0)	5.7(0.8)	116.7	65.7
TZSTR150	0.0(0.0)	5.3(0.8)	83.7	34.0
TZSTR167	0.0(0.0)	0.0(0.0)	59.3	30.7
TZSTR166	0.0(0.0)	0.0(0.0)	94.7	54.3
TZSTR154	0.3(0.1)	4.3(0.7)	91.7	46.7
TZSTR182	0.3(0.1)	0.7(0.2)	110.7	55.7
TZSTR139	0.0(0.0)	1.3(0.4)	108.0	51.7
TZSTR179	0.0(0.0)	1.3(0.4)	85.3	52.0
Mean	0.4	3.5	91.0	48.7
LSD $_{(0.05)}$	3.4	1.15	62.5	39.4
CV (%)	25.2	19.4	40	47
SEM	1.6	5.5	29.8	18.8
P	*	*	*	*

Key: $^{\copyright}$Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed {$\log_{10}(x+1)$} values of *Striga* counts, w.a.c.e: weeks after crop emergence.* significant ($P < 0.05$), $^{\beta}$-Tolerant check, $^{¥}$Resistant check, $^{\infty}$Susceptible check SEM (standard error of mean), LSD (Least significant difference), CV (Co-efficient of variation).

4.3.2 Plant Height

Significant differences (P < 0.05) were observed amongst the maize inbred lines for plant height. The mean plant height for all the maize inbreds was 91.0 cm. The plant heights ranged from 25.7 cm to 139.3 cm. Maize inbred ABR had the highest plant height (139.3 cm) whereas the susceptible check 5057 had the lowest plant height of 25.7 cm.

4.3.3 Ear Height

There were significant differences (P < 0.05) amongst the inbred lines for ear height (Table 8). Ear heights ranged from 10 to 100 cm with a mean ear height of 48.7 cm

4.4 Maize Hybrid Evaluation under *Striga* and *Striga* Free Environment

Maize hybrids were evaluated under *Striga* infested and *Striga* free conditions with the objective of examining their performance based on multiple traits under stress and non-stress conditions. This enables identification of superior genotypes for release for commercial production under *Striga* and *Striga* free environments.

4.4.1 Maize Hybrid Evaluation under *Striga* Infestation at Kibos in short Rains Season of 2010

The results of the 18 hybrids including 12 hybrids from IITA (0602-1STR,0502-5STR,0501-6STR, 9022-13, 0602-8STR, 0501-STR, 0602-3STR, 0702-1STR, 0702-2STR, 8338-1, 0501-2STR), 4 hybrids from Maseno university (EH11S, EH10T, EH12, EH21) and 2 commercial checks (H513, PhB3253) are shown in Table 9 below.

4.4.1.1 Grain Yield

There were significant differences (P<0.05) observed amongst the hybrids for grain yield. Grain yields ranged from 0.19 to 2.69 tons/ha with an overall mean grain yield of 1.59. The highest yielding hybrid was 0602-1STR from IITA. Among the top five hybrids were two hybrids from Maseno University, EH11s and EH10T. The yield of the top five hybrids were however not significantly different from each other. The lowest ranked hybrids in terms of grain yield were H513,0501-2STR and the commercial check Pioneer PhB3253 with a yields of 0.97,0.52 and 0.19 tons/ha.

4.4.1.2 Emerged *Striga* Counts

Significant differences (P<0.05) were observed among the maize hybrids for emerged *Striga* count at eight weeks after crop emergence (Table 9). The mean *Striga* count at eight weeks after crop emergence was 77.7. The maize hybrids with low *Striga* emergence and that were not significantly different were 0602-1STR, 0502-5STR. The maize hybrids with high number of emerged *Striga* included Pioneer PhB3253 and 0501-2STR.

Significant differences (P<0.05) amongst were observed amongst the hybrids for emerged *Striga* at 10 weeks after crop emergence (Table 9). The mean *Striga* count at 10 weeks after crop emergence was 85.0. The hybrids with the highest number of emerged *Striga* were the commercial hybrid checks H513 and PhB3253. The hybrids with the least emerged *Striga* were 0602-1STR and 0502- 5STR.

4.4.1.3 *Striga* Damage Rating at 10 Weeks after Crop Emergence

Highly significant differences (P<0.001) were observed amongst the maize hybrids for *Striga* damage rating at 10 weeks after crop emergence. The *Striga* damage ratings ranged from 1.0 to 3.8. The mean *Striga* damage rating was 1.99. The hybrids with high *Striga* damage ratings were 8338-1, H513 and PhB3253 with 3.5, 3.5 and 3.8 respectively. The hybrids, 0602-1 STR, EH11S, 0502-5, 0602-1STR, 0501-6STR, EH10T, 0501-STR, EH21 and 0501-2STR had the lowest ratings of between 1.0-1.5 on the scale of 1-5.

4.4.1.4 Plant Height

There were significant differences (P<0.05) among the hybrids for plant height. The plant heights ranged from 103 to 206 cm. The mean plant height amongst the hybrids was 154 cm. Hybrid EH10T had the highest plant height of 206.0 cm whereas the hybrid 0501-2STR had the lowest plant height of 103.0 cm. This however was not significantly different from the height of commercial check PhB3253.

4.4.1.5 Ear Height

There were no significant differences amongst the hybrids for ear height. The ear heights ranged from 39.5 to 103.5 cm and the average ear height was 73.9 cm.

Table 9. Mean performance of maize hybrids evaluated at Kibos under *Striga* infestation during 2010 short rains season.

Variety	**Grain Yield (t/ha)**	**$^{\copyright}$Number of Emerged *Striga* Plants**		**SDR (scale 1-5)**	**Plant height**	**Ear Height**
		8 w.a.c.e	**10 w.a.c.e**	**10 w.a.c.e**	**(cm)**	**(cm)**
0602-1STR	2.69	9.5(1.0)	12.0(1.1)	1.5	185.5	87.0
EH11S	2.61	74.0(1.9)	74.0(1.90	1.3	172.0	80.5
0502-5 STR	2.55	9.5(1.0)	10.5(1.1)	1.0	204.5	103.5
0501-6STR	2.37	20.0(1.3)	20.0(1.3)	1.5	180.0	85.0
EH10T	2.22	35.0(1.6)	37.5(1.6)	1.5	206.0	92.5
0601-6STR	1.81	97.0(2.0)	53.0(1.7)	2.5	163.0	73.5
EH12	1.81	86.0(1.9)	139.0(2.2)	2.0	139.5	68.5
9022-13	1.73	36.5(1.6)	40.5(1.6)	1.8	136.5	67.0
0602-8STR	1.54	51.5(1.7)	53.0(1.7)	2.5	146.5	85.0
0501-STR	1.45	81.5(1.9)	85.0(1.9)	1.0	147.5	65.5
0602-3STR	1.39	80.5(1.9)	85.5(1.9)	1.8	143.5	69.5
0702-1STR	1.35	54.0(1.7)	55.5(1.8)	1.8	154.0	84.5
0702-2STR	1.16	125.0(2.1)	125.0(2.1)	2.0	138.0	80.0
8338-1	1.14	81.5(1.9)	134.0(2.1)	3.5	162.0	73.0
EH21	1.14	124.0(2.1)	126.5(2.1)	1.5	144.0	61.0
H513¶	0.97	82.5(1.9)	161.0(2.2)	3.5	140.5	58.5
0501-2STR	0.52	177.0(2.3)	143.5(2.2)	1.5	103.0	39.5
PhB3253¶	0.19	173.5(2.3)	174.0(2.2)	3.8	106.5	56.0
Mean	1.59	77.7	85.0	1.99	154.0	73.9
LSD $_{(0.05)}$	1.68	135.8	108.4	0.74	60.5	33.7
CV (%)	28	20.7	19.8	18	19	22
SEM	0.80	64.4	51.4	0.35	28.7	16.0
P	***	*	*	***	*	*

Key: $^{\copyright}$Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed $\{\log_{10}(x+1)\}$ values of *Striga* counts, w.a.c.e: weeks after crop emergence; SDR-*Striga* Damage Rating. ***-highly significant ($P < 0.001$), *-significant ($P < 0.05$), ¶ Commercial hybrid checks, ns-non significant, SEM-standard error of mean, LSD (Least significant difference, CV (Co-efficient of variation)

4.5 Hybrid Evaluation under *Striga* Infestation at Nyahera in Short Rainy Season of 2011

The results of nine hybrids including six experimental hybrids from Maseno University (EH14, EH12, EH11M, EH21S, EH21H, and EH11S) and three commercial checks (DK8031, H513, PHB3253) are shown in table 10 below.

4.5.1 Grain Yield

There were highly significant differences ($P < 0.001$) among the hybrids for grain yield under *Striga* infestation (Table 10). The mean grain yield of the hybrids ranged from 0.29 to 6.27 tons/ha under *Striga* infestation. The highest yielding hybrid under *Striga* was EH14 while the lowest yielding hybrid was Pioneer hybrid PhB3253.

4.5.2 *Striga* Damage Rating

There were highly significant differences ($P < 0.001$) among the hybrids for *Striga* damage rating at eight and 10 weeks after emergence (Table 10). *Striga* damage rating at eight weeks after emergence ranged from 1.0 to 2.8 whereas the damage rating at 10 weeks ranged from 1.0 to 3.5. The mean *Striga* damage rating at eight and 10 weeks were 1.4 and 1.7 respectively. Commercial hybrids H513 and PhB3253 hybrids both had higher *Striga* damage rating of 2.8 at eight weeks. They also had the highest *Striga* damage rating at 10 weeks of 4.0 and 3.5 respectively. EH12, EH14, EH11M, EH21H had the lowest *Striga* damage rating of 1.0. This was however not significantly different from the damage rating for the hybrids EH21S and EH11S.

4.5.3 Emerged *Striga* Counts

There were significant differences (P<0.05) among the hybrids for *Striga* count at eight weeks after crop emergence (Table 10).The emerged *Striga* count ranged from 2.0 to 9.7 with an overall mean of 5.1. The commercial hybrids H513 and PhB3253 had the highest emerged *Striga* count at eight weeks. Experimental hybrid EH12 had the lowest emerged *Striga* count of 2.0.

There were significant differences (P<0.05) amongst the hybrids for emerged *Striga* count at 10 weeks. The mean emerged *Striga* at 10 weeks was 44.5. The hybrids with the least emerged *Striga* count was EH12 with a count of 17.3. The hybrid with the highest number of emerged *Striga* was H513 and PhB3253 with counts of 79.7 and 64.0 respectively.

Table 10. Mean of hybrids along with checks included in a trial evaluated at Nyahera under *Striga* infestation in 2011 short rains season.

Variety	Grain Yield (tons/ha) Infested	*Striga* damage rating 8 WAP	*Striga* damage rating 10 WAP	©Number of Emerged *Striga* Plants 8 WAP	©Number of Emerged *Striga* Plants 10 WAP
EH14	6.27	1.0	1.0	4.7(0.8)	50.0(1.7)
EH12	6.25	1.0	1.0	2.0(0.5)	17.3(1.3)
EH11M	5.72	1.0	1.0	4.0(0.7)	34.7(1.6)
EH21S	5.65	1.0	1.2	6.0(0.9)	35.7(1.6)
EH21H	5.37	1.0	1.0	5.7(0.8)	43.7(1.7)
DK8031¶	4.99	1.2	1.3	6.7(0.9)	50.3(1.7)
EH11S	4.75	1.0	1.2	3.7(0.7)	25.7(1.4)
H513¶	0.58	2.8	4.0	9.7(1.0)	79.7(1.9)
PHB3253¶	0.29	2.8	3.5	4.0(0.7)	64.01.8)
Mean	**3.76**	**1.4**	**1.7**	**5.1**	**44.5**
LSD$_{(0.05)}$	**1.75**	**0.3**	**0.5**	**7.0**	**41.0**
CV (%)	**25**	**12**	**17**	**14**	**4.75**
SEM	**0.25**	**1**	**1**	**1**	**17.3**
P	*******	*******	*******	*****	*****

Key: ©Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed {$\log_{10}(x+1)$} values of *Striga* counts, ***-highly significant ($P < 0.001$), * - significant at 0.05, SEM-standard error of mean, LSD-Least significant difference, WAP-weeks after planting;¶ Commercial hybrid check.

4.6 Maize Hybrids Evaluation under *Striga* Infestation at Nyahera in long Rains Season of 2012

The results of nine hybrids including sic experimental hybrids from Maseno University (EH14, EH12, EH11M, EH21S, EH21H, and EH11S) and three commercial checks (DK8031, H513, PHB3253) are shown in table 11 below.

4.6.1 Grain Yield

There were highly significant differences ($P < 0.001$) among the hybrids for grain yield (Table 11). Grain yields of the cultivars ranged from 3.05 to 7.68 tons/ha with an overall mean of 5.85. The highest yielding hybrid was EH14 with 7.68 tons/ha while the lowest yielding hybrid was Pioneer hybrid PhB3253 with grain yield of 3.05 tons/ha.

4.6.2 *Striga* Damage Rating

There were highly significant differences ($P < 0.001$) among the hybrids for *Striga* damage rating at eight and 10 weeks (Table 11). The mean *Striga* damage rating was 1.4 and 2.0 at eight and 10 weeks respectively. Commercial hybrids PhB3253 and H513 had a higher damage rating of 3.8 and 3.0 at eight weeks and also had the poorest rating at 10 weeks of 4.8 and 4.3 respectively. Among the hybrid checks, DK8031 had the lowest damage rating of 1.5 at both eight and 10 weeks. All the experimental hybrids had a rating of 1.5 and below at eight weeks. All the experimental hybrids except EH12 had a damage rating of 2.0 and below at 10 weeks.

4.6.3 Emerged *Striga* Counts

There were significant differences ($P<0.05$) among the Hybrids at eight and 10 weeks. The emerged mean *Striga* count was 49.7 and 129.2 at eight and 10 weeks respectively (Table 11). The hybrid with the lowest emerged *Striga* count at 8 weeks was EH21H. The hybrids with the highest number of mean emerged *Striga* were H513 and PhB3253 with 80.3 and 118.0. The hybrid with the lowest mean emerged *Striga* count at 10 weeks was EH21S. The hybrids with the highest emerged mean *Striga* counts were the susceptible commercial checks H513 and PhB3253 with 199.7 and 192.7.

Table 11. Means of Hybrids along with checks included in a trial evaluated at Nyahera under *Striga* infestation in 2012 long rains season.

	Grain Yield	***Striga* damage rating**		**©Number of Emerged *Striga* Plants**	
Variety	**(t/ha)**	**8 WAP**	**10 WAP**	**8 WAP**	**10 WAP**
EH21S	7.31	1.3	2.0	18.6(1.3)	47.3(1.7)
EH11M	7.23	1.5	1.8	42.3(1.6)	143.0(2.2)
DK8031¶	4.56	1.5	1.5	58.3(1.8)	128.0(2.1)
EH21H	7.05	1.5	2.0	26.3(1.4)	106.3(2.0)
EH11S	7.31	1.2	1.8	36.0(1.6)	137.7(2.1)
EH14	7.68	1.3	1.5	26.6(1.4)	87.3(2.0)
H513¶	3.69	3.0	4.3	118.0(2.1)	199.7(2.3)
EH12	4.78	1.3	2.3	40.6(1.6)	120.7(2.1)
PHB3253¶	3.05	3.8	4.8	80.3(1.9)	192.7(2.3)
Mean	**5.85**	**1.4**	**2.0**	**49.7**	**129.2**
LSD $_{(0.05)}$	**1.77**	**0.5**	0.5	**54.3**	**100.8**
CV (%)	**16**	**16**	17.5	**58.0**	**41.4**
SEM	**0.77**			**0.01**	**0.06**
P	***	***	***	*	*

Key: ©Analysis based on transformed data, means presented as original figures. Values in parenthesis are log transformed {$\log_{10}(x+1)$} values of *Striga* counts, ***-highly significant ($P < 0.001$),*-significant ($P < 0.05$), LSD (Least significant difference), CV (Co-efficient of variation), SEM (Standard error of mean), ¶, Commercial hybrid checks. WAP-weeks after planting

Plate 2: A susceptible hybrid on the right versus a resistant hybrid on the left at 10 weeks after crop emergence at Nyahera during the long rain season of 2012.

Plate 3: The same picture as the one in plate 2 above at 14 weeks after planting showing the *Striga* resistant hybrid on the left and two rows of the susceptible hybrid on the right.

Plate 4: The deleterious effects of *Striga hermonthica* at Nyahera during the hybrid trial evaluation at Nyahera in the long rainy season of 2012.Notice the susceptible two row plots on the left which got a *Striga* damage rating of 4.0 at 10 weeks after crop emergence.

Plate 5: The differences among the hybrids evaluated under *Striga* infestation just before harvest at Nyahera during the 2012 long rainy season. The two row plot on the left is a highly susceptible hybrid with no cob formation. The two row plot on the right depicts a highly resistant/tolerant hybrid.

4.7 Maize Hybrids Evaluation under non *Striga* Infestation at Maseno in Short Rains Season of 2011

The results of nine hybrids including six experimental hybrids from Maseno University (EH14, EH12, EH11M, EH21S, EH21H, and EH11S) and three commercial checks (DK8031, H513, PHB3253) are shown in table 12 below.

4.7.1 Grain Yield

There were significant differences ($P < 0.05$) among maize genotypes for grain yield (Table 12). The grain yields ranged from 3.74 to 7.39 tons/ha with an overall mean grain yield of 5.11 tons/ha. The highest yielding hybrid was EH11M with a mean yield of 7.39 followed by EH14 with 6.30 tons/ha. The lowest yielding hybrids were the commercial checks, H513, DK8031 and PHB3253 with 4.44, 3.90 and 3.74 tons/ha respectively. The mean yield of the checks was 4.02 tons/ha. All the experimental hybrids yielded more than the mean of the checks.

4.7.2 Days to 50 Percent Flowering

There were significant ($P<0.05$) differences amongst the hybrids for the number of days to 50 percent anthesis (Table 12). The average number of days to pollen shedding was 68.9 while the pollen shedding period ranged from 66.3 to 71 days.

4.7.3 Plant Height

There were significant differences ($P<0.05$) amongst the hybrids for plant height (Table 12). The plant heights ranged from 188cm to 236 cm. The mean plant height for all the genotypes was 218.1cm.

4.7.4 Ear Height

There were significant differences ($P<0.05$) amongst the hybrids for ear height (Table 12). The average ear height for all the hybrids was 104.4. The ear heights ranged from 85.7 to 118.7 cm.

Table 12. Means of Hybrids along with checks included in a trial at Maseno without *Striga* infestation in 2011 short rains season.

			Growth Components					
Variety	**Grain Yield (t/ha)**	**Days to 50% Flower**	**Plant Height (cm)**	**Ear Height (cm)**	**Ear Aspect (1-5)**	**Plant Aspect. (1-5)**	**Turc (1-5)**	**GLS (1-5)**
EH11M	7.39	68.3	226.0	99.7	1.8	2.0	1.8	1.5
EH14	6.30	70.3	236.7	112.7	2.0	1.7	1.0	1.7
EH12	5.99	71.0	216.7	118.7	1.5	1.7	1.5	1.7
EH21S	4.98	69.7	226.0	115.3	1.5	1.2	1.5	1.5
EH11S	4.69	70.3	230.3	112.3	1.7	1.5	2.0	1.5
EH21H	4.55	68.7	213.0	104.7	1.5	1.3	1.5	1.7
H513¶	4.44	68.0	188.0	95.7	2.5	2.3	2.0	2.5
DK8031¶	3.90	66.3	205.7	85.7	2.8	1.8	1.0	1.0
PhB3253¶	3.74	67.7	220.3	95.3	3.8	3.2	2.5	3.3
Mean	**5.11**	**68.9**	**218.1**	**104.4**	**2.1**	**1.9**	**1.6**	**1.8**
LSD $_{(0.05)}$	**2.35**	**4.6**	**35.0**	**30.7**	**0.7**	**0.5**	**0.2**	**1.1**
CV (%)	**24**	**4**	**9**	**16**	**18**	**14**	**6**	**33**
SEM	**1.02**	**2.0**	**15.2**	**13.3**	**0.3**	**0.2**	**0.1**	**0.5**
P	*	*	*	*	***	***	***	*

Key: ***-highly significant ($P < 0.001$), **-significant ($P<0.01$),*-significant ($P < 0.05$), ns-non significant, ¶ Commercial hybrid checks, SEM (standard error of mean), LSD (Least significant difference),CV(Co-efficient of variation, Ear Asp-Ear Aspect, E. turc- turcicum, GLS-Gray leafspot.

4.7.5 Ear Aspect

There were highly significant differences ($P<0.001$) among the genotypes for ear aspect (Table 12). The overall mean ear aspect for all the maize hybrids was 2.1 on the scale of 1.0-5.0. The ear aspect scores ranged from 1.5 to 3.8. The hybrids EH21H, EH12 and EH21S had the best score of 1.5. PhB3253 had the worst score of 3.8. Experimental hybrids had lower ear aspect scores below 2.5 compared to the commercial check hybrids.

4.7.6 Plant Aspect

There were highly significant differences ($P < 0.001$) for plant aspect amongst the maize hybrids (Table 12). The mean plant aspect score of all the hybrids was 1.9. All the experimental hybrids had better scores than the commercial hybrids PhB3253 and H513. However a commercial hybrid DK8031 had a lower score of 1.8 which was comparable to the experimental hybrids.

4.7.7 E.turcicum

There were highly significant differences ($P<0.001$) amongst the hybrids in their reaction to turcicum leaf disease (Table 12). The hybrid with the worst response to turcicum was Pioneer PhB3253. All the experimental hybrids and one commercial check DK8031 had good response to the disease.

4.7.8 Gray Leaf spot (GLS)

There were significant differences ($P < 0.05$) among the hybrids for Gray Leaf Spot (GLS) scores (Table 12). The average GLS score for all the hybrids was 1.8. The Gray Leaf Spot scores ranged from 1.0 to 3.3. The most susceptible hybrids with high GLS scores were H513 and PhB3253 with 2.5 and 3.3 scores, whereas, the most resistant hybrid was DK8031. All the experimental hybrids had relatively low scores between 1.5-1.7 and responded well to the disease pressure.

4.8 Maize Hybrids Evaluation under Non Striga Infestation at Maseno in Long Rains Season of 2012

The results of nine hybrids including six experimental hybrids from Maseno University (EH14, EH12, EH11M, EH21S, EH21H, and EH11S) and three commercial checks (DK8031, H513, PHB3253) are shown in table 13 below.

4.8.1 Grain Yield

There were significant differences ($P < 0.05$) observed among the hybrids for mean grain yield. The mean grain yield amongst the hybrids ranged between 7.66 to 9.72 tons/ha with an overall mean of 8.75. The best yielding hybrid was EH21S. The lowest yielding hybrid was PhB3253 with 7.66 tons/ha (Table 13).

4.8.2 Days to 50 Percent Flowering

There were significant differences ($P<0.05$) amongst the hybrids for the number of days to 50 percent anthesis (Table 13). The average number of days to pollen shed was 71.5 while the pollen shedding period ranged from 68.7 to 74 days after planting. The earliest flowering hybrids were PhB3253 and H513. All the experimental hybrids including the commercial hybrid DK8031 flowered after 70 days.

4.8.3 Plant Height

There were highly significant differences ($P < 0.001$) amongst the hybrids for plant height (Table 13). Plant heights ranged from 183.3 to 256 cm. The mean plant height was 229.0 cm.

4.8.4 Ear Height

There were highly significant differences ($P<0.001$) among the hybrids for ear height (Table 13). Ear heights ranged from 71.7 to 128.0 cm. The mean ear height was 107.7 cm.

4.8.5 Ear Aspect

There were significant differences ($P<0.05$) among the maize hybrids for ear aspect Table 13). The mean ear aspect score was 2.0. Ear aspect scores ranged from 1.5 to 3.3 with PhB3253 having the poorest score.

4.8.6 Plant Aspect

There were highly significant differences ($P<0.001$) amongst the hybrids for plant aspect scores (Table 13). The mean plant aspect score was 2.1.The scores ranged from 1.0 to 3.8. DK8031 had the best lowest score of 1.0 whereas PhB3253 had the poorest highest score of 3.8.

Table 13. Mean performance of hybrids along with checks included in a trial evaluated at Maseno without *Striga hermonthica* infestation in 2012 long rains season.

Variety	Grain Yield t/ha	Days to 50% Flower	Plant Height cm	Ear Height cm	Ear Aspect 1-5	Plant Aspect 1-5
EH21S	9.72	72.0	251.7	126.7	1.8	1.8
EH11M	9.50	72.3	228.3	105.0	1.5	1.8
DK8031¶	9.09	70.7	183.3	71.7	1.8	1.0
EH21H	8.90	73.3	245.0	120.0	1.5	1.3
EH11S	8.89	71.3	235.0	110.0	1.7	1.8
EH21	8.81	72.0	256.0	128.0	2.5	1.8
H513¶	8.31	69.0	218.3	110.0	2.3	3.2
EH12	7.85	74.0	236.7	109.7	1.5	2.0
PhB3253¶	7.66	68.7	206.7	88.3	3.3	3.8
Mean	8.75	71.5	229.0	107.7	2.0	2.1
LSD $_{(0.05)}$	1.18	3.2	20.3	21.3	1.5	0.6
CV (%)	7	2	5	11	41	16
SEM	0.51	1.4	8.8	9.2	0.7	0.3
P	*	*	***	***	*	***

Key: ***-highly significant ($P < 0.001$),*-significant ($P < 0.05$), LSD (Least significant difference), SEM-Standard Error of Mean, CV (Co-efficient of variation) ¶, Commercial hybrid checks.

4.8.7. Correlation between Host Damage Rating , *Striga* Emergence and Grain Yield under *Striga* Infestation

Figures 3, 4, 5 and 6 are the correlation plots of the host damage rating score with the number of emerged *Striga* plants. The correlation between the two traits was positive. The two traits were however negatively correlated with grain yield; that is, the lower their values, the higher the grain yield under *Striga* infestation (Figures 7, 8, 9, 10 and 11)

Figure 3 is a correlation plot of the *Striga* counts and *Striga* damage rating at 8 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the short rains of 2011.The correlation was positive but weak (r =0.244) but not significant ($P<0.05$). The co-efficient of determination of the relationship (R^2 = 0.0597) means that *Striga* damage rating accounted for 6% of the variance in *Striga* counts.

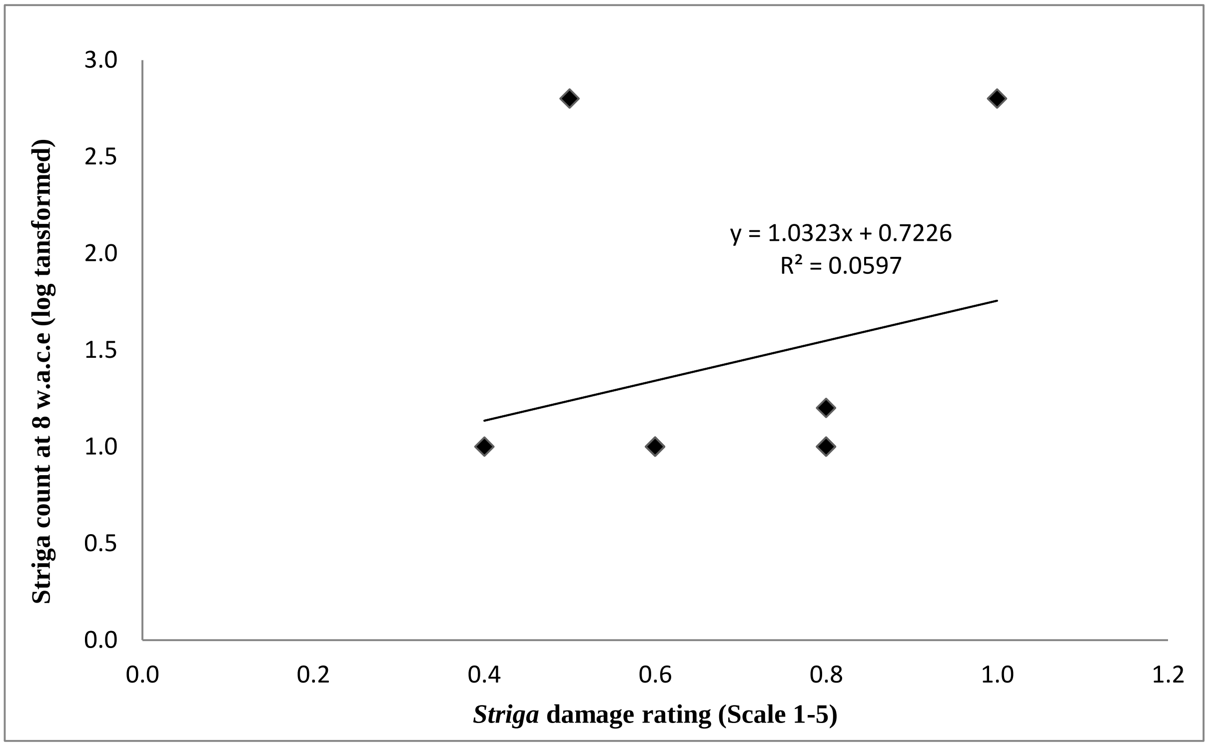

Figure 3 . Correlation plot between *Striga* counts and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the short rains of 2011.

Key:w.a.c.e = weeks after crop emergence.

Figure 4, below shows the correlation plot between *Striga* counts and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the short rains of 2011.The correlation was positive and strong (r =0.65) and significant (P<0.05). This shows that *Striga* damage rating is a significant factor of Striga count, that is, Striga counts increases in a linear way with *Striga* damage rating score. The co-efficient of determination of the relationship is 0.42, that is, *Striga* damage rating accounts for 42% of the variance in *Striga* counts at 10 weeks after emergence.

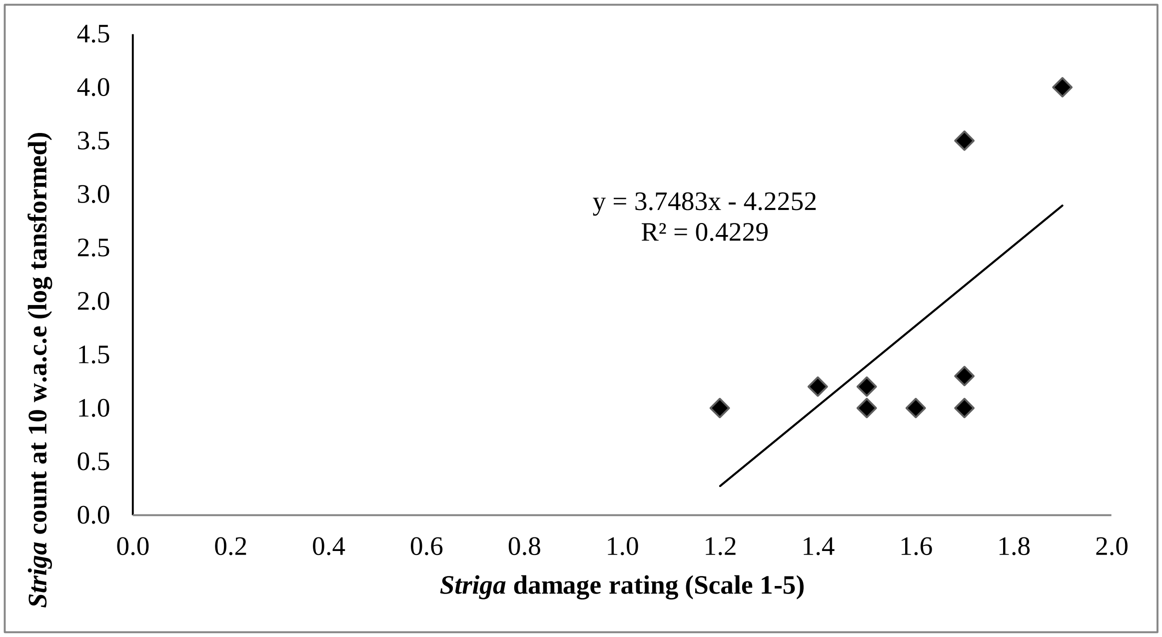

Figure 4. Correlation plot between *Striga* counts and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the short rains of 2011.

Key:w.a.c.e = weeks after crop emergence.

Figure 5, is a correlation plot between *Striga* counts and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.The correlation was strong and positive (r =0.67) and significant (P<0.05)

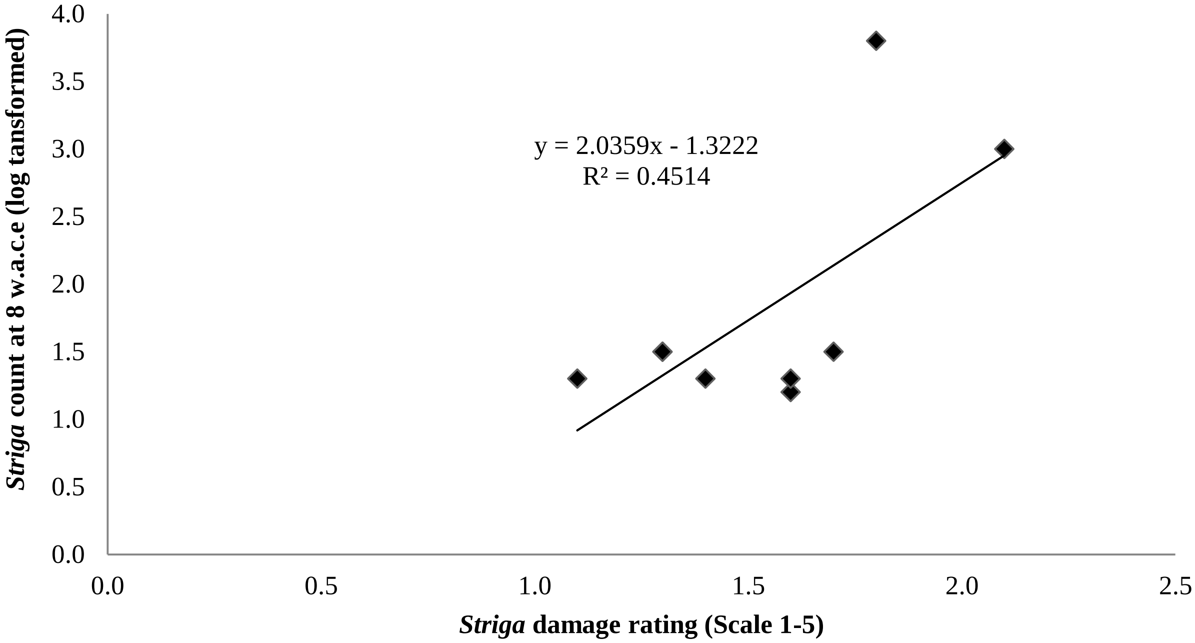

Figure 5. Correlation plot between *Striga* counts and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.

Key: w.a.c.e – weeks after crop emergence.

Figure 6, is a correlation plot between *Striga* counts and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.The correlation was strong and positive (r =0.56) but not significant (P<0.05)

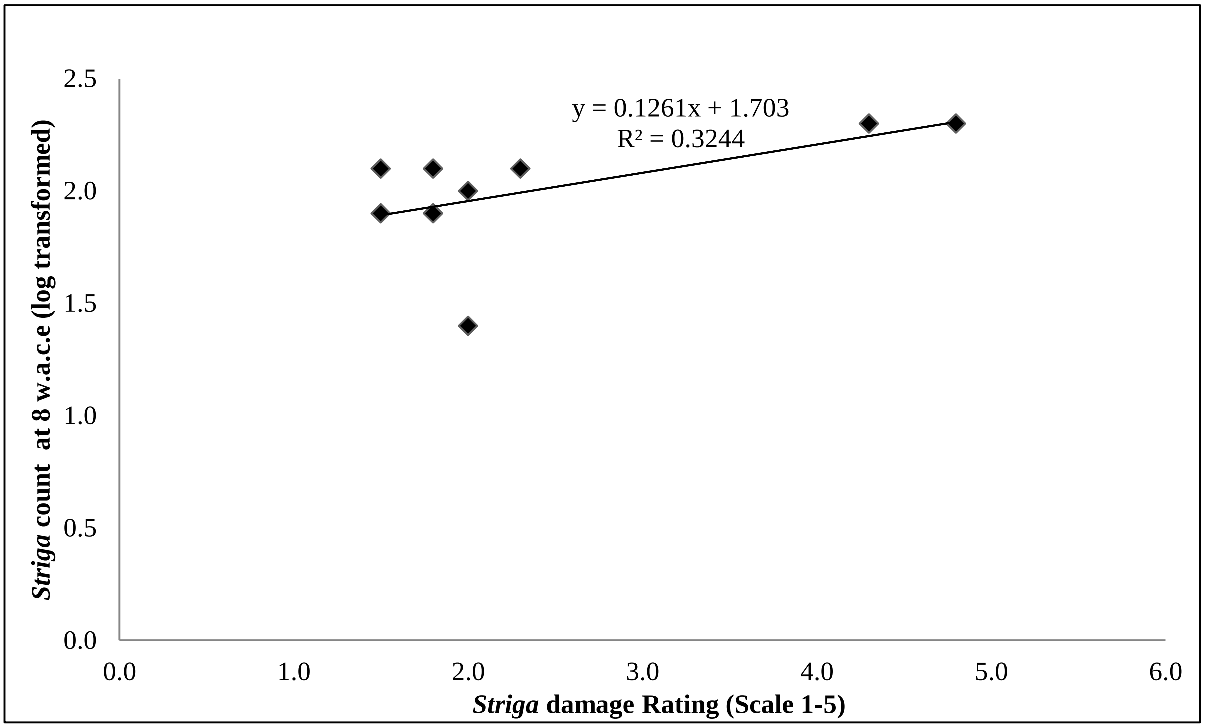

Figure 6. Correlation plot between *Striga* counts and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.

Key: w.a.c.e – weeks after crop emergence.

Figure 7, is a correlation plot between grain yield and *Striga* damage rating at 10 weeks after crop emergence for the hybrids evaluated at Kibos under *Striga* infestation in the short rains of 2010.The correlation was negative (r =0.58) but not significant ($P<0.05$)

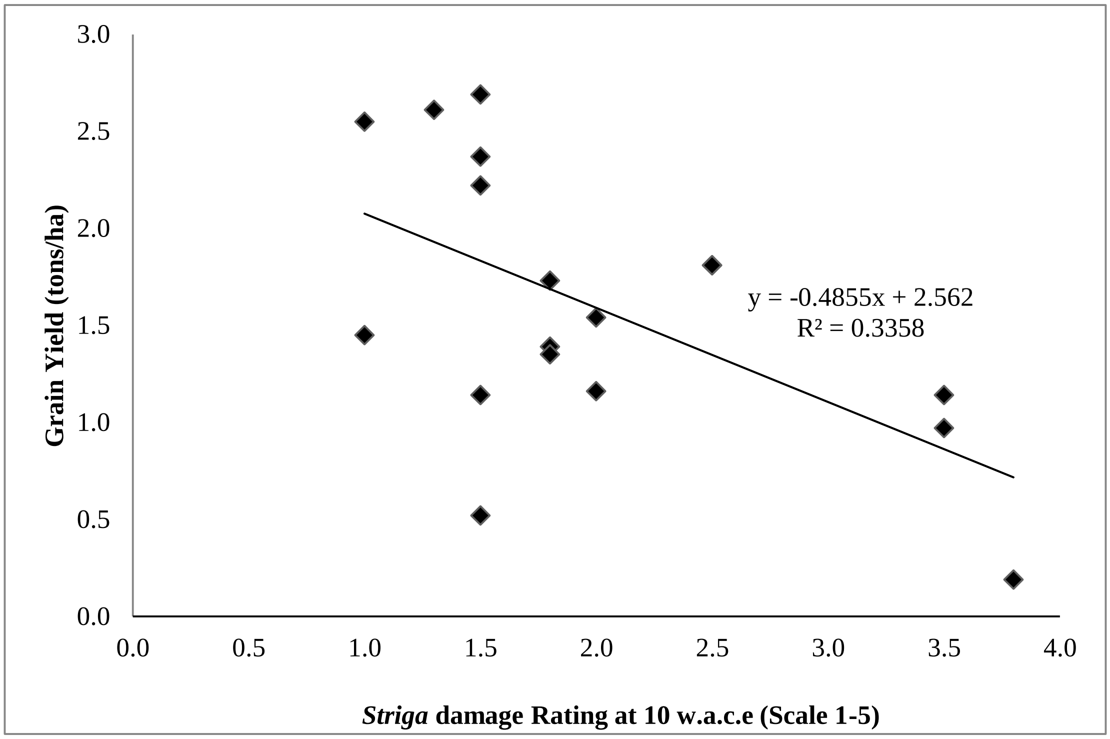

Figure 7. Correlation plot between grain yield and *Striga* damage rating at 10 weeks for the hybrids evaluated at Kibos under *Striga* infestation in the short rains of 2010.

Key: w.a.c.e – weeks after crop emergence.

Figure 8, is a correlation plot between grain yield and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2011.There was a very strong negative correlation (r =0.98) and highly significant (P<0.05).

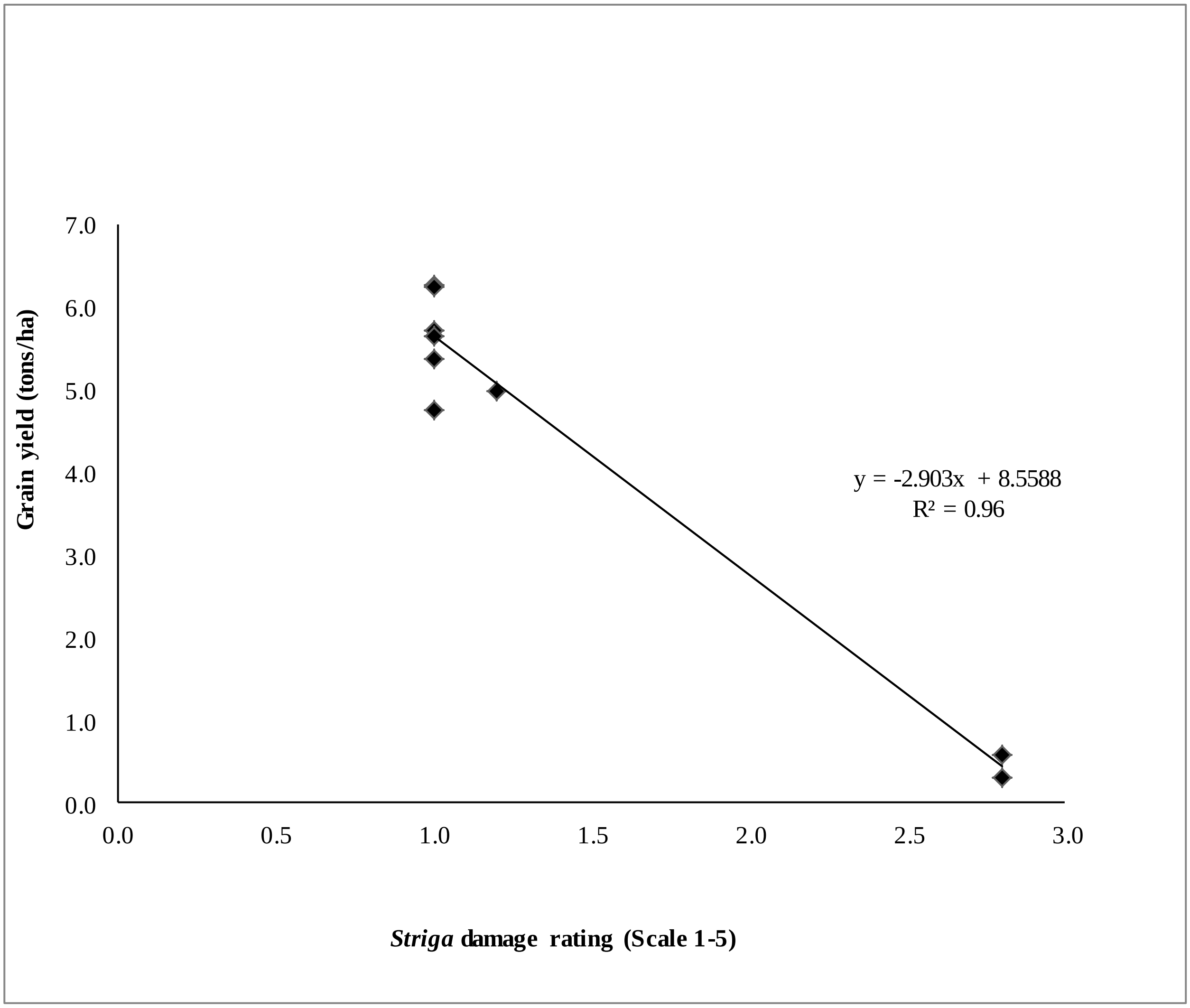

Figure 8. Correlation plot between grain yield and *Striga* damage rating at eight weeks after crop emergence for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2011.

Figure 9, is a correlation plot between grain yield and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2011.There was a very strong negative correlation (r =0.98) and highly significant (P<0.05).

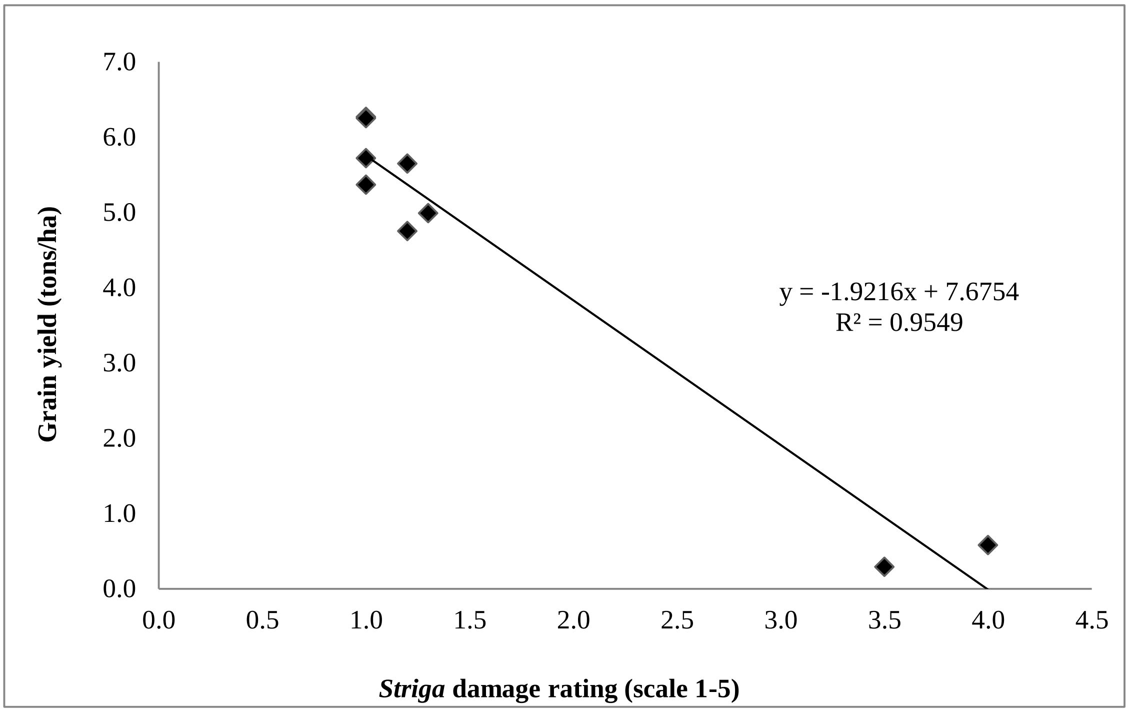

Figure 9. Correlation plot between grain yield and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the short rains of 2011.

Figure 10, is a correlation plot between grain yield and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.There was a very strong negative correlation (r =0.79) and highly significant (P<0.05).

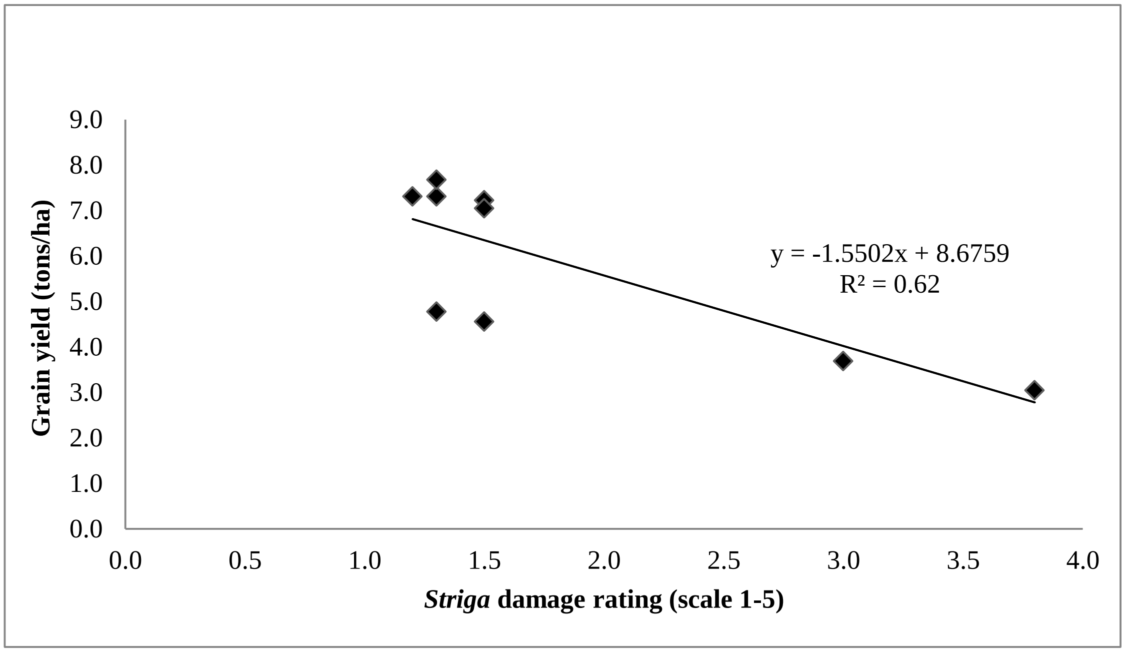

Figure 10. Correlation plot between Grain yield and *Striga* damage rating at eight weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.

Figure 11, is a correlation plot between grain yield and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.There was a very strong negative correlation (r =0.78) and was highly significant (P<0.05).

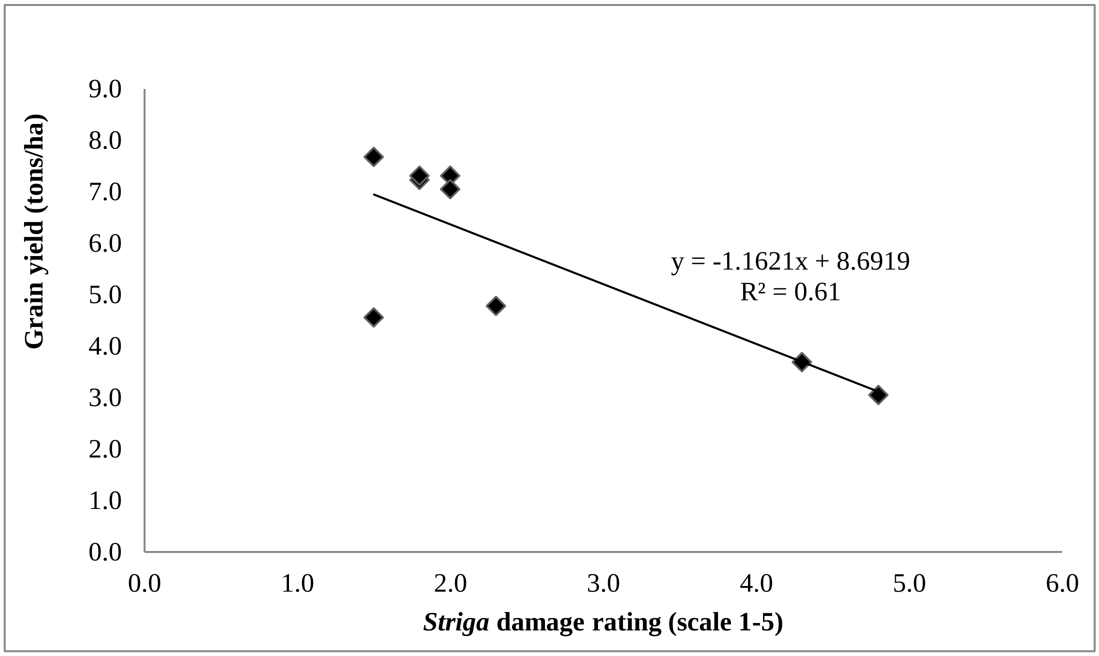

Figure 11. Correlation plot between grain yield and *Striga* damage rating at 10 weeks for the hybrids evaluated at Nyahera under *Striga* infestation in the long rains of 2012.

4.9: Maize Hybrid Genotypes Combined Grain Yield and Stability under *Striga* Infested and *Striga* Free Environments

The results of the combined grain yield and the maximum plant yield values at each environment are underlined (Table 14). A combined analysis of variance constructed to determine the effects of environments (E), genotypes (G) and genotypes by environment interaction (GEI) shows that grain yields of the maize hybrid genotypes were significantly affected by environment ($P < 0.001$) which accounted for 50% of the total variation (G+E+GEI), whereas genotype and genotype x environment interaction accounted for 39% and 11% respectively (Table 15). Partitioned first two components of grain yield and ranking are shown in table 16 below.

Table 14. Mean grain yield (tons/ha) of nine maize hybrids tested in four environments under *Striga* and non *Striga* infestation.

Year	2011	2012	2011	2012	
Environments	*Striga* infested		Non *Striga* infested		
Genotype	**Nyahera**	**Nyahera**	**Maseno**	**Maseno**	**Mean**
EH14	**6.27**	**7.68**	6.30	8.81	7.27
EH12	6.25	4.78	5.99	7.85	6.22
EH11M	5.72	7.23	**7.39**	9.50	7.46
EH21S	5.65	7.31	4.98	**9.72**	6.92
EH21H	5.37	7.05	4.55	8.90	6.47
EH11S	4.75	7.31	4.69	8.89	6.41
DK8031	4.99	4.56	3.90	9.09	5.64
H513	0.58	3.69	4.44	8.31	4.26
PHB3253	0.29	3.05	3.74	7.66	3.69
Mean	4.43	5.85	5.11	8.75	6.03

Key: Underlined and bolded values are highest grain yield values at each test environment

Table 15. Combined analysis of variance of grain yield of 9 hybrid maize genotypes tested across two environments *Striga hermonthica* infested and non *Striga hermonthica* infested in 2011 and 2012.

Source of Variation	Df	SS	MS	F	P	Explained (%)
Season	1	229.45	229.45	0.688*	0.25	
Genotype	8	57.465	7.183	1.92**	0.05	39
Environment	1	73.788	73.788	19.7***	0.00	50
Genotype*Environment	8	16.173	2.022	0.54^{ns}	0.81	11
Error	18	67.348	3.742			
Total	36	444.224				

Key: ***-highly significant ($P < 0.001$), **-significant ($P < 0.05$), ns-non significant. DF=degrees of freedom; MS=mean square

Table 16. The first two Principal Component of Mean grain yield and ranking of the 9 maize hybrids (two season data).

Genotype	IPCA1	IPCA2	Mean Yield	Rank
DK8031	0.40501	0.91431	5.64	7
EH11M	-0.04669	0.02068	7.46	1
EH11S	-0.35422	0.15691	6.47	4
EH12	-0.06975	0.0309	6.22	6
EH14	-0.29656	0.13137	7.27	2
EH21H	-0.31078	0.13767	6.47	5
EH21S	-0.26888	0.11911	6.92	3
H513	0.50996	-0.2259	4.26	8
PHB3253	0.43192	-0.19133	3.69	9

KEY: IPCA1- First Principal Component Analysis; IPCA2 -Second Principal Component Analysis.

Based on the overall mean grain yield of all sites, the experimental hybrids performed better than the commercial hybrids. The highest yielding hybrid in each environment is underlined (Table 14). The Combined mean grain yield of the nine genotypes across all the environments ranged from 3.69 to 7.46 tons/ha (Table 14 and Table 16). Hybrid EH11M had the highest mean of 7.46 tons/ha and performed quite well in both infested and non *Striga* infested sites. EH14 performed very well with the highest mean grain yields in *Striga* infested environment. The best performing commercial hybrid was DK8031 with a mean yield of 5.64. The average grain yield of check varieties was 4.66 tons/ha. The lowest yielding hybrid was PhB3253. Based on the overall mean grain yield of all sites, all the experimental hybrids performed better than the commercial hybrids with the ascending order of grain yield ranking being EH11M, EH14, EH21S, EH11S, EH21H, EH12, DK8031, H513 and PHB3253 (Table 16).

Also, considering the first Principal Component Analysis (IPCA1) scores of G*E biplot analysis (Figure 12 below) the most unstable genotypes were the commercial hybrids DK 8031, H513 and PhB3253 since they were further from the Centre. They were however specifically adapted to non *Striga* infested environment (NS). Genotypes adapted to *Striga* infestation and associated with Nyahera were EH12, EH21H, EH11M, EH21S and EH11S. The most stable genotypes based on IPCA1 scores were 4 (EH11M) and 2 (EH12).

Figure 12. AMMI Bi-Plot of Genotype*Environment of the nine Maize hybrids evaluated under *Striga* (S) and Non-*Striga* (NS) infestation.

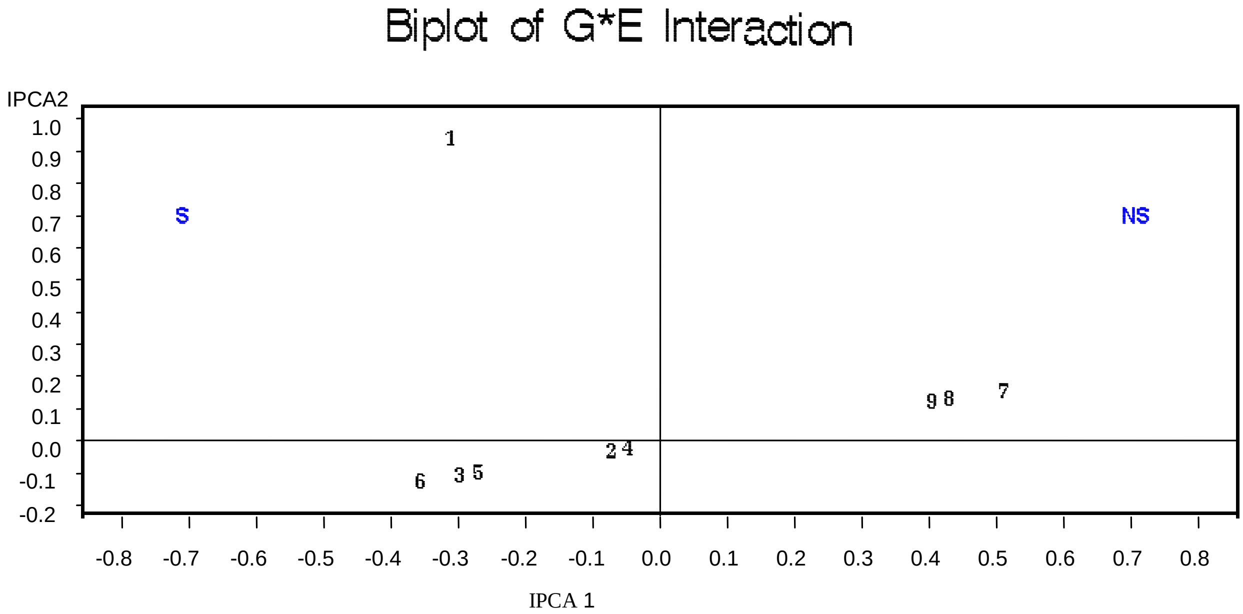

Figure 12: AMMI (Additive Main Effects and Multiplicative Interaction) biplot of main effects and interaction. Where, 1 =EH14; 2 = EH12; 3 = EH21S; 4=EH11M; 5 = EH21H; 6 = EH11S; 7 =H513; 8 = PHB3253; 9 =DK8031; S=*Striga* infested Environment Nyahera; NS = Non *Striga* infested Environment Maseno University. IPCA1-First Principal Component Analysis; IPCA2-Second Principal Component Analysis.

4.9.1 Generation Mean Analysis

The observed values of all the generation means along with standard errors, standard deviation and coefficient of variation are shown in Table 17. It was possible to assess whether the variation observed in the generation means could be explained on an additive-dominance basis or whether the interaction between genes at different loci (epistasis) was important. This was achieved by using the *A*, *B* and *C* scaling tests proposed by Mather (1949) and joint scaling test of Cavalli

(1952) for detection of non-allelic interaction. The *A, B* and *C* and joint scaling tests were estimated from Table 17. Linear correlations were done between the *Striga* damage ratings and the various growth components. The estimates of the genetic components were done and the results of the estimates of the six parameters i.e. additive (a), dominance (d), additive x additive (aa), additive x dominance (ad) and dominance by dominance (dd) and F_2 means (m) are shown in Table 18. The estimate of the number of genes controlling various traits was done using the formulae of Burton's and Castle-Wright's) and the results are presented in Table 19.

Table 17. Means of *Striga* counts, *Striga* damage ratings, plant and ear height of P_1, P_2 and F_1, F_2, B_1CP_1, BC_1P_2 generations

Variable						
Generation	*Striga* Count		*Striga* Damage Rating		PH	EH
	8 weeks	10 Weeks	8 weeks	10 weeks		
P_1	0.0^{c}	0.4^{e}	1.1^{c}	1.1^{e}	134.4^{a}	60.3^{a}
P_2	3.1^{a}	6.2^{a}	2.7^{a}	3.6^{a}	82.3^{d}	36.1^{bc}
F_1	0.1^{c}	1.5^{cd}	1.4^{c}	1.7^{d}	109.8^{b}	50.9^{ab}
F_2	1.4^{b}	2.0^{bc}	1.8^{b}	2.8^{b}	85.9^{d}	42.1^{bc}
BC_1P_1	0.3^{c}	0.7^{de}	1.3^{c}	1.7^{d}	96.8^{c}	37.5^{bc}
BC_1P_2	1.5^{b}	2.8^{b}	1.1^{c}	2.1^{c}	84.7^{d}	34.5^{c}
Mean	1.1	2.3	1.6	2.2	99.0	43.6
CV (%)	1.1	0.9	0.4	0.4	0.2	0.2
SE±	0.5	0.9	0.3	0.4	8.2	4.1
Std	1.2	2.1	0.6	1.0	20.1	10.1
Mid-parent (m)	1.5	3.1	1.9	2.4	108.1	48.2

Note. Means followed by the same letter within columns do not differ significantly according to DMRT. P_1 = resistant Parent (MSMP1/P2); P_2 = Susceptible parent (5057); BC_1P_1 = Backcross to resistant parent; BC_1P_2 = Backcross to susceptible parent. PH = Plant height; EH = Ear height; SE±, Standard error of the mean; Std (Standard deviation).

4.9.1.1 Emerged *Striga* Counts

There were significant differences ($P < 0.05$) among the maize generations for emerged *Striga* count at eight weeks after crop emergence (Table 17). The mean *Striga* count at eight weeks after crop emergence was 1.1. The highly resistant generation with low (zero) *Striga* emergence was P_1. The maize generation with the highest number of emerged *Striga* count of 3.1 was the susceptible parent P_2.

There were significant differences ($P < 0.05$) in the emerged *Striga* count amongst the maize generations for emerged *Striga* at 10 weeks after crop emergence (Table 17). The mean *Striga* count at 10 weeks after crop emergence was 2.2. The generation with the highest mean number of emerged *Striga* of 6.2, was the susceptible parent P_2. The resistant parent P_1 had the least mean emerged *Striga* count of 0.4.

4.9.1.2 *Striga* Damage Rating at 8 Weeks after Crop Emergence

Significant differences ($P < 0.05$) were observed amongst the maize generations for *Striga* damage rating at eight weeks after crop emergence (Table 17). *Striga* damage ratings ranged from 1.1 to 2.7. The mean rating was 1.6. The susceptible parent P_2 had the highest damage rating of 2.7 on the scale of 1-5, whereas the resistant parent P_1 had the lowest damage score of 1.1. This was however not significantly different from F_1, BC_1P_1 and $BC_1\ P_2$ generations. The susceptible parent damage score rating of 2.7 was significantly different from the rest of the generations.

4.9.1.3 *Striga* Damage Rating at 10 Weeks after Crop Emergence

There were significant differences ($P < 0.05$) among the maize generations for *Striga* damage rating at 10 weeks (Table 17). The mean *Striga* damage rating was 2.2. The susceptible parent P_2 had the worst damage rating score of 3.6 whereas the resistant parent, P_1 had the best score of 1.1. F_1 generation was similar to BC_1P_1 but significantly different from P_1, P_2 F_2 and BC_1P_2. Among the segregating generations, F_2 had the highest score followed by BC_1P_2 and BC_1P_1 respectively. The means for *Striga* counts and *Striga* damage ratings for B_1CP_2 generations were skewed towards the susceptible parent P_2 whereas the BC_1P_1 generations were skewed towards the resistant parent P_1. (Figures 13 and 14 respectively).

4.9.1.4 Plant Height

There were significant differences ($P < 0.05$) among the generations for plant height (Table 17). The plant heights ranged from 82.3 to 134.4 cm. The mean plant height amongst the generations was 99 cm. The resistant parent P_1 had the highest plant height of 134.4cm whereas the susceptible parent P_2 had the lowest plant height of 82.3 cm. This however was not significantly different from the height of the segregating F_2 and BC_1P_2 at 84.7 and 85.9 cm respectively.

4.9.1.5 Ear Height

There were no significant differences ($P < 0.05$) amongst the hybrids for ear height (Table 17). The average ear height was 43.6cm. The ear heights ranged from 34.5 to 60.3 cm. The mean ear height was 43.6 cm. The resistant Parent P_1 had the highest ear placement at 60.3 centimeters whereas the susceptible Parent, P_2 had the ear placement at 36.1 centimeters. The back cross to the susceptible parent BC_1P_2 had the lowest ear placement at 34.5 cm. The ear heights for the susceptible parent P_2, F_2 and backcross to the resistant parent BC_1P_1 were however not significantly different.

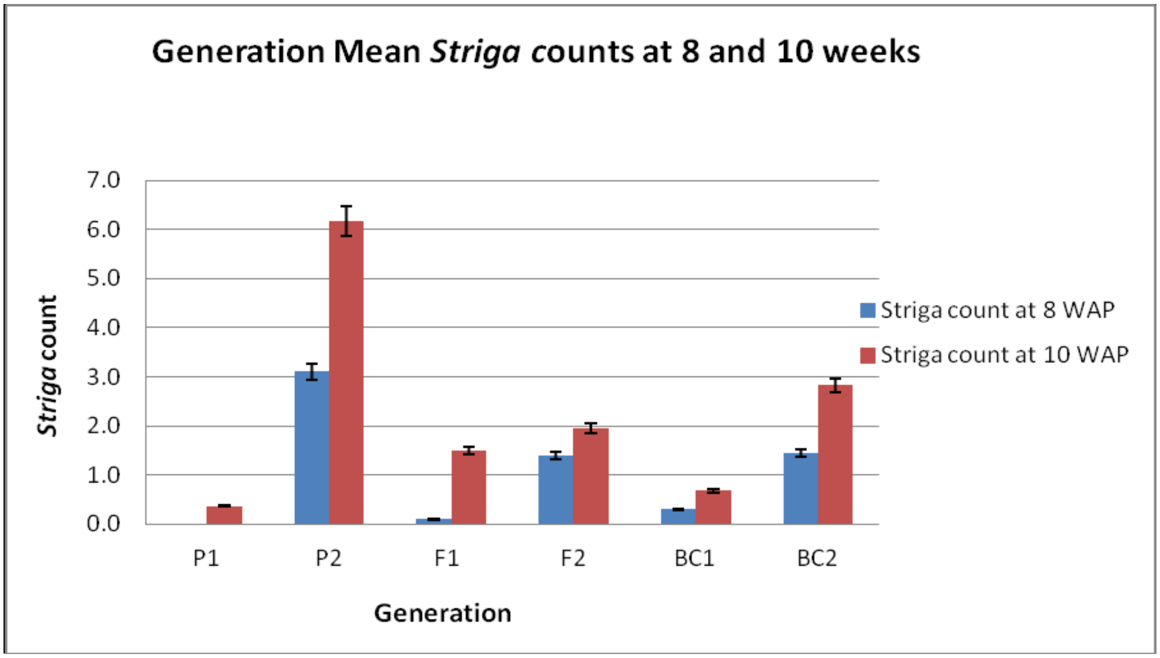

Figure 13. Mean *Striga* counts for different generations of the cross between resistant P_1 (MSMP1/P2) and susceptible P_2 (5057) in 2012.

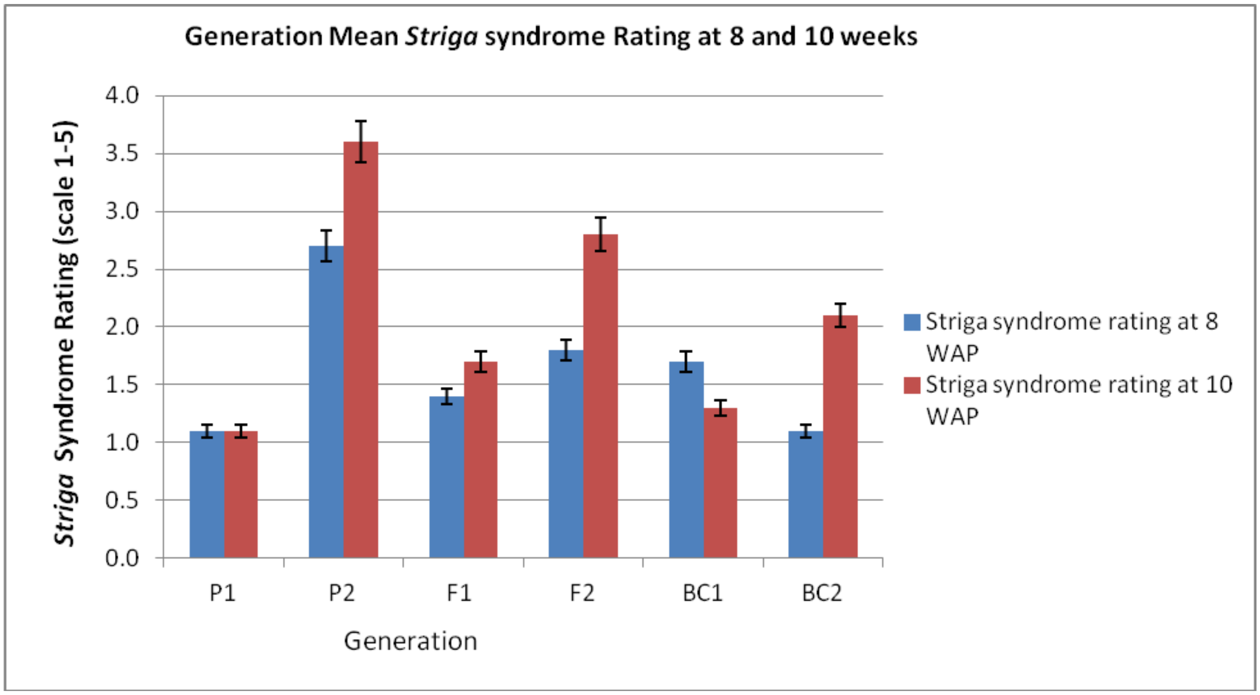

Figure 14. Mean *Striga* damage ratings for different generations of the cross between resistant P_1 and susceptible P_2 in 2012.

4.9.2 Correlation between *Striga* Damage Rating and Plant Height of the Maize Generations

Figure 15 & Figure 16 are the correlation plots of *Striga* damage rating and plant height of the maize generations of the cross between P_1 (MSMP1/P2) and P_2 (5057). The correlation was negative (r = -0.56) and the coefficient of the relationship (R^2) was 0.3 at 8 weeks after crop emergence (WAP). The same negative correlation scenario (r = -0.75) and (R^2 = 0.57) was observed at 10 WAP.

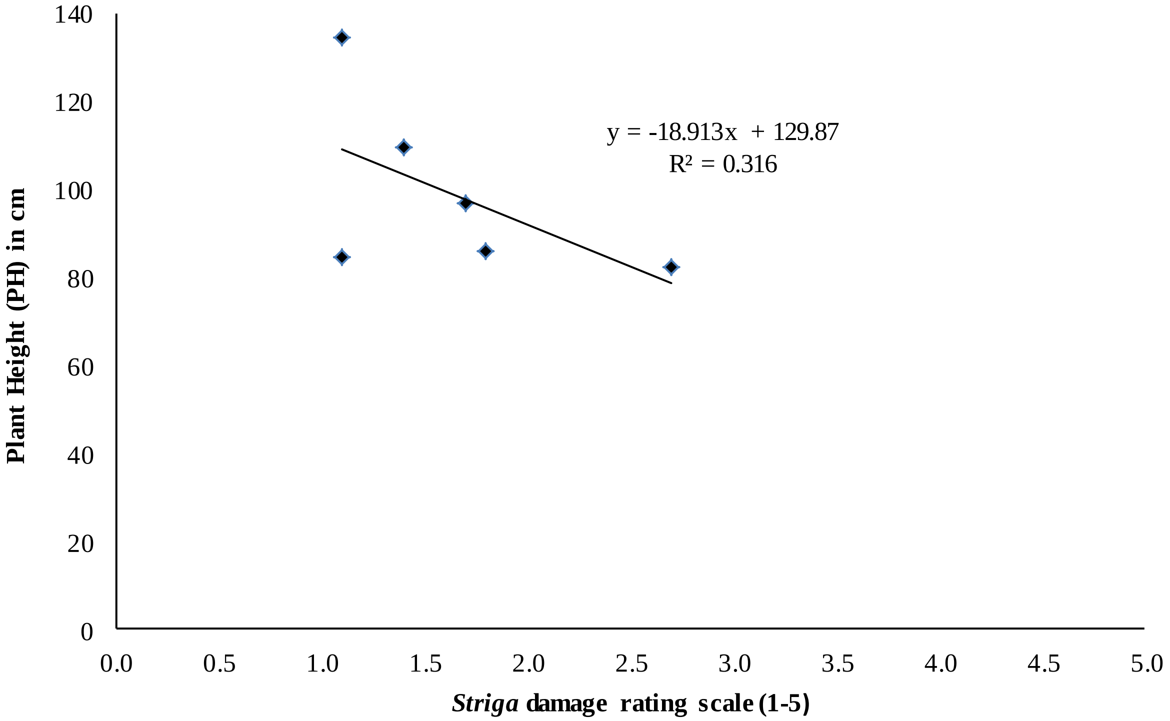

Figure 15. Linear correlation plot between plant height and *Striga* damage rating for the generations at eight weeks after crop emergence

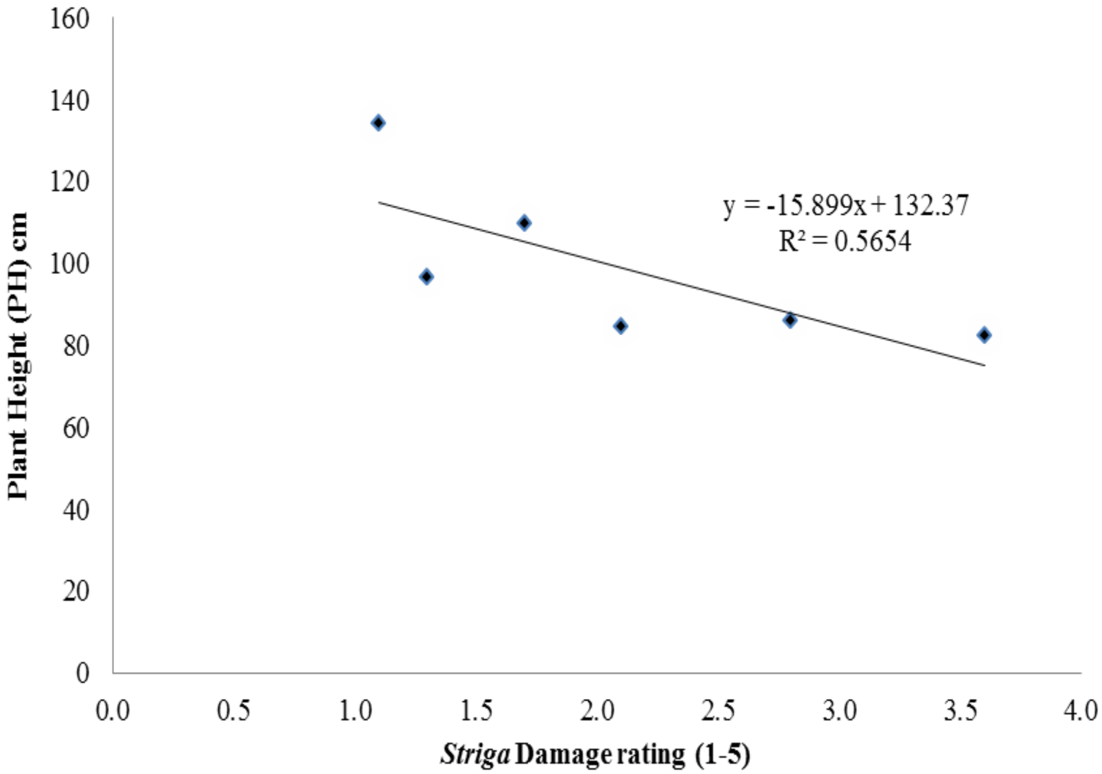

Figure 16. Linear correlation plot between plant height and *Striga* damage rating of the generations at 10 weeks after crop emergence.

4.9.3 Correlation between *Striga* Damage Rating and Ear Height of the Maize Generations.

The estimates of linear correlation was negative (r = -0.48 and r = -0.56) at eight and 10 weeks after planting respectively (Figure 17 & Figure 18). The coefficient of determination (R^2) was 0.23 and 0.31 respectively for *Striga* damage rating and ear height at 8 and 10 weeks after crop emergence respectively.

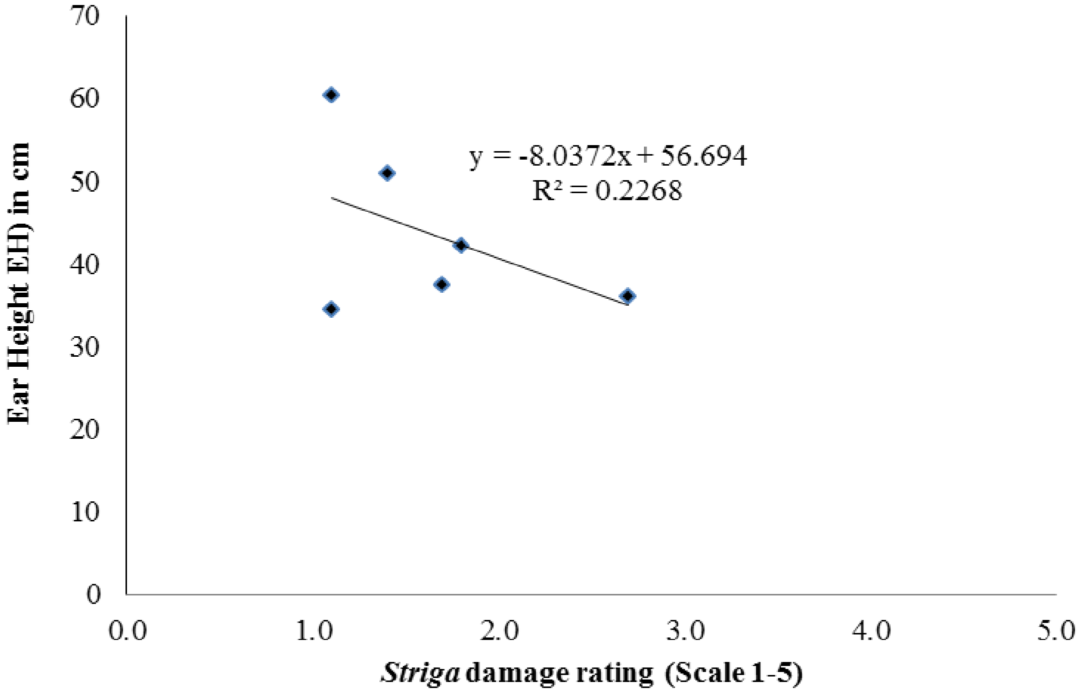

Figure 17. Linear correlation between ear height and *Striga* damage rating of the generations at 8 weeks after crop emergence.

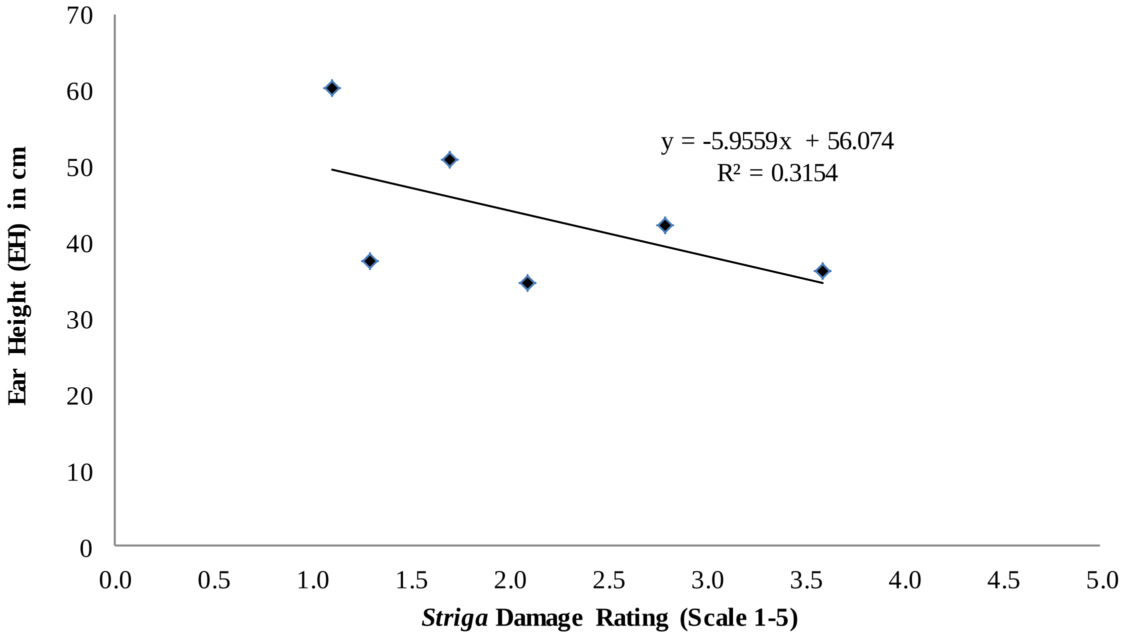

Figure 18. Linear correlation between Ear height and *Striga* damage rating of the maize generations at 10 weeks after crop emergence.

4.9.4 Estimates of Genetic Components

Estimates of the six parameters, i.e. additive [a], dominance [d], additive x additive [aa], additive x dominance [ad] and dominance x dominance [dd] and F_2 means (m) are presented in Table 18. The results indicated that the mean effects (m) were highly significant for the variables.

From the experiment, all kinds of gene effects were significant $P < 0.05$, highly significant $P < 0.001$ except additive x additive, additive x dominance for emerged *Striga* count at 10 weeks after crop emergence and dominance, additive x additive effects for plant height which were not significant. Among the interactions, dominance x dominance interactions[dd] are larger than additive x additive [aa] and additive x dominance [ad] except for *Striga* damage rating at eight weeks after crop emergence while among the main effects, dominance [d] is greater than the additive [a] component. The [d] and [dd] are in opposite directions except for plant height hence the nature of epistasis is duplicate. The [d] is negative, whereas [dd] is positive.

The additive gene effects [a] were positive and highly significant for *Striga* damage rating at eight weeks, plant height and ear height. Meanwhile negative and significant values were detected for emerged *Striga* count at eight, 10 weeks after crop emergence and *Striga* damage rating at 10 weeks.

With regard to dominance gene effects [d] negative values were observed for *Striga* count eight, *Striga* count 10, *Striga* damage rating at eight weeks, *Striga* damage rating at 10 weeks and ear height. Positive and non-significant gene effects were observed for plant height.

With respect to additive x additive type of gene effects, positive but non-significant effects were observed for plant height. Negative and non-significant effects were observed for *Striga* count at 10 weeks. Negative and significant effects were observed for *Striga* count at eight weeks. *Striga* damage rating at eight and 10 weeks and ear height.

Additive x dominance type of gene effects [ad] was found to be positive and significant for *Striga* count eight weeks and *Striga* damage rating at eight and 10 weeks. Emerged *Striga* count at 10 weeks was positive and non-significant. Plant and ear heights had negative and highly significant effects.

Concerning the type of dominance x dominance [dd], positively significant and highly significant effects were detected for all the variable

Table 18. Estimates of genetic components of mean for various traits of the cross P_1 (MSMP1/P2 x P_2 (5057) of Maize under *Striga* infestation.

Variable	M	[a]	[d]	[aa]	[ad]	[dd]
Striga Count 8	1.35±0.12**	-1.15±0.13**	-3.33±0.57*	-1.90±0.55*	0.83±0.40*	1.80±0.79*
Striga Count 10	1.95±0.12**	-2.15±0.29**	-2.53±0.85*	$-0.77±0.74^{ns}$	$1.50±0.82^{ns}$	3.27±1.50*
Striga Damage Rating 8	1.77±0.12**	0.63±0.11**	-1.93±0.52**	-1.40±0.51**	2.93±0.26**	2.27±0.68**
Striga Damage Rating 10	2.75±0.11**	-0.82±0.08**	-4.85±0.50**	-4.23±0.48**	0.87±0.22**	5.63±0.62**
Plant Height (cm)	85.85±2.46**	12.08±2.25**	$21.10±12.11^{ns}$	$19.70±10.81^{ns}$	-27.97±7.79**	53.47±17.24**
Ear Height (cm)	42.1±1.86**	2.95±1.38*	-21.72±8.39**	-24.43±7.92**	-18.27±4.17**	78.63±10.77**

Note. m: F_2 means; ns, **, * = non-significant, Significant at 1% and 5% probability level, respectively; [a], [d], [aa], [ad], [dd] = net directional effects of loci contributing to additive, dominance, additive x additive, additive x dominance, and dominance x dominance components, respectively.

4.9.5 Estimates of the Number of Genes

The estimated number of genes controlling various traits in both crosses is presented in Table 19. Considering formulas and crosses, around 1.0 major gene is responsible for emerged *Striga* and *Striga* damage rating and ear height. The number of genes controlling plant height ranged from 3 to 8 genes.

Table 19: Estimates of the number of genes for the various traits in the cross P_1 x P_2.

Trait	**Castle-Wright's**
Striga Count 8	0.781
Striga Count 10	-4.553
Striga damage rating 8	0.629
Striga damage rating 10	0.685
Plant Height	2.627
Ear Height	0.284

CHAPTER FIVE: DISCUSSION

5.1 Maize Inbred Lines Response to *Striga* Infestation at Nyahera during the Short Rains of 2010 and Long Rains 2011

A broad range of genetic variation in *Striga* resistance traits amongst the maize inbred lines were exhibited in this study, particularly in the number of emerged *Striga* plants (Tables 6, 7 & 8). Similar results have been reported by Amusan *et al.*, (2008). At Nyahera site in 2011 long rains season, where grain yield was recorded, the ear aspect of the tolerant and resistant inbred lines was significantly superior to those of susceptible maize inbred lines. The importance of ear aspect in the assessment of host plant reaction to *Striga* infection has also been reported (Kim *et al*., 1997) .The Maseno University maize inbred line GF4/S1S2 exhibited the best ear aspect and also had the highest yield.

Results from this study indicated that *Striga* emergence in some moderately susceptible lines were similar to *Striga* emergence in some resistant and tolerant lines (Table 6, 7). Studies done before by other workers have also shown that *Striga* emergence counts from tolerant maize genotypes were not significantly different from *Striga* emergence counts from moderately susceptible genotypes. This discredits the use of *Striga* emergence counts as the only means or criteria to distinguish genetic control of *Striga* tolerance in maize (Kim, 1994; Kim and Adetirimin *et al*., 2000). Probably, this is because resistance may often be confounded by tolerance existing in the same host germplasm.

In the short rains of 2010, the mean emerged *Striga* plants at eight and 10 weeks after crop emergence at Nyahera (Table 6) was lower than the emerged *Striga* count during the long rains season of 2011 at eight and 10 weeks after crop emergence (Table 7). The difference in the emerged *Striga* plants can be attributed to the seasonal variation in rainfall pattern and temperature. Increased moisture and favorable temperature during the long rains season provided suitable conditioning and germination of *Striga* seed (Visser, 1989). It has been reported that complex interactions among the parasite, its host and the environment had greater effect on the *Striga* emergence in the field (Haussmann *et al.,* 2000). Differences in the number of emerged *Striga* plants between plots of the same genotype have also been reported in maize (Efron, 1993).

The *Striga* count at eight weeks after crop emergence ranged from 0.0 to 4.7, whereas the emerged *Striga* count at 10 weeks after crop emergence ranged from 0 to 11.3 (Table 8). The same trend of increasing emerged *Striga* numbers is observed during the long rains of 2011 where emerged count at eight and 10 week were 0.5 to 9.8 and 0.3 to 41.3 (Table 7) respectively. This means that the peak period for observing emerged *Striga* plants should be at 10 weeks after crop emergence.

There were no grain yield data captured in the short rains of 2010 and short rains season of 2011.This was attributed to the drought just before flowering in the 2011 season and soon after flowering in 2010 season. This means that there was no fertilization hence no yield. In the long rains of 2011 the results revealed a clear impact of *Striga* infection on grain yield. Analysis of variance revealed highly significant differences (P<0.001) among the inbred lines for grain yield. Maximum grain yield is the prime objective in most breeding programs. In general, grain yield is determined by the levels of tolerance of the host genotype, by severity of infestation and/or by the levels of soil fertility. Kim *et al.* (2002) reported that tolerant varieties suffer lower yield reduction and often produce 2 - 2.5 times the yield of susceptible varieties, especially under high infestation. Okonkwo (1966) attributed grain yield losses to the diversion of photosynthates, mineral salts and water from the host to the parasite. The observation made in variation in plant height where susceptible hosts had lower plant and ear height compared to tolerant or resistant host, is a clear manifestation that *Striga hermonthica* had caused reduction in the growth of the host plants as a result of reduction in photosynthetic capacity (Press and Graves, 1991). It is estimated that this reduction in photosynthesis in the host results in 80-85% growth reduction in infested maize and sorghum, whilst 20% of the damage is as a result of the actual removal of carbon by the parasite (Graves *et al.,* 1989; 1990). *Striga* might have also acted not only as an additional sink but probably also had a strong 'toxic' or 'pathological' effect on the host and hence causing the reduction in growth and development of the host. Graves *et al.* (1989) stated that this parasitic plant induces reduction in host photosynthesis and this has been the most important mechanism of growth reduction. The authors also reported that about 80% of the decrease in host growth rate could be attributed to the impact *Striga* has on host photosynthesis.

The co-efficient of variation (CV) was higher at Nyahera, 41.8%, 45% in the short and longs rains of 2010 and 2011 respectively compared to Kibos in the short rains of 2010.The lower CV at Kibos is attributed to the artificial inoculation of *Striga* which ensures uniform plot infestation compared to the natural infestation at Nyahera which is random.

From the above results, the majority of inbred lines with resistance to *Striga* for example TZSTR154, TZSTR133, TZSTR139, MSMP1/P2, TZSTR166, TZSTR167 and resistant check 9450 had significantly fewer or zero emerged *Striga* count compared with some tolerant and susceptible inbred check 5057 which had higher *Striga* emergence and high damage rating. These results were consistent with observations reported in maize (Kim *et al.,* 1999, Menkir, 2006) and sorghum (Oliver *et al.,* 1991, Arnaud *et al.,* 1999). These results suggest that screening for field resistance to *Striga* was successful in identifying inbred lines with reduced numbers of emerged *Striga* plants. Significant differences observed in the inbreds reaction to *Striga* can be attributed to their differences in their capacity to stimulate *Striga hermonthica* germination which could account for the differences in the emerged *Striga* counts. It is important to note that significant genetic differences in the amount of *Striga* germination strigol production have been found in maize (Fasil *et al.,* 1994) and in wild relatives (Weera-Suriya *et al.,* 1993, Vogler *et al.,* 1996). Such differences could account for the variation in host sensitivity to *Striga* like the one recorded in sorghum cultivars (Hess *et al.,* 1992, Haussmann *et al.,* 2001). The low emerged *Striga* in the inbred line trial could be also be attributed to the variation in their rooting system. The less dense rooting system reduces the root *Striga* contact between the host inbred line and the parasite and vice versa. Rich and Ejeta, (2008) had also summarized avoidance of the parasite through fewer branched roots, production of less germination stimulant, as well as low haustorial induction as additional potential defense mechanisms in maize. The diverse resistant /tolerance lines identified in the study are thus likely to be good sources of different resistance mechanisms for use in breeding maize genotypes with durable resistance to *Striga hermonthica.*

5.2 Maize Hybrid Evaluation under *Striga* and Non *Striga* Infestation at Nyahera and Maseno during the Short Rains of 2011 and Long Rains 2012

For all the hybrid evaluations under *Striga hermonthica* infestation there were varietal differences in response to *Striga hermonthica* damage (Table 9, 10 &11). Commercial hybrids H513 and PhB3253 hybrids had higher *Striga* damage symptoms and higher emerged *Striga* plants at eight and 10 weeks after crop emergence and low yield (Table 9, 10 &11). This was in comparison to experimental hybrids that had high yields under *Striga hermonthica* infestation

(Table 9, 10 &11). Ransom *et al.*, 1990, reported that the severity of infestation varied with genotypes. The differences among the cultivars/genotypes in the level of yield reduction could be due to differences in the level of resistance/tolerance of the maize genotypes studied (Akaogu *et al.,* 2012). Consistent performance of *Striga*-resistant varieties in contrasting environments was reported by Menkir *et al.* (2012b), who attributed this to the presence of polygenic resistance in the germplasm used. Consistency of performance could also mean that the S. *hermonthica* populations were similar in the diverse environments used in the present study.

Mean grain yield of the maize genotypes varied among the environments. Generally, the mean yields at Maseno, a non *Striga hermonthica* infested location was higher than the mean yields at Nyahera, a *Striga hermonthica* infested area. This suggests that low grain yield can be associated with increased *Striga* damage symptoms and number of emerged *Striga* plants. Grain yield reduction of up to 42 percent under *Striga* infestation has been reported by Badu-Apraku *et al.*, 2004. The mean grain yield ranged from 3.76 to 5.85 and 5.85 to 8.75 tons/ha under *Striga hermonthica* infestation and non *Striga hermonthica* infestation, respectively. The mean grain yield of cultivars under *Striga* infestation was between 65-75% of that under *Striga* free conditions. The observed large loss in grain yield, high host plant damage rating and large number of emerged *Striga* plants recorded are clear indications of the severe parasite pressure achieved during the evaluation of the cultivars at *Striga hermonthica* infested location at Nyahera. The results also showed the merits of growing *Striga* tolerant maize varieties in *Striga* endemic areas rather than using susceptible varieties. This is in agreement with the findings of Badu-Apraku *et al*, 2009, who observed that *Striga* tolerant varieties to have the highest observed grain yield, and *Striga* susceptible varieties to have the lowest grain yield under *Striga* infested environment.

The genotypic correlation between the host damage rating and emerged *Striga* plants was positive but low suggesting that different genes control the two traits (Figure 3, 4, 5 & 6). Similar results have been reported by Kim, 1994; Akonvou *et al.,* 1997; Menkir and Kling 2007; Badu-Apraku *et al.,* 2007; Badu-Apraku *et al.,* 2011. Also, the positive correlation observed between *Striga* damage rating at eight and 10 weeks after crop emergence on one hand, and the number of emerged *Striga* plants at eight and 10 w.a.c.e, on the other, suggest that either of these traits may serve as a selection parameter for the evaluation of genotypes for *Striga* resistance without a great loss in precision. However, *Striga* emergence count alone is not reliable for the evaluation of resistance, especially when genotypes are highly susceptible because such materials suffer more damage even when few *Striga* plants are attached to the roots of the host plant (Kim *et al.,* 1998). Therefore, for maximum gain from selection for *Striga* resistance and increased grain yield, it is desirable to use a combination of host damage rating and *Striga* emergence counts to simultaneously improve both traits (Efron, 1993; Kim, 1991, 1994; Kim and Ademitrin, 1997; Badu-Apraku *et al.,* 2004, 2007).

The highly significant and negative correlations between the grain yield and *Striga* damage ratings shows that these traits/parameters are highly associated in a nonlinear way (Figure 7, 8, 9 & 10). It appears that the most susceptible hybrids with high severity rating like PhB3253 and H513 tended to have low grain yields and vice versa. These results are not unusual since low grain yield of varieties under *Striga* infestation have been associated with high *Striga* damage symptoms high emerged number of *Striga* plants (Menkir *et al*, 2006). Similarly, Badu-Apraku *et al.,* 2007, Karaya *et al.,*2012, reported high negative genetic and phenotypic correlations between grain yield and host plant damage rating and concluded that *Striga* damage rating is an appropriate trait for the assesment of tolerance under *Striga* infestation (Kim and Ademitrin, 1995).

5.3 Maize Hybrid Genotypes Combined Grain Yield and Stability under *Striga* Infested and *Striga* Free Environments

The development of maize hybrids which are high yielding and relatively stable when grown in different environments is of fundamental importance to commercial maize production (Gamma and Hallauer, 1980). At the same time yield stability in maize is under genetic control and thus suitable for selection (Scott, 1967). Combined analysis of variance of grain yield showed that the grain yields of the maize hybrid genotypes were significantly affected by environment which explained 50% of the total variation (G + E + GEI), whereas genotype and genotype x environment interaction accounted for 39% and 11% respectively (Table 16). Evaluation of genotypic performances of hybrid maize cultivars in a number of environments provides useful information to identify their adaptation and stability (Crossa *et al.,* 1990).

Stability of expected grain yield is one of the most desirable properties, in order to recommend hybrid use (Radomir *et al.,* 2009). The most accurate model for AMMI can be predicted using the first two PCAs (Gauch and Zobel, 1996; Yan *et al.,* 2000; Annicchiarico, 2002). By plotting both the genotypes and the environments on the same graph, the associations between the genotypes and the environment can be seen clearly (Fig.12). The IPCA (Principal Component Analysis) scores on the genotype in the AMMI analysis are an indication of the stability or adaptation over environments (Gauch and Zobel, 1996; Purchase, 1997; Alberts, 2004). The greater the IPCA scores, the more specific adapted is a genotype to certain environments. The more the IPCA scores approach zero, the more stable or adapted it is over all the environments sampled. Genotypes adapted to *Striga* infestation were EH12, EH14, EH11M, EH21S and EH11S. The most stable genotypes based on IPCA1 scores were 4 (EH11M) and 2 (EH12). Commercial check hybrids DK8031, PhB3253 and H513 fell within the NS (Non *Striga*) component of the bi-plot meaning that they do well under *Striga hermonthica* free conditions. On the contrary they had low yields and high instability in the Bi-Plot. This low yield was expected because they were evaluated in a *Striga* infested area which is outside their range of adaptation (Eskridge *et al.*, 1993). The rest of the hybrids fall under the S (*Striga hermonthica* infested)-component of the biplot which means they tolerate *Striga hermonthica* infestation. However the ideal genotype is EH 14 denoted by 1 in the S-biplot component showing excellent performance under *Striga hermonthica* infestation. The variety was however not among the most stable, suggesting that it has a specific adaptation to *Striga* prone areas. This result is consistent with that of Badu-Apraku *et al.,* 2012 who identified high yielding but unstable varieties in West Africa.

5.4: Generation Means analysis: Genetics of Resistance

The mean *Striga* emergence and *Striga* damage ratings for the *Striga* resistant parent was significantly lower than the susceptible parent P_2. This result was manifested and expressed by a lower number of emerged parasitic plants and minimum damage sustained by the host. It also suggests that screening progenitors was effective in differentiating the resistant from susceptible inbred lines. These results are consistent with the observations reported in maize (Kim *et al.,* 1999) and sorghum (Oliver *et al.,* 1991; Arnaud *et al.,* 1999).

The means for emerged *Striga* counts at eight and 10 weeks after crop emergence and *Striga* damage rating at 10 weeks after crop emergence for BC_1P_1 were skewed towards the resistant parent P_1. This may possibly indicate that several genes could be involved in *Striga* resistance/tolerance. When the backcross to the susceptible parent (BC_1P_2) was performed, population distribution skewed towards the susceptible parent P_2 (5057). In general, backcrossing to susceptibility increases frequency of alleles for susceptibility. Backcrossing to resistant parent increases alleles for resistance hence skews it towards resistant direction. However, the presence of transgressive segregants that performs better or worse than parents do exist in this study. Transgressive segregants were observed in BC_1P_2 population which resulted in more susceptible plants than the susceptible parent P_2 (5057) for the *Striga* damage rating at eight weeks.

Plant and ear heights were negatively correlated with *Striga* damage rating which accounted for 30 and 57 % of the variance in plant height at eight and 10 weeks. On the other hand, *Striga* damage rating accounted for 23 and 30 % of the variance in Ear height at eight and 10 weeks. This is not unusual since susceptibility to *Striga* is manifested by decreased plant and ear height and the converse is true (Fasil, 1994). This scenario is supported by Akanvou *et al.* (1997) who reported a negative genetic correlation between plant height, *Striga* count, *Striga* rating and ear height. According to Akanvou and Doku (1998) negative association are expected since *Striga* reduces yield through its adverse effects on the physiology of the infested plants.

Estimates of the six parameters, i.e. additive (a), dominance (d), additive x additive (aa), additive x dominance (ad) and dominance x dominance and F_2 means (m) presented in Table 18 indicate that the mean effects (m) were highly significant for the variables indicating that all the variables except plant height, are qualitatively inherited. *Striga* resistance in maize, reported to date, appears to be qualitative and recessive in nature (Lane *et al.*, 1997; Oswald and Ransom, 2004; Gethi and Smith, 2004), qualities that may further ensure its stability (Rispail *et al.,* 2007). Other reports also suggest that *Striga* resistance is controlled by relatively few genes with additive effects (Shinde and Kulkarni, 1982; Vasudeva Rao *et al.*, 1982). On the contrary Lane *et al.* (1997); Ejeta (2007); Haussmann *et al*. (2004) reported that resistance/tolerance to *Striga* was quantitatively inherited.

Higher mean values of dominance effects over additive effects, significant dominant genetic effects (d) for *Striga* emergence and *Striga* damage rating suggested a preponderance of non-additive genetic effects in the inheritance of *Striga* tolerance. This is in agreement with Kim (1994), who reported the importance of both additive and non-additive effects for *Striga* emergence in a di-allele study. This is also in agreement with Akanvou *et al.* (1997), who reported the preponderance of non-additive genetic effects for *Striga* emergence. On the contrary, Gethi and Smith (2004) reported that additive gene effects were more important than non-additive gene effects in the expression of all the resistance traits measured.

Gene interaction is considered to be complementary when the (d) and (dd) estimates have the same signs and to be duplicating when the signs differ (Mather and Jinks, 1982). Gene interactions in this study were of duplicate type except for plant height which was complementary. This is contrary to Azizi *et al*. (2006), who reported duplicate type of non-allelic interaction for plant height in maize. The presence of duplicate type of gene interaction confirms the importance of dominance effects.

The additive gene effects (a) were positive and highly significant for *Striga* damage rating at eight weeks. Meanwhile negative and significant values of these parameters were detected for emerged *Striga* count at eight and 10 weeks after crop emergence and *Striga* damage rating at 10 weeks. The results indicate that selection for *Striga* tolerance, plant and ear height are important in early generations. The negative and significant values mean that the materials that were used in the study have decreasing alleles for *Striga* tolerance and selection to improve it could be effective. One such effective way is to use recurrent selection methods that capitalize on additive gene action for the screening of segregating families (Badu-Apraku *et al.,* 2013). This should facilitate the pyramiding or accumulation of resistance/tolerance genes to develop germplasm with multi-genic resistance/tolerance that could be effective and durable over time (Berner *et al.,* 1995; Menkir and Kling, 2007; Badu-Apraku *et al.,* 2012).

With regard to dominance gene effects (d) negative values were observed for *Striga* count eight, *Striga* count 10, *Striga* damage rating at 8 weeks, *Striga* damage rating at 10 weeks and Ear height. This means that the alleles responsible for low values for *Striga* tolerance and ear height were dominant over the alleles controlling high values. Positive and non-significant gene effects were observed for plant height indicating the presence of dominant gene effect in the inheritance of plant height.

With respect to additive x additive (aa) type gene effects, positive and non-significant effects were observed for plant height. This means that early selection for plant height might be effective for *Striga* breeding. Negative and non-significant effects were observed for *Striga* count at 10 weeks. Negative and significant effects were observed for *Striga* count at eight weeks, *Striga* damage rating at eight and 10 weeks as well as ear height. This means that early generation selection for *Striga* tolerance simultaneous with ear height might not be an effective strategy in a *Striga* breeding programme.

Additive x dominance type gene effects (ad) were found to be positive and significant for *Striga* count eight and *Striga* damage rating at eight and 10 weeks. Emerged *Striga* count at 10 weeks was positive but non-significant. Plant and Ear heights had negative but highly significant effects. Negative sign of interaction suggest an interaction between increasing and decreasing alleles, thus providing evidence of dispersion of genes in the inbred parents (Mather and Jinks, 1982). Yi-Hong Wang *et al*. (2014) reported that both additive and dominant gene action are involved in *Striga* resistance under conditions of *Striga* infestation.

Concerning the dominance x dominance (dd) gene action, positive and highly significant effects were detected for all the variables. Positive and significant results confirm the important role of dominance x dominance gene interactions in the genetic system which controls *Striga* emergence, *Striga* tolerance, plant and ear heights.

For estimation of the number of effective factors, differences between parents and variation in F_2 and backcrosses are needed. The Castle/Wright formula (Weber, 1950) was used to estimate the number of effective factors. With regard to *Striga* count, *Striga* damage rating and ear height an estimate of number of genes was approximately one. These values should be considered as one and probably more according to Burton's formula. This may be due to the existence of interaction between pertinent non-allelic genes. The estimates of number of genes involved and mode of gene action is important in deciding the breeding procedure for maize improvement under *Striga* infestation. A method that involves accumulation of favorable genes for the improvement of the trait under selection would be ideal. When inherited through additive gene action the favorable genes are expected to make equal contribution to the improvement of the trait.

With regard to plant height estimates of the effective factors when using Castle/Wright was 3.0 and 8 according to Burton's suggesting that the parental varieties differed in three and eight pairs of genes. Thus, the number of effective factors might not be the actual number of genes due to the existence of interaction of non-allelic genes between the pertinent genes and dominance. This result is in accordance with that reported by Swamy Rao (1979) who found that plant height was under the control of polygenes. The more than one gene responsible for the trait plant height, in the cross, stipulates polygenic inheritance of this trait in maize. The genes controlling quantitative traits could be linked and therefore segregate as a group or as an effective factor (Milus and Line, 1986).

The negative Castle-Wright estimates for *Striga* count at 10 weeks are probably due to violations of the assumptions of the Castle-Wright estimator. The Castle-Wright equation assumes fixed differences between the parents, additive gene action, unlinked loci, and equality of allelic effects (Lynch and Walsh, 1998). The assumption most likely violated is that of additive gene action, especially since dominance calculation indicates partial dominance for the trait examined (Table 19).

CHAPTER SIX:CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The results of this study confirm that there are available inbred lines with good levels of resistance to *Striga hermonthica*. The inbred lines identified in this study that supported fewer emerged *Striga hermonthica* plants and low *Striga* damage ratings, like 9450, TZSTR139 and MSMP1/P2 should be used in breeding programs focused on developing resistant maize cultivars that support fewer parasites and thus add less parasite seeds into the soil for subsequent crop. The identified maize inbred lines with good levels of resistance and different resistance mechanisms can facilitate pyramiding of several resistant alleles to obtain more durable and stable polygenic resistance to *Striga hermonthica* in maize. The identified resistant lines can be used as potential candidate genotypes for studies to elucidate the mechanisms of resistance to *Striga hermonthica* and its genetic basis in maize. The inbred lines could also be used as sources of *Striga* resistance for the development of synthetic varieties and hybrids as well as for improvement of breeding populations in Kenya.

The study supported the hypothesis that different maize genotypes respond differently to *Striga hermonthica* infection. The maize genotypes identified in this study that are high yielding, supports fewer emerged *Striga hermonthica* plants, have low *Striga* damage ratings and broad adaptation can contribute significantly to the integrated efforts to eradicate *Striga* menace. Their parents should be used in breeding programs focused on developing resistant maize cultivars that support fewer parasites and thus add less parasite seeds into the soil for subsequent crop. The parental lines of the Maseno experimental hybrids exhibiting tolerance/resistance were previously selected from maize landraces from western Kenya and the finding from this study suggest that they have potential sources of *Striga* weed tolerance genes that could be used in breeding programs. EH12 and EH14 maize hybrids have since been released for commercial production targeting *Striga* endemic areas of western Kenya. The rest of the cultivars, EH11M, EH21S, EH11M and EH11S should be also be extensively tested in on farm and national performance trials and vigorously promoted for adoption for commercialization in *Striga* endemic areas in the sub region.

The evidence presented in this study confirms that the genetic control for *Striga hermonthica* tolerance in maize inbred tested is oligogenic. Resistance to *Striga hermonthica* is predominantly due to additive gene action which plays a major role in *Striga* emergence.

6.2 Recommendations from this Study

1. The maize inbred lines identified in this study, which exhibit tolerance/resistance to *Striga* could be used in *Striga* resistance breeding. They would be useful sources of alleles for introgression of genes for tolerance/resistance to *Striga* stress in population improvement, hybrid production and development of inbred lines. The inbred lines with good yields under *Striga* infestation could be used to form synthetics and open pollinated varieties.

2. The tolerant hybrids identified in this study, EH12, EH14, EH21S and EH11M should be used and promoted for adoption and commercialization in the *Striga* prone areas of western Kenya.

6.3 Recommendations for further Research

1. More resistant and susceptible lines need to be tested to determine if their resistance is different from the ones tested in this study: allelism testing.

2. The resistant maize inbred lines identified in this study, should be sent for genotyping in a molecular laboratory for the same reason to see if the genes are different, and in principle can be

pyramided in common backgrounds. This would shed more light on the understanding of the mechanism of and confirm tolerance/resistance to *Striga hermonthica* in the maize genotypes identified.

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APPENDICES

APPENDIX A: NATIONAL PERFORMANCE TRIALS

INTRODUCTION

In crop variety development, it is a routine procedure to evaluate potential cultivars widely over seasons and sites for bio-adaptation, yield and stability prior to release of the best varieties to farmers for commercial use. In Kenya, varietal testing has been an integral component of maize and other crop development programs since inception in 1930's. Maize National Performance Trials (NPT), initiated in 1979, is designed to evaluate varieties for release to the farmers. Entries are contributed by various institutes and seed companies. The objectives of the National Performance Trials are to identify suitable maize varieties for release in the various maize growing zones in Kenya; to evaluate performance of maize genotypes developed by various institutions for grain yield, tolerance to physical stress of environment and response to pests and diseases prevalent in the various growing zones; to provide forum for breeders in various institutions to interact during evaluation of their materials. NPT is currently the final gateway for entry of new varieties in the commercial world and it is mandatory for seed of all maize varieties sold in Kenya to have passed through NPT. Each entry is tested for three years. However, varieties that perform extremely well can be recommended for release in the second year of testing thus getting exemption for the third and final year of testing.

TRIALS EVALUATIONS

EH12 and EH14 hybrids were submitted for evaluation as candidates to Kenya Plant Health Inspectorate Services in National Variety performance trials alongside three cultivars; *Ua-Kayongo*, GFVC04 and PhB3253 at eight *Striga* infested locations in western Kenya. *Ua*

Kayongo is a herbicide resistant maize coated with imazapyr at 30g/ha. The evaluation sites were Alupe, Busia, Homabay, Kibos, Luanda, Nyahera, Ndori and Rarieda. Kibos and Alupe sites were artificially inoculated whereas the rest of the sites were farmer's fields with natural *Striga* infestation. The cultivars were evaluated in 4 row plots and data taken on the two central rows. Grain yield and *Striga* counts were computed across sites and the two hybrids data combined over two and three years respectively to allow assessment for release.

Stability was estimated by the Eberhart and Russell methods. A combined three factor analysis of variance was performed on data collected for all locations and years using the statistical model;

$$Y_{ijk} = \mu + g_i + p_j + t_k + (gp)_{ij} + (gt)_{jk} + (gpt)_{ijk} + e_{ijkl}$$

Where, Y_{ijk} is the i^{th} observation on the l^{th} cultivar in j^{th} location in the k^{th} year. The first four terms are the mean and main effects of cultivar, location and years. The next three terms are the first order interaction and finally the micro environmental deviation within locations and years. It is usually assumed that cultivars and locations are fixed effects and years random effects, so that the model is mixed effects model. Data was analyzed across all locations and years using pooled data. To characterize genotypic stability the following linear regression model was also used (Eberhart and Russel, 1966)

$$Y_{ij} = \mu + b_i L_{\mathrm{i}} + \delta_{ij} + \varepsilon_{ij}$$

Where; Y_{ij}; the mean for the genotypes i at location j,

μ; the general mean for genotype

b_i; the regression co-efficient for the i^{th} genotype at a given location index which measures the response of a given genotype to varying location.

L_i; the environmental index, which is defined as the mean deviation for all genotypes at a given location from the overall mean.

δ_{ij}; the deviation from regression for the i^{th} genotype at the j^{th} location.

ε_{ij}; the mean for experimental error.

Two stability parameters were calculated based on the regression coefficient. Regression performance of each genotype in different locations calculating means over all genotypes. The regression coefficient (b_i) and mean square deviation (δ_{ij}) were estimated by Singh and Chaudhry (1985). The significance of the regression coefficients were determined using the‘t test’ and coefficient of determination (R^2) were computed by individual linear regression analysis (Pinthus, 1973). All statistical analyses were performed using the SAS program (SAS Institute, 2001).

RESULTS

The national performance trials for five cultivars-EH14, EH12, GFVC04, *Ua- Kayongo* and PHB3253 were carried out across eight sites (Alupe, Busia, Homabay, Kibos, Luanda, Ndori, Nyahera and Rarieda) during the long rains season of 2012. Two and three year stability parameters were conducted for grain yield and *Striga* damage rating for the five cultivars.

Grain yield across eight sites during the long rainy season of 2012

The results for grain yield across eight sites during the long rains season of 2012 are shown in Table A.1. The mean grain yield across sites ranged from 5.17 to 7.78 tons/ha. The entry with the highest yield was Maseno EH14 and the least performing hybrid was the susceptible check variety Phb3253. Nyahera site had the highest mean yield of 7.95 whereas Ndori site had the lowest mean of 2.83 tons/ha.

Combined grain yield and *Striga* damage rating of the five cultivars evaluated at the eight *Striga* locations in 2012.

The combined grain yield and *Striga* damage rating of the 5 cultivars evaluated at the 8 locations are presented in Table A.2. The mean grain yield ranged from 5.15 to 7.78 tons/ha. The grain yield of the best performing hybrid EH14 was 50.64% above the best performing check, GFC04 in terms of yield and 51.17% above the mean of the checks. Maseno EH12 yield was 44.87% above the best check and 45.38% above the mean of the checks. The most susceptible hybrid was a susceptible check Ph3253 with a high *Striga* damage rating of 4.0 and high emerged *Striga* counts at 8, 10 and 12 weeks after emergence (Figure A.1). EH14 and EH 12 had the lowest *Striga* damage rating of 1.3 and 1.58 respectively but not significantly different from the herbicide resistant maize coated *Ua- Kayongo* which had a rating of 1.88 (Table A.2).

Combined 2-year Grain Yield and *Striga* Damage Rating Across 8 locations Infested with *Striga*.

The results for the combined two year grain yield and *Striga* damage rating across eight locations are shown in Table A.3. The mean grain yield was 4.7 tons/ha. Hybrid EH14 had the highest mean grain yield of 5.21 tons/ha, 45.56% above the best check, Ua Kayongo and 48.04% above the mean of the checks (Table A.3). Hybrid PhB3253 had a higher *Striga hermonthica* damage rating of 4.07 whereas EH14 had the lowest damage rating of 1.82. There were highly significant differences ($P < 0.001$) for yield and *Striga hermonthica* damage rating among the cultivars across the 8 *Striga* infested locations.

Combined 3 Year Grain Yield and *Striga* Damage Rating Across 8 Locations

The mean yield ranged from 3.48 to 4.69 tons/ha. The variety with the highest mean grain yield was EH12 whereas the variety with the lowest mean grain yield was Phb3253. The *Striga* damage rating ranged from 1.98 to 4.01 (Table A.4)). Ua Kayongo had the lowest damage rating and low emerged *Striga* (Table A.4) among the varieties over a 3-year period. This is attributed to the herbicide seed coating which oozes out of the coated seed and kills germinating *Striga* seed close to the maize seed. Hybrid EH14 was not included in the 3-year testing since it had been recommended for release in the second year of testing (Table A.5) whereas EH12 went to a full 3-year trial.

Stability Parameters for Combined Two-Year Grain Yield.

The results for the combined stability parameters for two and three years are shown in Table A.5. The stability was measured using the Eberhart and Russell statistical approach who defined both the linear (b_i) and nonlinear (S^2d_i) components as stability parameters.

Grain yield

The combined two year grain yield, *Striga* damage rating and yield stability rating is shown in Table A.5.

The mean grain yield ranged from 4.13 to 6.21 tons/ha (Table A.5). The highest yielding variety was EH14 whereas the variety with the lowest yield was the commercial hybrid check PhB3253.

Striga Damage Rating

The *Striga* damage rating ranged from 1.3 to 2.1. EH14 had the lowest mean *Striga* damage rating score of 1.3. It was followed by the herbicide resistant variety; Ua-Kayongo with a mean of 1.6. GFVC04 had the worst damage score of 2.10.

Stability Rating.

The regression coefficients ranged from 0.88 to 0.91. The variety with the highest regression coefficient was EH14.The varieties with the least regression coefficients were GFVC04 and Ua-Kayongo.

Stability parameters for combined 3-year grain yield.

Grain Yield

The mean grain yield ranged from 3.48 to 4.69 tons/ha. The highest yielding variety was EH12 whereas the variety with the lowest yield was the commercial hybrid check PhB3253 (Table A.5).

Striga Damage Rating

The *Striga* damage rating ranged from 2.4 to 4.1. Ua-Kayongo had the lowest mean damage rating score of 2.4. The experimental hybrid, EH 12 had a high damage rating of 4.02 just like the susceptible PhB3253 which had a rating of 4.10. The herbicide resistant, Ua-kayongo had the least damage score of 2.40.

Stability Rating.

The regression coefficients ranged from 0.80 to 0.94. The variety with the highest regression coefficient was EH12. The varieties with the least regression coefficients were GFVC04 and Ua-Kayongo with 0.80 and 0.83 respectively.

Discussion

Maize hybrid EH14 generally had the least *Striga* damage rating of 1.3 and highest yield of 6.21 tons/ha suggesting it was resistant to *Striga* damage. EH12 had a higher damage rating of 4.02 on a scale of 1-5 and high yield of 4.69 tons/ha suggesting it is exhibiting tolerance. Resistance to *Striga* refers to the ability of the host plant to stimulate the germination of *Striga* seeds but prevent the attachment of the parasite to its roots, or kill the attached parasite. When under infestation, the resistant genotype supports significantly fewer *Striga* plants and produces higher yield than a susceptible genotype (Dogget, 1988; *Ejeta et al.,* 1992; Hausman *et al.,* 2000; Rodenburg *et al.*, 2006). A *Striga* tolerant genotype on the other hand germinates and supports as many *Striga* plants but produces more grain yield than a susceptible genotype (Kim, 1994).

The mean grain yield of the four maize genotypes ranged from 4.13 tons/ha to 6.21 tons/ha and 3.48 tons/ha to 4.69 tons/ha in two and three year combined grain yield respectively (Table A.5). The highest grain yield of 6.21 tons/ha and 4.69 tons/ha was obtained from genotypes EH14 and EH12 respectively (Table A.5). It was emphasized that both linear (b_i) and non-linear (s^2 d_i) components of G x E interactions are necessary for judging the stability of a genotype (Eberhart and Russell, 1966). A regression coefficient (b_i) approximating 1.0 coupled with an s^2 d_i (δij) of zero indicates average stability (Eberhart and Russell, 1966). Regression values above 1.0 describe genotypes with higher sensitivity to environmental change (below average stability) and greatly specify adaptability to high yielding environments. A regression coefficient below 1.0 provides a measurement of greater resistance to environmental change (above average stability), and this increases the specificity of adaptability to low yielding environments (Wachira *et al.*, 2002). Linear regression coefficient (b_i) for the mean grain yield of a single genotype on the average yield of all genotypes in each environment resulted in regression coefficient (b_i values) ranging from 0.81 to 1.36 for grain yield. This large variation in regression coefficient explains different responses of genotypes to environmental changes (Akcura *et al.,* 2005). Genotypes with high mean yield, a regression coefficient equal to unity (b_i = 1.0) and small deviation from regression (δ_{ij} = 0) are considered stable (Finlay and Wilkinson, 1963; Eberhart and Russell, 1966). Accordingly, genotypes EH12 and EH 14 had a co-efficient of determination close to unity and lower deviation from regression. R^2 Values were as high as 0.91 and 0.94 across the *Striga* environments respectively (Table A.5) confirming their stability in *Striga* infested areas.

Genotypes EH14 and EH12 for grain yield had regression coefficients greater than one, and so were regarded as sensitive to environmental changes. They also had regression coefficients significantly greater than unity for grain yields over mean grain yield. Therefore, these genotypes are sensitive to environmental changes and can be recommended for cultivation under *Striga* conditions. Genotypes-EH14 and EH12 had insignificant regression coefficients. These genotypes could be considered widely adapted. Among these lines, genotype EH12 could be considered the most stable genotype. The varieties EH14 and EH12 have since been released for commercialization in *Striga hermonthica* infested areas in western Kenya. Genotypes Ua-Kayongo, GFVC04 and PhB3253 had significant regression coefficients, but they were less than unity (b_i = 1.0) and had lower grain yields than EH14 and EH12. These genotypes are, therefore, insensitive to environmental changes and have adapted to the poor environments.

Table A.1: Grain yield at different sites of National Performance Trials in 2012

			SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8	
NAME	**SOURCE**	**TEST STATUS**	**ALUPE**	**BUSIA**	**HOMA BAY**	**KIBOS**	**LUANDA**	**NDORI**	**NYA-HERA**	**RA-RIEDA**	MEAN
GFVC04	KARI KIBOS	CHECK	6.95	4.43	5.78	6.64	3.85	4.18	4.61	3.55	5.53
MASENO-EH12	MASENO UNIVERSITY	CANDIDATE	7.58	7.09	8.43	9.13	5.20	3.30	9.96	.	7.49
MASENO EH-14	MASENO UNIVERSITY	CANDIDATE	8.49	8.04	7.79	8.35	6.24	3.52	9.66	4.64	7.78
PHB3253	PIONEER SEEDCO	CHECK	4.73	4.01	6.77	6.43	3.80	2.21	6.08	3.25	5.15
UA-KAYONGO	CIMMYT	CHECK	5.86	3.68	6.41	5.00	4.89	2.36	9.01	2.60	5.17
		MEAN	6.39	5.21	6.99	7.23	4.63	2.83	7.95	3.38	5.73
		P-VALUE	0	0	0	0	0.01	0.07	0.07	0.19	0
		CV (%)	14.94	19.72	11.49	12.39	16.14	22.7	27.6	26.79	13.69
		R^2	0.84	0.77	0.92	0.84	0.88	0.64	0.71	0.64	0.849
		LSD (5%)	1.74	1.72	1.46	1.69	1.36	1.18	4.13	1.75	1.052

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Key: CIMMYT-International Maize and Wheat Improvement Centre

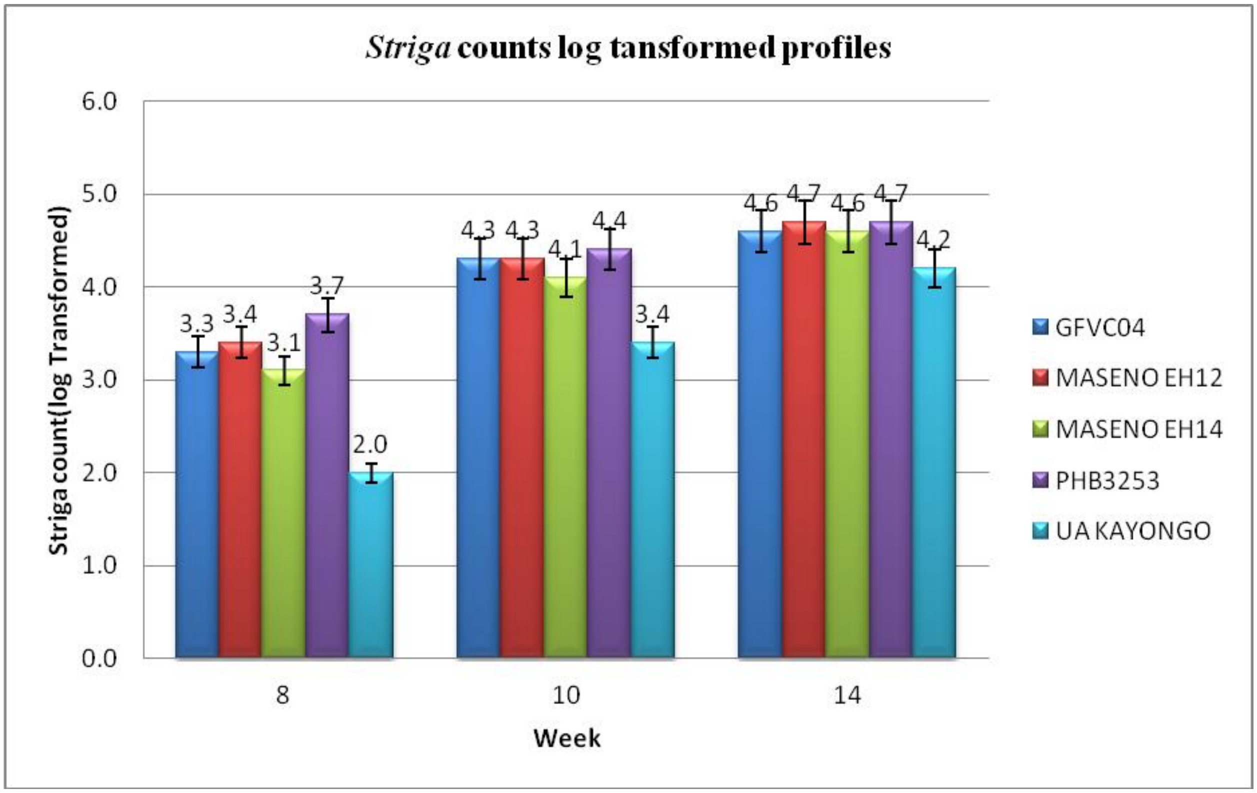
Table A.2: Maize *Striga* kit 2012 NPT mean grain yield (t/ha) and *Striga* damage rating (SDR)

Name	TYPE	SOURCE	MEAN GY (t/ha)	% ABOVE BEST CHECK	% ABOVE MEAN OF CHECKS	SDR Scale (1-5)
EH14	HYBRID	MSU	7.78	50.54	51.17	1.33
EH12	HYBRID	MSU	7.49	44.87	45.38	1.58
GFVC04	OPV	KARI KIBOS	5.53			2.08
UA KAYONGO	HYBRID	CIMMYT	5.17			1.88
PHB3253	HYBRID	PIONEER SEED	5.15			4.02
		Mean	5.73			2.18
		P-Value	0.00			0.00
		CV (%)	13.69			25.75
		R^2	0.85			0.84
		LSD (5%)	1.05			0.76

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Key: OPV-Open pollinated maize variety; MSU-Maseno University; CIMMTY-International Maize and Wheat Improvement Centre; KARI-Kenya Agricultural Research Institute; SDR-*Striga* Damage Rating, CV=coefficient of variation; R^2=coefficient of determination; LSD=Least significant difference.

Figure A.1: 2012 *Striga* counts log transformed profiles



Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Table A.3: Maize *Striga* Kit 2012: Combined 2-Year Grain yield and *Striga hermonthica* damage rating.

Name	TYPE	SOURCE	TEST STATUS	MEAN GY (t/ha)	% ABOVE BEST CHECK	% ABOVE MEAN OF CHECKS	SDR Scale (1-5)
EH14	HYBRID	MSU	CANDIDATE	6.21	45.56	48.04	1.82
UA KAYONGO	HYBRID	CIMMYT	CHECK	4.27			2.44
GFVC04	OPV	KARI KIBOS	CHECK	4.20			2.49
PHB3253	HYBRID	PIONEER SEED	CHECK	4.13			4.07
		Mean		4.70			2.71
		P-Value		0.00			0.00
		CV (%)		18.58			31.06
		R^2		0.87			0.85
		LSD (5%)		0.52			0.60

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Key: OPV-Open pollinated Maize Variety; MSU-Maseno University; CIMMYT-International Maize and Wheat Improvement Centre; KARI-Kenya agricultural Research Institute; GY-Grain yield; SDR-*Striga* Damage Rating, CV=coefficient of variation; R^2=coefficient of determination; LSD=Least significant difference.

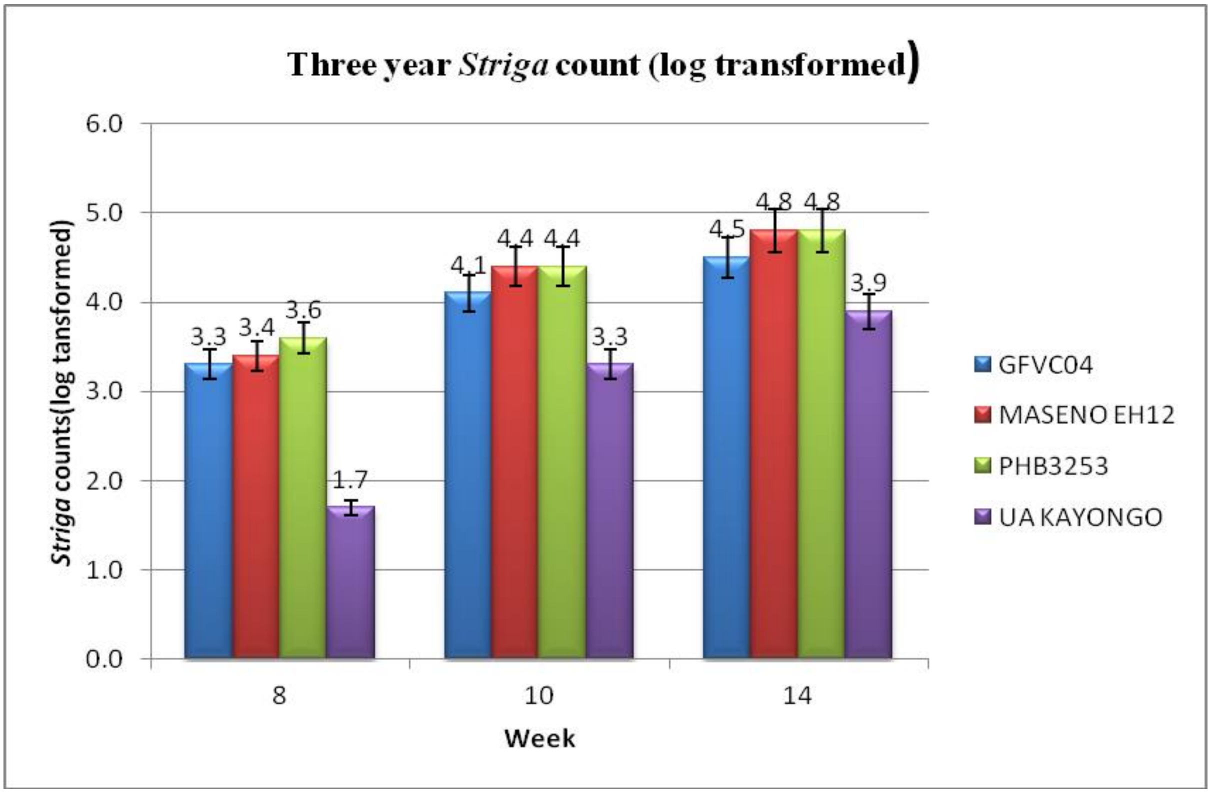
Table A.4: Combined 3 year grain yield (t/ha) and *Striga hermonthica* damage ratings.

Name	TYPE	SOURCE	TEST STATUS	DUS YRS	MEAN GY (t/ha)	% ABOVE BEST CHECK	% ABOVE MEAN OF CHECKS	SDR Scale (1-5)
EH12	HYBRID	MSU	CANDIDATE	0	4.59	17.49	23.17	2.45
UA KAYONGO	HYBRID	CIMMYT	CHECK	2	3.98			1.98
GFVC04	OPV	KARI KIBOS	CHECK	2	3.95			2.40
PHB3253	HYBRID	PIONEER SEED	CHECK	2	3.48			4.01
		Mean			4.03			2.71
		P-Value			0.00			0.00
		CV (%)			22.32			30.79
		R^2			0.85			0.82
		LSD (5%)			0.52			0.48

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Key: MU-Maseno University; CIMMYT-International maize and Wheat Improvement Centre; KARI-Kenya Agricultural Research Institute; OPV-Open pollinated Variety; DUS-distinctiveness, Uniformity and Stability tests; SDR-*Striga* Damage Rating; CV=coefficient of variation; R^2=coefficient of determination; LSD=Least significant difference.

Figure A.2: 3 year *Striga* counts (log transformed) profiles



Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Figure A.5: Two and three years Stability parameters for Grain yields and *Striga* damage rating

					Stability Estimate				
					S^2d_i		b_i		
NPT years	Variety	Source	Yield (t/ha)	R^2	Estimate	P-Value	Estimate	P-value	SDR
2	EH14*	Maseno University	6.21	0.91	0.58	0.71	1.26	0.03	1.30
2	Ua-Kayongo	CIMMYT	4.27	0.83	0.67	0.60	0.96	0.74	1.60
2	GFVC04	KARI	4.20	0.82	0.50	0.82	0.81	0.07	2.10
2	PhB3253	Pioneer Seeds	4.13	0.88	0.39	0.92	0.89	0.23	1.90
3	EH12$^{\infty}$	Maseno University	4.69	0.94	0.41	0.96	1.36	0.00	4.02
3	Ua-Kayongo	CIMMYT	3.98	0.83	0.55	0.84	0.89	0.19	2.40
3	GFVC04	KARI	3.95	0.80	0.56	0.83	0.82	0.05	2.50
3	PhB3253	Pioneer Seeds	3.48	0.87	0.45	0.93	0.95	0.53	4.10

Source: Kenya Plant Health Inspectorate Services (KEPHIS) National Performance Trials Report 2012.

Key: NPT-National Performance Trials; SDR-*Striga* damage rating (Scale 1-5) at 12 weeks after planting.*, b_i (regression coefficient-linear component of stability), S^2d_i (deviation from regression-non linear components of stability), ∞Variety released by the National Variety release Committee (NVRC) in 2012 and 2013 respectively.

APPENDIX B: Mixed Effects Model: YIELD versus SEASON, GENOTYPE, ENVIRONMENT

Method

Variance estimation	Restricted maximum likelihood
DF for fixed effects	Kenward-Roger

Factor Information

Factor	Type	Levels	Values
SEASON	Random	2	2011, 2012
GENOTYPE	Fixed	9	DK8031, EH11M, EH11SNS (, EH12, EH14, EH21H, EH21S, H513, PHB3253
ENVIRONMENT*GENOTYPE)	Random	18	NS(DK8031), S(DK8031), NS(EH11M), S(EH11M), NS (EH11S), S(EH11S), NS (EH12), S(EH12), NS(EH14), S(EH14), NS(EH21H), S(EH21H), NS(EH21S), S(EH21S), NS(H513), S(H513), NS(PHB3253), S(PHB3253)

Variance Components

Source	Var	% of Total	SE Var	Z-Value	P-Value
SEASON	3.116560	48.93%	4.526211	0.688558	0.246
ENVIRONMENT*GENOTYPE)	1.743214	27.37%	1.205808	1.445680	0.074
Error	1.510012	23.71%	0.517930	2.915476	0.002
Total	6.369786				

-2 Log likelihood = 119.031968

Tests of Fixed Effects

Term	DF Num	DF Den	F-Value	P-Value
GENOTYPE	8.00	9.00	1.35	0.329

Model Summary

S	R-sq	R-sq(adj)
1.22883	83.65%	78.81%

Coefficients

Term	Coef	SE Coef	DF	T-Value	P-Value
Constant	6.034444	1.302716	1.12	4.632201	0.115
GENOTYPE					
DK8031	-0.399444	1.053717	9.00	-0.379081	0.713
EH11M	1.425556	1.053717	9.00	1.352883	0.209
EH11S	0.375556	1.053717	9.00	0.356410	0.730
EH12	0.183056	1.053717	9.00	0.173724	0.866
EH14	1.230556	1.053717	9.00	1.167823	0.273
EH21H	0.433056	1.053717	9.00	0.410979	0.691
EH21S	0.880556	1.053717	9.00	0.835666	0.425
H513	-1.779444	1.053717	9.00	-1.688731	0.126

Marginal Fits and Diagnostics for Unusual Observations

Obs	YIELD	Fit	Resid	Std Resid	
35	8.310000	4.255000	4.055000	2.148423	R
36	7.660000	3.685000	3.975000	2.106037	R

R Large residual

Conditional Fits and Diagnostics for Unusual Observations

Obs	YIELD	Fit	Resid	Std Resid	
11	4.780000	6.959150	-2.179150	-2.394455	R

R Large residual

Conditional Means

Term	Fitted Mean	SE Mean	DF	T-Value	P-Value
SEASON					
2011	4.80260	0.42383	14.4416	11.33	0.000
2012	7.26629	0.42383	14.4416	17.14	0.000
GENOTYPE					
DK8031	5.63500	1.67553	2.8826	3.36	0.046
EH11M	7.46000	1.67553	2.8826	4.45	0.023
EH11S	6.41000	1.67553	2.8826	3.83	0.034
EH12	6.21750	1.67553	2.8826	3.71	0.036
EH14	7.26500	1.67553	2.8826	4.34	0.025
EH21H	6.46750	1.67553	2.8826	3.86	0.033
EH21S	6.91500	1.67553	2.8826	4.13	0.028
H513	4.25500	1.67553	2.8826	2.54	0.088
PHB3253	3.68500	1.67553	2.8826	2.20	0.119

ENVIRONMENT(GENOTYPE)					
NS(DK8031)	6.23509	1.48297	1.8775	4.20	0.058
S(DK8031)	5.03491	1.48297	1.8775	3.40	0.084
NS(EH11M)	8.14732	1.48297	1.8775	5.49	0.036
S(EH11M)	6.77268	1.48297	1.8775	4.57	0.050
NS(EH11S)	6.67516	1.48297	1.8775	4.50	0.052
S(EH11S)	6.14484	1.48297	1.8775	4.14	0.060
NS(EH12)	6.70769	1.48297	1.8775	4.52	0.051
S(EH12)	5.72731	1.48297	1.8775	3.86	0.067
NS(EH14)	7.46736	1.48297	1.8775	5.04	0.042
S(EH14)	7.06264	1.48297	1.8775	4.76	0.047
NS(EH21H)	6.64718	1.48297	1.8775	4.48	0.052
S(EH21H)	6.28782	1.48297	1.8775	4.24	0.057
NS(EH21S)	7.21854	1.48297	1.8775	4.87	0.045
S(EH21S)	6.61146	1.48297	1.8775	4.46	0.052
NS(H513)	5.73430	1.48297	1.8775	3.87	0.067
S(H513)	2.77570	1.48297	1.8775	1.87	0.210
NS(PHB3253)	5.09103	1.48297	1.8775	3.43	0.082
S(PHB3253)	2.27897	1.48297	1.8775	1.54	0.272

APPENDIX C: GENERATION MEANS ANALYSIS

Striga Count 8

Generations	Means	Variance	Sample Size	Var of Mean	Stand. Error
P_1	0.000	0.000	15	0.000	0.000
P_2	3.133	2.740	15	0.091	0.427
F_1	0.133	0.120	15	0.004	0.089
F2	1.350	1.692	60	0.014	0.168
BC1P1	0.300	0.214	30	0.004	0.084
BC_1P_2	1.450	0.862	30	0.014	0.169

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	-0.467	0.135	-3.457
B	0.367	0.391	0.938
C	-2.000	0.577	-3.467
D	0.950	0.273	3.485

6-parameter model

Component	Estimate	Stand. Error	t-Calculated		
M	1.350	0.119	11.370		
D	-1.150	0.134	-8.590		
H	-3.333	0.569	-5.856		
I	-1.900	0.545	-3.485		
J	0.833	0.404	2.064		
L	1.800	0.787	2.287		

Components of heterosis	0.783
Standard Error of heterosis	1.122
Calculated value of t	0.698
Heterosis	-3.000
Inbreeding Depression	-1.217
Inbreeding Effect (%)	-912.500

Potence Ration (h1) in F1	0.915
Potence Ration (h2) in F2	0.277
Number of Effective genes (Burton's Formula)	1.240
Number of Effective genes (Castle-Wright's Formula)	0.781

***Striga Count* 10**

Generations	**Means**	**Variance**	**Sample Size**	**Var of Mean**	**Stand. Error**
P1	0.367	0.516	15	0.017	0.185
P2	6.167	9.937	15	0.331	0.814
F1	1.500	2.534	15	0.084	0.411
F2	1.950	1.611	60	0.013	0.164
BC1P1	0.683	0.390	30	0.006	0.114
BC1P2	2.833	4.548	30	0.076	0.389

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	0.500	0.357	1.399
B	2.000	0.848	2.359
C	1.733	0.949	1.826
D	0.383	0.369	1.039

6-parameter model

Component	Estimate	Stand. Error	t-Calculated
M	1.950	0.116	16.830
D	-2.150	0.287	-7.495
H	-2.533	0.846	-2.995
I	-0.767	0.738	-1.039
J	1.500	0.823	1.822
L	3.267	1.489	2.194

Components of heterosis	-0.650
Standard Error of heterosis	1.887
Calculated value of t	-0.345
Heterosis	-4.667
Inbreeding Depression	-0.450
Inbreeding Effect (%)	-30.000

Potence Ration (h1) in F1	0.609
Potence Ration (h2) in F2	0.908
Number of Effective genes (Burton's Formula)	-8.957
Number of Effective genes (Castle-Wright's Formula)	-4.553

JOINT SCALING TEST

Component	Estimate	Stand. Error	t-Calculated
M	2.821	0.189	14.888
D	2.493	0.172	14.458
H	-1.728	0.310	-5.566

The Chi-square value is = 6.16765319190904

***Striga* Damage Rating at** 8 weeks after crop emergence **(**SDR**8)**

Generations	Means	Variance	Sample Size	Var of Mean	Stand. Error
P_1	1.067	0.064	15	0.002	0.066
P_2	2.733	0.478	15	0.016	0.179
F_1	1.367	0.240	15	0.008	0.127
F_2	1.767	0.792	30	0.013	0.162
BC1P1	1.733	0.606	30	0.010	0.142
BC1P2	1.100	0.125	30	0.002	0.065

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	-1.033	0.225	-4.597
B	1.900	0.180	10.571
C	-0.533	0.511	-1.043
D	0.700	0.255	2.746

6-parameter model

Component	Estimate	Stand. Error	t-Calculated
M	1.767	0.115	15.376
D	0.633	0.110	5.738
H	-1.933	0.522	-3.704
I	-1.400	0.510	-2.746
J	2.933	0.259	11.347
L	2.267	0.675	3.356

Components of heterosis	-1.700
Standard Error of heterosis	1.000
Calculated value of t	-1.699
Heterosis	-1.367
Inbreeding Depression	-0.400
Inbreeding Effect (%)	-29.268

Potence Ration (h1) in F1	0.640
Potence Ration (h2) in F2	0.320
Number of Effective genes (Burton's Formula)	1.211
Number of Effective genes (Castle-Wright's Formula)	0.629

JOINT SCALING TEST

Component	Estimate	Stand. Error	t-Calculated
M	1.416	0.050	28.145
D	0.267	0.049	5.493
H	-0.271	0.107	-2.533

The Chi-square value is = 177.638726345851

***Striga* damage rating at 10 weeks after crop emergence (SDR10)**

Generations	Means	Variance	Sample Size	Var of Mean	Stand. Error
P1	1.100	0.093	15	0.003	0.079
P2	3.600	0.524	15	0.017	0.187
F1	1.733	0.409	15	0.014	0.165
F2	2.750	1.550	60	0.013	0.161
BC1P1	1.283	0.206	30	0.003	0.083
BC1P2BC1P2	2.100	0.193	30	0.003	0.080

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	0.267	0.175	1.527
B	1.133	0.210	5.403
C	-2.833	0.531	-5.337
D	2.117	0.242	8.763

6-parameter model

Component	Estimate	Stand. Error	t-Calculated
M	2.750	0.114	24.193
D	-0.817	0.082	-10.006
H	-4.850	0.502	-9.658
I	-4.233	0.483	-8.763
J	0.867	0.217	3.988
L	5.633	0.623	9.039

Components of heterosis	-2.633
Standard Error of heterosis	0.938
Calculated value of t	-2.806
Heterosis	-1.867
Inbreeding Depression	-1.017
Inbreeding Effect (%)	-58.654

Potence Ration (h1) in F1	0.493
Potence Ration (h2) in F2	-0.640
Number of Effective genes (Burton's Formula)	1.462
Number of Effective genes (Castle-Wright's Formula)	0.685

JOINT SCALING TEST

Component	Estimate	Stand. Error	t-Calculated
M	2.158	0.058	37.356
D	1.028	0.052	19.735
H	-0.616	0.118	-5.229

The Chi-square value is = 97.9249754900616

EAR HEIGHT (EH) IN CENTIMETERS

Generations	Means	Variance	Sample Size	Var of Mean	Stand. Error
P_1	60.267	164.133	15	5.471	3.308
P_2	36.100	130.369	15	4.346	2.948
F_1	50.900	156.093	15	5.203	3.226
F_2	42.100	412.931	60	3.441	2.623
BC1P1	37.467	66.524	30	1.109	1.489
BC1P2BC1P2	34.517	47.406	30	0.790	1.257

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	36.233	3.887	9.322
B	17.967	3.565	5.040
C	29.767	9.257	3.216
D	12.217	3.958	3.087

6-parameter model

Component	Estimate	Stand. Error	t-Calculated
M	42.100	1.855	22.695
D	2.950	1.378	2.141
H	-21.717	8.385	-2.590
I	-24.433	7.915	-3.087
J	-18.267	4.173	-4.378
L	78.633	10.773	7.299

Components of heterosis	51.250
Standard Error of heterosis	15.841
Calculated value of t	3.235
Heterosis	14.800
Inbreeding Depression	8.800
Inbreeding Effect (%)	17.289

Potence Ration (h1) in F1	0.225
Potence Ration (h2) in F2	-1.007
Number of Effective genes (Burton's Formula)	0.732
Number of Effective genes (Castle-Wright's Formula)	0.284

JOINT SCALING TEST

Component	Estimate	Stand. Error	t-Calculated
M	41.214	1.343	30.683
D	-7.161	1.034	-6.928
H	-4.074	2.608	-1.562

The Chi-square value is = 92.4068328599184

PLANT HEIGHT (PH) IN CENTIMETERS

Generations	Means	Variance	Sample Size	Var of Mean	Stand. Error
P_1	134.433	991.013	15	33.034	8.128
P_2	82.300	223.321	15	7.444	3.859
F_1	109.767	594.530	15	19.818	6.296
F_2	85.850	723.860	60	6.032	3.473
BC1P1	96.817	191.034	30	3.184	2.523
BC1P2	84.733	112.470	30	1.875	1.936

Scaling Test

Component	Estimate	Stand. Error	t-Calculated
A	50.567	8.099	6.244
B	22.600	5.896	3.833
C	92.867	14.706	6.315
D	-9.850	5.403	-1.823

6-parameter model

Component	Estimate	Stand. Error	t-Calculated
M	85.850	2.456	34.955
D	12.083	2.249	5.373
H	21.100	12.111	1.742
I	19.700	10.805	1.823
J	-27.967	7.792	-3.589
L	53.467	17.239	3.101

Components of heterosis	45.850
Standard Error of heterosis	23.784
Calculated value of t	1.928

Heterosis	27.467
Inbreeding Depression	23.917
Inbreeding Effect (%)	21.789

Potence Ration (h1) in F1	0.054
Potence Ration (h2) in F2	-1.728
Number of Effective genes (Burton's Formula)	7.602
Number of Effective genes (Castle-Wright's Formula)	2.627

JOINT SCALING TEST

Component	Estimate	Stand. Error	t-Calculated
M	95.140	2.413	39.428
D	-14.987	1.812	-8.272
H	-5.670	4.668	-1.215

The Chi-square value is = 48.99450333950