UNIVERSITY OF CAPE COAST

DIALLEL ANALYSIS OF MAIZE INBRED LINES (*Zea mays*) FOR RESISTANCE TO STRIGA (*Striga hermonthica*)

BY

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DECLARATION

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

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ABSTRACT

Striga hermonthica (Del.) Benth. infest millions of hectares of land under cereals in sub-Saharan Africa, threatening food security. One of the major crops threatened is maize (*Zea mays* L.), a staple food for many Ghanaians.

The objectives of this study were to investigate the combining ability and heritability of *Striga*-resistant maize inbred lines for the selection of superior lines for hybridization. A diallel cross involving ten (10) maize inbred lines was made to produce forty-five (45) F_1 single crosses excluding reciprocals. All 45 F_1's with their parents were evaluated under artificially infested *Striga* fields at the Savanna Agricultural Research Institute (SARI) trial farms at Nyankpala using the randomized complete block design.

The genotype means were partitioned into general combining ability (gca) and specific combining ability (sca) effects according to Griffing method 2 model 2 diallel. The study found gca and sca effects to be significant ($p < 0.01$) for grain yield, days to flowering, plant height and *Striga* emergence count (STEC). Both additive and non-additive gene actions were thus responsible for these traits. The ratios of gca to sca components were relatively low, from 0.09 (STEC) to 0.46 (days to 50% silking), indicating that sca was important in predicting the F_1 hybrid performance.

Heritability values for grain yield, days to flowering, plant height and STEC ranged from 0.72 for STEC to 0.98 for plant height, indicating that these traits can easily be transferred from the inbred lines to the single-cross hybrids. Inbred lines TZISTR 101, TZISTR 108 and TZISTR 102 were found to have

good combining abilities for *Striga* resistance and may be exploited for single-cross hybrid development.

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DEDICATION

This work is dedicated to my parents, family and all other people who educate themselves or their children under extreme difficulties.

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CHAPTER ONE

1.1 INTRODUCTION

Maize (*Zea mays*) is a member of the grass family, Gramineae, to which all the major cereals belong. Cultivated maize is a fully domesticated plant that is unable to survive without human husbandry. It has the highest grain yield potential of all the cereals (Dowswell *et al.*, 1996).

Maize is said to have originated from Mexico and Central America, from where it migrated to the rest of Latin America, the Caribbean, the United States, Canada and then to Asia and Africa. It is grown from latitude 58°N without interruption through the temperate, sub-tropical and tropical regions of the world to latitude 40°S (Hallauer and Miranda Filho, 1988). It tolerates a wide range of environmental conditions but grows well in warm sunny climates with adequate moisture (Purseglove, 1992). Among the cereal crops of the world, it ranks third to wheat and rice in terms of production (Ochse *et al.*, 1996). Among the developing economies, maize ranks first in Latin America and Africa but third after rice and wheat in Asia (Dowswell *et al.*, 1996). About 140 million hectares of maize is grown globally with a production of 600 million tons (CIMMYT, 2000).

Maize has been put to a wide range of uses than any other cereal as a human food, a feed grain, a fodder crop, and for hundreds of industrial purposes because of its broad global distribution, its diverse grain type, and its wide range of biological and industrial properties. It serves as primary staple food for majority of people in the developing world, and as livestock feed (especially poultry and pigs) in both the developing and developed worlds. It is also the source of an increasing number of important industrial products. On the domestic market, maize is one of the most popular food crops and an important source of income to a great majority of Ghanaian farmers and others in the maize industry. It is the primary staple in the areas of production and constitutes the basis of several local food preparations. It is also the main feedstuff for poultry and other livestock, and an important raw material in the brewery industry.

In terms of production and consumption, maize is the most important cereal in Ghana (PPMED, 1999). It is grown almost everywhere, from the coastal belt across the forest transition, Guinea savannah to the north-eastern corner of the country. The crop is cultivated by 1.75 million (64%) of the 2.74 million households operating farms in Ghana covering a total area of about 713,000 hectares with production levels averaging 1.5 metric tons (mt) per hectare (FASDEP, 2002). The achievable yield however, is 5.0 mt/ha and the preference of the Ministry of Food and Agriculture (MOFA) to arrive at this is to increase production through the application of improved technology including use of improved/hybrid seeds, rather than area expansion.

The productivity of maize is menaced by the threat of low yields as a result of poor soils, pest/disease damage, erratic rainfall, the reliance on low yielding planting materials and most importantly in the Northern regions of the country, the infestation of farmers' fields by the parasitic weed of the genus *Striga* (Scrophulariaceae) generally known as witch weeds. These are angiosperm root hemi-parasites of cereals and legumes throughout the world.

Striga species are widely distributed in the savannah regions of Africa. It is the largest biological constraint to food production in Africa. It is reported to infest an estimated 20 to 40 million hectares of farmlands cultivated by farmers throughout sub-Saharan Africa (CIMMYT, 2000). In Ghana the witch weeds occur in both the coastal and guinea savannah zones (Laing, 1984, cited by Aflakpui *et al.*, 1997). According to Kroschel *et al.*, (1999) *Striga* infestation is widespread in Northern Ghana and none of the districts is being free of *Striga*. The most widespread is *S. hermonthica* with infestation levels as high as 98%.

Yield losses due to *Striga* damage range from 20 to 80% (CIMMYT, 2004). Losses of up to 100% occur when farmers abandon the fields as they become unproductive due to *Striga* infestation (Kroschel *et al.*, 1999). Annually *Striga* damage to crops accounts for an estimated US $7 billion in sub-Saharan Africa, and affects the welfare and livelihood of over 100 million people (CIMMYT, 2004). Apart from the direct yield losses other socio-economic losses include locating farms at increasely longer distances from settlements in an effort to avoid *Striga*-infested fields, shifting cultivation, farm abandonment, or change of cropping pattern.

The bulk of the maize varieties grown in the Northern Region are either susceptible to *Striga* or low yielding. The low average yields due to *Striga*-infestation leave the farmers in perpetual hunger and poverty. Consequently, majority of households cannot ensure food security or quality standard of living. As a result they cannot enrol and sustain their wards in school.

Several *Striga* control measures that have been suggested include hand pulling, crop rotation, fallowing, intercropping, nitrogen fertilization, chemical use and the use of resistant/tolerant varieties. The use of resistant crop species seems the cheapest, most affordable, most feasible and potentially durable method for the use of the African farmer to reduce losses to *Striga*. The development of resistant/tolerant lines of susceptible crops will thus constitute an important, practical and reliable approach to solving the *Striga* problem.

Developing and using *Striga*-resistant maize seed (hybrids) have unlimited opportunities for augmenting maize output growth and productivity of the maize farmers of the north in particular and the country as a whole. Use of *Striga*-resistant hybrid maize seed could result in significant shifts in the yield frontier with economically exploitable yield levels and enhance productivity in the maize industry. This could create employment and improve incomes of the poor, create food security, stimulate development in the rest of the economy and ensure prosperity through stimulating exports of maize and an increased likelihood of political stability in the country.

Several types of hybrids are possible in maize; however, the most common ones used for commercial production are derived from inbred lines (Nass and Miranda Filho, 1995). Not all combinations of inbreds will produce superior single crosses. The inbred combinations must first be tested for their combining ability to find which combinations may be useful for the production of *Striga*-

resistant hybrid seed. The performance of the hybrid is related to the general combining ability (gca) and the specific combining ability (sca) of the inbred lines involved in the cross. Determining general and specific combining abilities will thus allow for selection of superior *Striga*-resistant inbred lines for the development of hybrids.

The main objective of the study was therefore to determine the performance of *Striga*-resistant maize inbred lines for the selection of superior lines for hybridization. The specific objectives were to:

- Determine the general combining ability (gca) of ten *Striga*-resistant maize inbred lines
- Determine the specific combining ability (sca) of ten *Striga*-resistant maize inbred lines
- Identify suitable inbred lines to be used for single cross hybrid development.
- Estimate heritability values in the broad and narrow sense.

The concept of combining ability is becoming increasely important in plant and animal breeding. It is especially useful in connection with "testing" procedures, in which it is desired to study and compare the performances of pure lines in hybrid combination. In the light of this observation, the following hypotheses form the focus of this study.

- H_o (1): There are no genotypic differences among the F_1 genotypes
- H_0 (2): There are no differences in combining ability in the *Striga*-resistant maize inbred lines.

CHAPTER TWO

LITERATURE REVIEW

2.1 Biology and Behaviour of *Striga*

The genus *Striga* belongs to the dicotyledonous family Scrophulariaceae and order Tubiflorae. Members of this genus are obligate annual hemiparasites, which are chlorophyllous but require a host to complete the life cycle (Musselman, 1987). *Striga* spread exclusively by seed. Two different, yet very successful, patterns – autogamy and allogamy – are involved in seed production within this genus (Kim, 1988). *Striga* flowers and sheds seeds within the life cycle of its host. The seeds are tiny (< 0.3 mm) and a single plant can produce up to 50,000 seeds, which mature at different times and can remain dormant and viable in the soil for up to 20 years (Lagoke *et al.*, 1988; CIMMYT, 2004).

Seeds require an after ripening phase; as such, they are not all pre-conditioned for germination at the same time (Kroschel *et al.*, 1999). Germination of *Striga* is temperature dependent, with 30^0C as the minimum threshold and 35^0C as the optimum (Carson, 1986). Chemical exudates from young host roots triggers germination under optimum soil temperature and moisture conditions (Sallah *et al.*, 2002). Immediately the host plants establish, germination initiates and only seeds exposed to the chemical stimulant of the host roots germinate (Kroschel *et al.*, 1999). The majority of the seed population is not reached by the stimulants and stays viable in the ground until the next growing season. The radicle of the

Striga seedling, in contact with the host root, is transformed into a haustorium followed by penetration and attachment to the host root and, finally, emergence from the soil (Sallah *et al.*, 2002). Thus, the parasitic nature of *Striga* also involves dependency on the host for developmental signals. The necessity of such a signal ensures that a suitable host is available and close enough to be reached by a germ tube and formation of the haustorium. Haustorium formation and host finding are thus very sensitive stages in *Striga* development. Like all parasitic seed plants, the haustorium represents the physical and morphological contact between the host and the *Striga*. Its primary task is the supply of water and nutrients (Kroschel *et al.*, 1999). Haustoria penetrate the host tissue until they reach the vascular system in order to have access to nutrients, water and organic substances. Attachment may occur as early as two weeks after germination of maize, depending on the size of the *Striga* seed bank in the soil and the exudation of germination stimulant by maize roots in the vicinity of *Striga* seeds (CIMMYT, 2004).

2.2 Ecology and Distribution of *Striga*

2.2.1 Ecology

Relatively high temperatures, of between 30^0C and 35^0C are reported to be optimal for conditioning, germination and growth of *S. hermonthica* (Carson, 1986). Species like *S. asiatica* has been found to germinate, develop and mature on sorghum at a mean daily temperature of 22°C (Patterson, 1990). In addition, dormant seed of this species is known to survive freezing winter temperatures as low as -7°C or even -15°C for 49 days. According to Kust (1963), germination of freshly harvested seed of *S. asiatica* could be induced by storage at 31°C for 6 weeks, 27°C for 24 weeks, 42°C for 32 weeks or -17°C for 40 weeks. *S. hermonthica* is not expected to tolerate such low temperatures since it rarely occurs outside the tropics. Generally, however, both *S. hermonthica* and *S. asiatica* are known to thrive best under conditions of erratic or limited rainfall and may be suppressed by irrigation (Andrew, 1945).

There are conflicting reports as to whether soil type influences the growth and development of *Striga*. *S. hermonthica* occurs on a wide range of soil types from heavy cracking clays to very light sandy soils. According Kroschel *et al.*, (1999) *S. hermonthica* can germinate and develop in all soil types. The influence of soil fertility on *Striga* species and other genera in the family Scrophulariaceae has not been well documented. In general, it is true that for both *S. hermonthica* and *S. asiatica* their growth and development is favoured by low soil fertility, particularly nitrogen level (Andrews, 1945; Ramaiah and Parker, 1982). Lagoke *et al.*, (1991) have reported that the occurrence of *Striga* and their virulence on host crops has long been associated with low soil fertility. Results obtained in Ghana and Togo has shown that infestation of *S. hermonthica* was positively correlated with continuous land use and with stone and gravel content, while there was negative correlation with organic matter content (Vogt *et al.*, 1991). It has also been demonstrated that *Striga* may be suppressed to some degree by increased application of nitrogenous fertilizer (Parker and Riches, 1993).

2.2.2 Distribution

Striga is found mainly in the tropical arid and semi-arid zones of Africa, Europe and Asia, with an annual rainfall of 400 – 1000 mm and where the dominant vegetation is natural savannah or grassland. *S. asiatica* is the most widespread species, occurring in Africa, Asia, Australia and New Zealand (Bharathalakshmi and Jayachandra, 1979) and in the United States of America (Eplee, 1981, 1982 and Eplee and Herbaugh, 1979). *S. hermonthica* occurs mainly in Africa and it is distributed throughout the savannah regions of Africa (Kroschel *et al.*, 1999). This species is thought to originate from the Nuba Mountains of Sudan and adjacent areas of Ethiopia, which are widely recognised as centres of origin based on its common occurrence there on wild grass hosts (Musselman and Hepper, 1986).

Out of the 30 *Striga* species listed by Musselman (1987) only four species are found in Asia and America while 23 species are found in Africa, of which 16 occur in West Africa (Kroschel, 1999). However, the economically important species include *S. asiatica* (L.) Kuntze [which had been re-classified as *S. lutea* by electrophoresis at IITA, Ibadan (Olakojo and Olaoye, 2003)], *S. hermonthica* (Del.) Benth., *S. aspera* (Willd.) Benth., *S. forbesii* Benth., (all infect cereals) and *S. gesnerioides* (Willd.) Vatke., which infects cowpea (Kim and Adetimirin, 1997). Among these, *S. hermonthica* is the most damaging (Ramaiah, 1991) and most widespread (Lagoke *et al.*, 1991). According to Badu-Apraku and Fakorede (2001), three species of *Striga* affect maize in Western and Central Africa, namely, *S. hermenthica, S. asiatica* and *S. aspera, S. hermonthica* being the most important

Striga is known to seriously affect two-thirds of the 73 million hectares devoted to cereal crop production in Africa (Lagoke, 1988). Two-thirds of the 600,000 hectares cultivated in northern Cameron is reported to be severely infested by *Striga* (Njinyam, 1985) whilst 75% of the fields used for cereal cropping in The Gambia carried *Striga* infestation (Carson, 1986). According to Tchemi (1986), *S. asiatica* and *S. hermonthica* had infested over 200,000 ha of maize and sorghum fields in Togo. Reports from an investigation carried out in eleven regional development organisations in Burkina Faso indicate that *Striga* infestations occurred throughout the country – both on research and farmers fields (Ouedraogo 1986). In Benin, Guinea, Mali, Cote d'Ivoire, Senegal and Nigeria, 20% to 80% of lands used for cereal and legumes grain cultivation are reported to carry *Striga* infestation (Lagoke *et al.*, 1988)

In Ghana *Striga* is important in the northern savannah, which has a single rainy season and annual rainfall ranging from 800 mm to 1200 mm (Nyarko, 1986). It is reported to be a serious problem in this part of the country, covering approximately all areas above latitude $9^0 30^l$ N which represents approximately 57% of the total land area (Nyarko, 1986). *Striga* species of importance in this area are *S. hermonthica and S. asiatica* – attacking sorghum, millet, maize rice and sugar cane - and *S. gesnerioides* – attacking cowpea and tobacco (Kroschel and Sauerborn, 1994).

The distribution and infestation intensity of *Striga* in agro-ecosystems is related to environmental and anthropogenic factors (Kroschel, 1998). The parasite thrives under conditions of intensifying land use (IITA, 1993). *Striga* infestation can thus be said to be a consequence of the following practices: monocropping with cereals, shortened fallow periods, reduced decomposition of *Striga* seed in the ground and declining soil fertility. From studies conducted in Togo on effect of population density and intensified agriculture on *Striga* infestation, Honisch (1989) reported significantly higher percentage *Striga* infestation of fields in areas with a high population density.

2.3 Damage by Striga and Extent of Losses

Striga is the largest biological constraint for food production in Africa. It infests an estimated 20 to 40 million hectares of farmlands cultivated by poor farmers throughout sub-Saharan Africa (CIMMYT, 2004). The grain production in Africa is potentially at risk on 44 million hectares of land (Sauerborn, 1991). *S. hermonthica* has a potential of invading 48 million hectares of arable land in Africa alone (Watson and Kroschel, 1998). The Food and Agriculture Organisation (FAO) has estimated that two-thirds of cultivated savannah areas are infested with *S. hermonthica* that can cripple cereal production (maize, sorghum and millet) by taking over whole fields of the crop (IITA, 1993).

Striga is not just an unwanted weed like other weeds which compete with food crops in fields for water and nutrients but as a root parasite, it literally sucks the life out of the crop on which it germinates. In addition to draining minerals, water and photosynthates, *Striga* does most of its damage to its host through phytotoxins before it emerges from the soil (CIMMYT, 2004). *Striga* infected maize is characterized by symptoms including leaf chlorosis, blotching, wilting, scorching, stunting, and reduction in tassel and ear size (Kim, 1991; IITA, 1991). Complete scorching of all leaves, severe stunting and premature death are characteristic of highly susceptible maize varieties (Sallah and Obeng-Antwi, 2002). *Striga* also reduces the dry matter and grain yield of maize (Kroschel, 1999)

Depending on the time and severity of *Striga* infection, yield losses of cereals due to *Striga* damage in Africa range from 10% to 100% (Kim, 1991; Lagoke *et al.*, 1991). Generally, maize is more vulnerable and stress-susceptible than sorghum and millet to parasitism by *Striga*, with yield losses under heavy infestation higher than 90% (Efron *et al.*, 1986). Many workers including Kim and Tanimonure (1993) and Olakojo *et al.* (2001) have reported yield losses of between 70% and 90% in maize. CIMMYT (2004) reports that *Striga* damage accounts for yield losses of 20 – 80% in maize in sub-Saharan Africa. In monetary terms, every year *Striga* damage to crops accounts for an estimated US $7 million in yield loss in sub-Saharan Africa affecting the welfare and livelihood of over 100 million people (CIMMYT, 2004). *S. hermonthica* and *S. asiatica* cause not only high yield losses, ranging up to total crop loss in the savannahs of Western and Central Africa, but they also often compel farmers to abandon maize cultivation entirely (Badu-Apraku and Fakorede, 2001).

Kim (1991) reported yield losses of 91% and 64% for susceptible and tolerant maize hybrids respectively under heavy *Striga* infestation. Carson (1988) in a two-year study in The Gambia reported a 20 – 35% crop loss due to *Striga*, resulting in an annual loss of about 10,000 tonnes of cereal grains worth over US $900,000. Lagoke *et al*., (1991) reported 30 - 90% damage to crops in Togo and 10,500 tonnes of cereal loss (valued at about US $1.3 million) in the Republic of Benin, due to *Striga*. From preliminary surveys at the farmer level in Mali, Konate (1986) reported a crop loss ranging from 25% to 100%. In Ghana, *S. hermonthica* has reduced maize yields in farmers' fields by about 16% in low infested fields to about 78 – 100% in heavily infested fields (GGDP, 1988; Sauerborn, 1991; Vogt *et al*., 1991)

2.4 *Striga* Control Methods

The control of *Striga* species is particularly different from ordinary weeds because much of the damage to the host crop occurs while the parasite is still underground (Parker and Riches 1993). In other to be effective, *Striga* control strategies must ensure good yield from the planted crop and reduction in *Striga* seed reserves in the soil (Adetimirin and Kim, 1997). Consequently, control methods that act before or during *Striga* attachment will be the most effective in preventing the damaging effects of the parasite. In the African resource-poor farmer's context, the method must also be at a minimal cost, sustainable, easily adoptable and fit well into his peasant cropping system.

Control strategies developed for the control of *Striga* in maize and other cereals include, land preparation, hand pulling and hoe weeding, rotation with non-host crops, land fallowing, the use of trap and catch crops, fertilizer, chemicals and resistant/tolerant varieties (Kim, 1991a; Lagoke *et al.*, 1991; Kroschel *et al.*, 1999; CIMMYT, 2004). Among these control strategies, the use of *Striga* resistant maize cultivars is thought to be the most effective and offer an economically feasible and culturally sustainable technology for the African resource-poor farmer, since it does not require extra inputs such as labour and fertilizers, (DeVries, 2000; Sallah and Obeng-Antwi, 2002).

2.4.1 Land Preparation

Options of land preparation for the control of *Striga* infestation include deep cultivation and zero tillage. Konate (1986) reports of deep cultivation to burry *Striga* seed as an effective control of the parasite in Mali. Deep cultivation is however tedious and expensive and may not be very practical as farmers of the endemic areas are resource-poor smallholders. Most of them will therefore not be able to acquire such land preparation equipment. Further more *Striga* seed buried at depth of 30 – 40 cm can remain viable and with regular tilling of the land, some of the buried seeds could be brought up to the soil surface resulting in re-infestation. Bebawi *et al.* (1984) found 10% of a given quantity of *Striga* seed viable after 14 years of deposition in the soil at a depth of 152 cm. The use of zero tillage such that host crop seed is planted with little soil disturbance resulted in low *Striga* infestation in The Gambia (Carson, 1986).

2.4.2 Hand Pulling and Hoeing

Hand pulling and hand weeding (hoeing) of emerged *Striga* plants are control options available to all farmers. It is most commonly used by smallholder farmers in most developing countries (Lagoke *et al.*, 1991) and in Ghana (Nyarko, 1986). In The Gambia, most farmers use hand weeding and/or hand pulling during the second or late weeding to control *Striga* infestation (Carson, 1985)

Even though widely recognised and most commonly used by smallholder farmers, hand pulling and hoeing are very tedious, labour-intensive and expensive operations (Lagoke *et al.*, 1991; Kroschel *et al.*, 1999). Hand pulling could only be effective in *Striga* control when infestations are light (Pieterse, 1985). However, these methods do not reduce damage to any significant level, since *Striga* inflicts most damages on the crop before it emerges from the soil (Lagoke *et al.*, 1991), but could prevent flowering and production of seed.

2.4.3 Use of Trap- and Catch crops

Trap- and catch crops are used to stimulate the germination of *Striga*. Catch crops are however parasitized and need to be destroyed as soon as they are infected. On the other hand, trap-crops are non-host crops and only induce the germination of *Striga* but do not sustain their growth for them to emerge to the surface (Kroschel *et al.*, 1999).

Rotating host crops with trap crops, especially leguminous trap crops, have been used as an intervention for the successful control of *Striga*. Rotating susceptible cereal crops with leguminous trap crops is reported to reduce *Striga* seed banks, or clean *Striga* infested fields, to enhance cereal production (Berner *et al.*, 1995). Soybean, groundnut, bambara groundnut and *Sesbania sesban* have been used as trap-crops in inter-cropping systems or rotated with susceptible host to successfully induce abortive germination of *Striga* seeds, with a consequent reduction in infestation in the savannah zones of sub-Saharan Africa (Carson, 1985; Tchemi, 1986; Parkinson *et al.*, 1986). *Sesbania sesban* has been found to be very promising since its establishment and removal later from the field are both very easy (ICRAF, 1996). In Nigeria, Parkinson *et al.*, (1986) reported a reduction in infestation, through abortive germination of the parasite, using soybean, cotton and bambarra groundnut in rotation or as intercrop with susceptible hosts. Eplee and Norris (1990) reported a 90% reduction of *S. asiatica* seed by cotton in artificial infestation trials.

The use of catch crops is disadvantaged since they have no immediate benefit even though they have to compete with the food crops for the limited resources available to the small-scale farmer. In addition, with the prevailing erratic rainfall of sub-Saharan Africa, it is very unlikely that farmers would be prepared to sacrifice part of the season to grow catch crops without any returns (Lagoke *et al.*, 1991).

2.4.4 Use of Fertilizers

The occurrence of *Striga* and their virulence on host crops has long been associated with low soil fertility (Lagoke *et al.*, 1991). Application of inorganic fertilizers and farmyard manure is reported to reduce infestation, emergence and damage by *Striga*, and crop yield losses, especially when high rates are used on moderately fertile lands (Lagoke *et al.*, 1991; Kroschel *et al.*, 1999). From their *in vitro* experiments, Pesch and Pieterse (1982) reported that urea and ammonium sulphate directly inhibited the germination of *Striga*. Agbobli (1991), working in Togo, reported a 53% reduction in emergence and achieved 132% increase in maize yield with 120 kg N/ha as urea. Similarly Kabambe (1991) obtained 50 to 75% reduction in emergence in Malawi using 112 kg N/ha as ammonium sulphate.

Ogborn (1972) indicated that two conditions of the host crop were responsible for inhibiting the parasitism by *Striga* – increased concentration of nitrogen in the host crop roots and shading of the soil surface by the resultant denser crop canopy. According to Parker (1984), nitrogen turns to reduce *Striga* infestation through reduction of stimulant exudation by the host crop, slowing *Striga* development and increasing crop tolerance. Cechin and Press (1993) have reported that after the germination of *Striga*, N affects the ability of the parasite's radicle to form a successful union with the host following attachment to the host root.

Genetic resistance/tolerance especially, the ability of the host plant to withstand *Striga*, underscores the importance of the efficacy of N in reducing *Striga* damage to host plants. In their study – the response of tolerant (8322-13) and susceptible (8338-1) maize hybrids to *S. hermonthica* as affected by timing and rate of N application - Kim and Adetimirin (1997) found that the tolerant cultivars at 60 kg N/ha performed better than the susceptible at 120kg N/ha. Thus, resistant or tolerant cultivars are well suited to the resource poor African farmers, relative to the high cost of N-fertilizes and the uncertainty surrounding their availability, especially under heavy *Striga* pressure. The unavailability and bulkiness of organic manure is also a limitation to the adoption of this control measure.

2.4.5 Chemical control

A number of potentially useful chemical interventions in the control of *Striga* have been developed. These include the use of chemically treated seeds, chemical stimulants and herbicides. Low-dose imazapyr seed coating on imazapyr resistant maize seed is reported to control *Striga*, leaving an infested field virtually cleared of emerging *Striga* blooms season-long (CIMMYT, 2004). Imazapyr act at the time of *Striga* attachment to the maize root and hence prevent the exertion of the phytotoxic effect of *Striga* on the maize plant, which usually occurs even before emerging of the *Striga* from the soil. In addition, imazapyr that is not absorbed by the maize seedling diffuses into the surrounding soil and kills ungerminated *Striga* seeds (CIMMYT, 2004). According to Lagoke *et al.*, (1991), farmers in Sokoto State (Nigeria) have claimed that soaking host seed in brine or an extract of *Parkia filicoides* reduces *Striga* infestation.

Certain chemicals such as strigol and strigol derivatives that generate ethylene gas are reported to serve as stimulants that induce abortive germination of *Striga* seeds in the absence of a suitable host, and therefore lead to the depletion of the seed reserve in the soil (Lagoke *et al.*, 1991; Egley *et al.*, 1990).

Ethylene was found to induce suicidal germination of *Striga* in the USA and it is reported to be the primary tool for reducing *Striga* seed banks in the witch weed eradication program in the Carolinas (Ransom, 1999). The high level of skill required for its application by injection and the cost however precludes its use by the small-scale resource-poor African farmer.

Studies have revealed that herbicides such as Dicamba, 2,4-D and MCPA are effective in the selective control of *Striga* (Lagoke *et al*., 1991; Odhiambo and Ransom, 1993). According to Odhiambo and Ransom (1993), Dicamba (a post-emergent herbicide) has been shown to control *Striga* when applied soon after attachment, timing being critical to maximising its effectiveness both in terms of *Striga* control and safety of the host crop. However, they have indicated that the added yield from the application of Dicamba is usually not sufficient to allow the treatment to be economical. Studies by Bagonneaud-Berthome *et al*., (1995) using six herbicides to control *S. hermonthica*, have revealed that several herbicides may be useful in controlling the parasite in cereal crops by an integrated programme involving selective herbicides acting at pre- and post-emergence stages of the parasite. In general, however, many herbicides are useful in preventing build up of *Striga* seeds in the soil but may not prevent the damage done by the parasite prior to its emergence.

2.4.6 Use of *Striga*-resistant Crops

Genetic variation for *Striga* resistance has been found in major crop species attacked by *Striga*. *Striga*-resistant crop genotypes have been defined as those when grown under *Striga* infestation, support significantly fewer *Striga* plants and have higher yield than susceptible cultivars, whilst tolerant genotypes are those that support as many *Striga* plants as susceptible genotypes but without showing resultant reduction in grain yield or overall productivity (Ejeta *et al.*, 1993). In *Striga* research, tolerance is the ability of the host plant to withstand the effects of the parasites that are already attached whereas resistance denotes the ability of the host plant to prevent attachment of the parasite to its roots (Kim, 1994). Tolerant genotypes have the disadvantage of encouraging the build up of *Striga* seeds in fields over time (Kim, 1991) whilst resistant cultivars have the distinct advantage of not requiring expensive inputs from the farmer and depleting the seed bank. Indeed, resistant varieties are seen as the most practical, cheap and durable tool that can be effectively used by subsistence farmers to control *Striga*.

Work on resistant crops has concentrated on sorghum, with research on maize starting relatively recently (Kim, 1991). Lagoke *et al.* (1988) report of extensive work in Nigeria that led to the identification of some varieties of sorghum exhibiting some level of resistance combined with tolerance to low levels of *Striga* infestation. Some lines found to show resistance to *S. hermonthica* include IS-7777, IS-7739 from Nigeria; IS-14825, IS-14928 and IS-16184 from Cameroun; IS-18440 from Uganda; and IS-6961 and IS-9830 from Sudan. However, these are noted to have poor agronomic characters. Resistance of *Striga*-resistant germplasm identified in sorghum and cowpea is reported not to be universal (Efron *et al.*, 1986), probably because of the existence of different biotypes of *Striga*.

The reactions of different maize genotypes to *Striga* vary. Preliminary studies indicate that different maize inbred lines may have different genetic mechanisms controlling the reactions of *Striga* (Efron *et al.*, 1986). Field resistance to *Striga* is the eventual expression of a series of interactive events between the parasite and its host. Kroschel *et al.*, (1999) reported that host plant resistance to *Striga* is generally due to interference of the crop genotype with one or several stages of the obligate parasite's life cycle. Lane *et al.* (1997) have reported reduction in *Striga* stem elongation and general development as *Striga* resistance reactions. According to Hess *et al.*, (1992) cultivars with *Striga* seed germination distances of less than 1cm are resistant while those with more than 1cm are susceptible. From their study of the genetic responses of single crosses of maize to *S. hermonthica* and *S. asiatica*, Gethi and Smith (2004) reported that resistant lines had very few *Striga* emerged plants per plot at 9 weeks (1.6 – 6.0) compared with susceptible lines that had a range of 7.0 – 22.6. From three years of trials in Nigeria, two hybrids (8322-13 and 8425-8) resistant to *S. hermonthica* were reported to score significantly less *Striga* emergence and host damage than did susceptible hybrids, while producing 85% and 51% greater grain yields respectively (IITA, 1993).

Other suggested resistance mechanisms include, low production of germination stimulant, mechanical barriers, unfavourable photo-hormone supply by the host, photoalexin synthesis, inhibition of germ tube exoenzymes by root exudates, inhibition of haustorial formation, insensitivity to *Striga* "toxin" and post-attachment hypersensitive reactions (Ejeta *et al.*, 1993; Berner *et al.*, 1995;

Gethi and Smith, 2004). The resistant maize hybrids of the IITA appear to control *Striga* through two modes of genetic action: (i) control of damage that the *Striga* can inflict on the maize plant and (ii) reduction in emergence of the parasite (IITA, 1993). Ejeta *et al*., (1993) reported that sorghum resistance is conferred from one or a combination of the various recognised mechanisms that influence the development of parasitism.

Cultivated maize, which originated from Mexico, is believed not to carry *Striga* resistant genes (Parker and Riches, 1993). A search for resistance genes in the wild relatives of maize has revealed that *Zea diplopernnis, Tripsacum sp.* and teosinte are promising sources of resistance to both *S. hermonthica* and *S. asiatica* (Kim, 1991; Berner *et al*., 1995; Lane *et al*., 1997). Since *Zea diplopernnis* is a species fully cross compatible with maize, incorporation of the alleles for resistance into cultivated maize is possible (Gethi and Smith, 2004). Crosses between *Zea mays* and *Tripsacum dactyloides* L. have been reported to have potential for resistance to *Striga* (Gurney *et al*., 2002). Several selections of *Z. diplopernnis*, identified to have resistance to *Striga* have been crossed with cultivated maize to transfer the resistance (IITA, 1993).

Scientists at IITA have identified inbreds and hybrids of maize showing much reduced damage from *S. hermonthica* (Kim et al., 1985, 1987; Efron *et al*., 1989). Hybrids such as 8322-13, 8321-11 and 9022-13 are reported to show moderate levels of tolerance. Grain yields of selected hybrids were reduced by 60% as compared to 90% of susceptible ones (Kim and Winslow, 1992). Inbreds tolerant to *S. hermonthica*, including TZi-011, TZi-12, TZi-25 and TZi-30 have also been developed. Indeed, TZi-30 has been confirmed to have genuine resistance to *S. asiatica* in the United States of America with *Striga* emergence count only about 10% of those on susceptible varieties (Ransom et al., 1990). Two maize hybrid varieties – Oba super 1 (hard, white grain) and Oba super 2 (hard yellow-orange grain) – available to farmers in Nigeria and the neighbouring countries of Benin and Cameroon have shown moderate levels of resistance to *S. hermonthica* and adopted for cultivation under moist savannah conditions of rainfall. Six others were identified with high resistance across trial locations to *S. hermonthica* (in Togo) and *S. asiatica* during the 1993 international trials of *Striga*-resistant hybrid maize varieties held in the savannah areas of six West African countries (IITA, 1993).

2.5 Origin of Maize

There are lots of speculations on the origin of maize. However it is generally accepted to have originated from Mexico and Central America from where it spread to the rest of Latin America, the Caribbean, the U.S, Canada and then to Asia and Africa (Dowswell *et al.*, 1996).

Maize tolerates a wide range of environmental conditions – heavy rainfall and semi-arid, cool and very hot climates – but grows well in warm sunny climates with adequate moisture (Purseglove, 1992). It is thus grown from latitude 58°N without interruption through the temperate, sub-tropical and tropical regions of the world to latitude 40°S (Hallauer and Miranda, 1988). It is reported to have the highest grain yield potential of all the cereals (Dowswell *et al.*, 1996).

2.6 Production of Maize

Maize ranks third to wheat and rice among the cereal crops of the world in terms of production (Ochse *et al.*, 1996). Among the developing economies, it ranks first in Latin America and Africa but third after rice and wheat in Asia (Dowswell *et al.*, 1996). Globally about 140 million hectares of maize is grown with a production of 600 million tons (CIMMYT, 2000). Asia plants almost half of the developing world's maize crop and in sub-Saharan Africa, maize accounts for more than 40% of total cereal production (IDRC, 2005)

In Ghana, maize is the most important cereal in terms of production and consumption (PPMED, 1992) and one of the most popular food crop on the domestic market. It is an important source of income to a great majority of Ghanaian farmers and others in the maize industry. It is the primary staple in the areas of production and constitutes the basis of several local food preparations and the main feedstuff for poultry and other livestock, and an important raw material in the brewery industry. Maize is grown in all the ecological zones of the country, from the coastal belt across the forest transition, Guinea savannah to the north-eastern corners of the country. The crop is cultivated by 1.75million (64%) of the 2.74 million households operating farms in Ghana (FASDEP, 2002). Total area put under maize cultivation being about 713,000 hectares with production levels averaging 1.5 metric tons (mt) per hectare even though 5.0mt/ha is the achievable yield (FASDEP, 2002). This production level has been inadequate for human and animal consumption. In the northern region total area put under maize cultivation rose from 98,500 ha in 2000 to about 157,020 ha in 2002, with average yields falling from 0.8 mt/ha in 2000 to 0.75 mt/ha in 2002 (MOFA, SRID, 2003).

2.7 Heritability in Maize

Heritability (h^2) as defined by Kang (1994) is the proportion of the total phenotypic variability for a trait that is due to heredity. It is measured as the ratio of the genotypic variance (σ^2_G) to the phenotypic variance (σ^2_P), i.e., $h^2 = \sigma^2_G / \sigma^2_P$ (Klug and Cummings, 2000) and it is most important in predicting gain from selection (Kang, 1994).

Most traits of agronomic importance in maize as well as resistance/tolerance of maize to *Striga* are quantitatively inherited (Hallauer *et al.*, 1988; IITA, 1993; Kim, 1994; Lane *et al.*, 1997). Their expression is more modified by fluctuations in environment and management factors than qualitative traits (Kang, 1994). Since the total observable variations of a quantitative character is a joint expression of the genotypic and environmental effects, it is important to determine what proportion of the phenotypic expression is due to genotypic and environmental effects. The phenotypic variance is the sum of the components of variance attributable to factors that cause differences in the performance among individuals (inbreds), i.e., the genotypic variance (σ^2_G), the non-genetic or environmental variance (σ^2_E) and the variance due to the genotype x environment interaction (σ^2_{GE}) (Hallauer and Miranda, 1988; Walter, 1991).

Mathematically this relationship can be expressed as:

$$\sigma^2_P = \sigma^2_G + \sigma^2_E + \sigma^2_{GE}$$

The genetic variance can be partitioned into: additive variance, σ^2_A , the dominance variance, σ^2_D , and non-allelic interactions or epistasis variance, σ^2_I , (Walter, 1991). Mathematically therefore:

$$\sigma^2_G = \sigma^2_A + \sigma^2_D + \sigma^2_I$$

Additive and non-additive (dominance and epistasis) effects contribute quite similarly for the control of the yield of maize (Hallauer and Miranda, 1988; Nass *et al.*, 2000; Aguiar *et al.*, 2003; Oyedokun and Chheda, 1982 (for rice)). It is reported that additive gene action was more important than non- additive gene action in the inheritance of maize grain iron and zinc concentration (Gorsline *et al.*, 1964; Long *et al.*, 2004). Kim (1994) and Adetimirin *et al.*, (2001) have reported that non-additive gene action played a greater role in inheritance of resistance for *Striga* emergence. Contrary, recent studies by Gethi and Smith (2004) on the genetic responses of single crosses of maize to *S. hermonthica and S. asiatica*, revealed that additive gene action played a relatively larger role than non-additive gene action in inheritance of *S. asiatica* resistance and *S. hermonthica* resistance for *Striga* emergence.

The ratio of the total genotypic variance (σ^2_G), including additive, dominance and epistasis variances, to the phenotypic variance is termed broad sense heritability (h^2_b). That is, $h^2_{(b)} = \sigma^2_G / \sigma^2_P = (\sigma^2_A + \sigma^2_D + \sigma^2_I) / \sigma^2_P$.

If the genetic investigation is such that σ^2_G can be partitioned into σ^2_A, σ^2_D and σ^2_I variance components, heritability in the narrow sense (h^2_n) can be determined as: $h^2_{(n)} = \sigma^2_A / \sigma^2_P$ (Hallauer and Miranda, 1988; Kang, 1994; Klug and Cummings, 2000). Narrow-sense heritability is the more useful concept since it measures the relative importance of the additive portion of the genetic variance that can be transmitted to the next generation.

2.8 Combining Ability in Maize

The productiveness an inbred contributes in a cross can be evaluated if it is crossed with other inbred lines. However, not all combinations of inbred lines will produce superior single crosses. Some inbred lines will combine with a large number of inbred lines to give high-yielding hybrid progenies while others will satisfactorily combine with a few or no inbred lines (Poehlman, 1987). Hence, the inbred combinations must first be tested for their combining ability to identify which combinations may be useful for the development of hybrids. The ability of an inbred to transmit desirable performance to the hybrid progeny is referred to as its combining ability (Poehlman, 1987). The concept of combining ability is useful to study and compare the performances of lines in hybrid combinations. It provides plant breeders with invaluable genetic information, which enables them to choose the most appropriate selection criteria for desirable genotypes from both segregating and advanced breeding population (Mutengwa *et al.*, 1999)

Sprague and Tatum (1942) partitioned the total combining ability of inbred lines into general combining ability (gca) and specific combining ability (sca). They defined the gca as the average performance of a particular inbred line in a series of hybrid combinations and the sca as those instances in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved. The concepts of gca and sca defined by Sprague and Tatum have been used extensively up to date in breeding several economic crop species. According to Hallauer and Miranda (1988), the concepts of gca and sca have become useful for characterization of inbred lines in crosses and often have been included in the description of an inbred line. They also indicated that the characterization of genetic variance and types of gene actions operative in crosses of inbred lines are also often interpreted relative to gca and sca of inbred lines. The International Maize and Wheat Improvement Centre (CIMMYT) have used measurements of gca and sca effects to establish heterotic patterns among its maize populations and pools (Han *et al.*, 1991; Vasal *et al.*, 1992).

The estimates of gca and sca of a group of inbred lines are obtained from the analysis of diallel crosses (Griffing, 1956a; Aguiar *et al.*, 2003). Viana and Matta (2003) have indicated that the gca effects, regarding cross-pollinating species like maize, is an indicator of the relative value of the population in terms of frequency of favourable genes and of its divergence, as compared to the other parents in the diallel. The analysis of gca effects thus allows identification of superior parents to be used in intra-population breeding programs. They have added that the sca effects of two populations expresses the differences of gene frequencies between them and their divergence, as compared to the diallel parents. Consequently, they maintain that the gca and sca effects should be considered in the selection of populations for hybrid production and for reciprocal recurrent selection programs. According to Hallauer and Miranda (1988), sca information is important in the choice of two varieties for initiating reciprocal recurrent selection. General combining ability is associated with additive effects of the genes, while sca is related to dominant and epistatic effects (non-additive effects) of the genes (Sprague and Tatum, 1942; Aguiar *et al.*, 2003). Rojas and Sprague (1952) indicate that in addition to those that come from dominance and epistasis, the variance of sca also contains deviations due to the interaction between genotypes and environments.

For maize yield and stalk lodging, Sprague and Tatum (1942) found that gca was relatively more important than sca for unselected inbred lines, whereas sca was more important than gca for previously selected lines. In their study of the combining ability of maize inbred lines evaluated in three environments in Brazil, Nass *et al.*, (2000) found that gca effects were more important than sca effects for the unselected hybrids that showed higher yields than the commercial hybrid controls. However, for the selected best five hybrids, sca effects were always more important than gca effects for each environment and over all environments. Evaluating the gca and sca of five inbred lines of maize and the stability of their respective single-crosses, Aguiar *et al.*, (2003) established that both additive (gca) and non-additive (sca) effects were important for grain yield, while for plant height, ear height, number of ears per plot, stand and grain moisture, additive effects were more important.

Information on combining ability and performance in hybrid combinations is of paramount importance in facilitating the transfer of resistance to other inbred lines and varieties, in identification of inbred lines producing crosses with better resistance and in the development of *Striga* resistant single-cross hybrids and synthetic varieties. Using the estimates of gca effects in a diallel analysis of six *Striga*-resistant and three *Striga*-susceptible early lines, Badu-Apraku and Fakorede (2001) identified four inbred lines as the best for gca for grain yield under both *Striga*-free and *Striga*-infested conditions. From the estimates of the gca and sca effects, Gethi and Smith (2004) identified inbred lines producing crosses with better resistance than the local checks for both *S. hermonthica* and *S. asiatica*. Berner et al. (1995) have reported gca and sca to be significant for damage ratings and *S. hermonthica* emergence in a diallel cross of ten inbred lines at IITA.

2.9 Heterosis and the Development of Hybrid Maize

Walter (1991) refers to heterosis as superiority in performance of hybrid individuals compared with their parents, whilst Kang (1994) sees it as the amount by which the mean of an F_1 (heterozygote) exceeds its high (better) parent or mid-parent. Heterosis (h) can be measured using the following relationships:

$$h = [(F_1 - MP) / MP] \times 100 \text{ .... Mid-parent heterosis}$$

$$h = [(F_1 - HP) / HP] \times 100 \text{ .... High parent heterosis}$$

Where: MP is the average performance of the parents

HP is the performance of the high parent

Heterosis being an expression of the performance of hybrids relative to that of inbred lines will vary among environments when hybrids and inbred lines respond differently to the environments (Tollenaar *et al.*, 2004).

The manifestation of heterosis depends on the genetic divergence of the parents in a cross. If the parents in a cross differ in gene frequency and directional dominance exists, heterosis would occur (Kang, 1994). According to Falconer (1960), heterosis will be expressed when some level of dominance exists and when there is relative differences in gene frequency of the two parents to determine the magnitude of the heterosis expressed in crosses. Falconer (1960) maintains that if either or both of the conditions do not exist, heterosis will not be manifested. Hallauer and Miranda (1988) have suggested that epistasis may also contribute to the heterosis expressed in crosses since epistatic effects have been shown to occur in specific crosses of inbred lines of maize.

Heterosis in maize occurs due to dominance and over dominance (Tollenaar *et al.*, 2004, Fu and Dooner, 2002). In maize heterosis provided tolerance to *S. hermonthica* that was reflected in higher grain yield and reduced ear rots (Kling *et al.*, 2000). Kim (1994) indicated that non-additive gene action (heterosis) was more important than additive gene action for resistance of *Striga* emergence. In another study on gene effects, Adetimirin et al. (2001) established that epistasis played a great role in inheritance of horizontal resistance to *S. hermonthica*.

Yields in maize increased dramatically as breeders moved away from open-pollinated cultivars and began developing double-cross and later single-cross hybrids (Duvick, 2001). This yield advance could be attributed to the successful harnessing of heterosis, which has since been exploited in the production of uniformly high-yielding F_1 seed in commercial quantities. A single-cross hybrid is the progeny from a cross between two unrelated inbred lines. They are heterozygous at all loci in which the two inbred lines differ and may be more vigorous and productive than the original parents from which the inbred lines were derived. The average heterosis of a cross is greatest for a single-cross hybrid due to the occurrence of the greatest possible number of loci with a dominant allele. Thus, mating of inbred lines resulting in single-cross individuals with a dominant allele at each locus provides the highest average performance for the cross.

The resistant reaction of a hybrid is dependent on the genes for resistance in the inbred lines. If resistance to a disease pathogen or parasite is quantitatively inherited, a single-cross hybrid progeny will be highly resistant if both parent inbred lines are resistant. However if one or a few dominant genes qualitatively control the resistance, having one parent with the dominant genes, may be sufficient to produce a resistant single-cross hybrid (Poehlman, 1987). Gethi and Smith (2004) have reported that the most resistant single-cross hybrid to *S. hermonthica and S. asiatica* had only one resistant parent. On the other hand, Kim (1991b) indicated that single-cross hybrids with the highest level of tolerance based on *Striga* syndrome rating had both parent inbreds resistant.

2.10 Mating Designs

Breeders employ many mating designs for purposes of estimating components of genetic and environmental variance. These provide important information for the breeders in making decisions of their breeding programs.

Mating designs or schemes commonly used by plant breeders include (1) Biparental progenies (Mather, 1949) (2) Gardner-Eberhart Analysis II (Gardner and Eberhart, (1966) (3) North Carolina Designs I & II (Comstock and Robinson, 1948) and North Carolina Design III (Comstock and Robinson, 1952) (4) Triallel and Quadrallel designs (Rawlings and Cockerham, 1962) (5) Complete diallel mating design (Griffing, 1956a) and (6) Partial diallel mating design (Kempthorne and Curnow, 1961)

The complete diallel mating design (hereafter diallel mating scheme) has been used more extensively than any other mating design in maize and other plant species (Kang, 1994). It is a particular mating scheme that requires making all possible crosses among a given set of p parental genotypes, giving rise to a maximum of p^2 combinations (Griffing, 1956a; Hallauer and Miranda, 1988; Kang, 1994). Four methods of diallel crossing techniques have been described (Griffing, 1956a; Kang, 1994). They include:

- Method I – parents, one set of F_1's and reciprocal F_1's are included (all p^2 combinations)
- Method II – parents and one set of F_1's are included, but reciprocal F_1's are not (1/2p (p+1) combinations)
- Method III - one set of F_1's and reciprocal F_1's are included, but not parents (p (p-1) combinations)
- Method IV - one set of F_1's included, but parents and reciprocal F_1's are not (1/2p (p-1) combinations)

The mode of choice of parents has great implications in the interpretations made from the analysis of diallel mating scheme. Relative to this, two models, designated Models I & II, have been distinguished for the analysis of variance and for the information derived from the analysis of variance (Griffing, 1956a; Hallauer and Miranda, 1988; Kang, 1994). In Model I (fixed effects), the parents are the population, whereas in Model II (random effects), the parents are a sample from a population (Griffing, 1956a; Kang, 1994). For Model I, estimation of the main effects (gca) and the interaction effects (sca) are of paramount interest whereas for Model II, estimation of the components of variance is of prime interest (Hallauer and Miranda, 1988; Kang, 1994).

Diallel analyses of self- and cross-pollinating populations are used to study the genetic control of quantitative traits (Jinks and Hayman, 1953 and Hayman, 1954 & 1958, cited by Viana and Matta, 2003), to assess gca and sca (Griffing, 1956a; Aguiar *et al.*, 2003, Long et al. 2004) and to perform heterosis analysis (Gardner and Eberhart, 1966). In a diallel cross involving sixteen inbred lines to study the genetics of resistance to *S. hermonthica and S. asiatica*, Gethi and Smith (2004) identified inbred lines producing crosses with better resistance than the local checks for both *Striga* species. Ogunbodede and Olakojo (2001) identified *S. asiatica* tolerant hybrids from eighteen maize inbred lines used in a non-reciprocal diallel crosses. From the diallel analysis of combining ability for five yield characters in upland rice (*Oryza sativa* L.), Oyedokun and Chheda (1982) obtained information on the genetic architecture of the crosses, identified suitable parents for hybridisation and estimated heritability values of the traits.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Genetic materials

The inbred lines used for (the development of) the diallel crosses were developed at IITA. They were made up of ten *Striga* resistant inbred lines (listed in Table 1). The diallel crosses were made at Nyankpala (Lat. $09^{0} 25^{\prime} 41^{\prime\prime}$ N, Long. 00 $58^{\prime}$ $42^{\prime\prime}$ W) in the Guinea Savannah zone of Ghana in the 2004 cropping season. An incomplete diallel, i.e., 45 F_1 single crosses excluding reciprocals were produced. The F_1s were developed by hand-pollinating the inbreds with bulk pollen from within each line while the parents were self-pollinated. All 45 F_1 single crosses with their parents were evaluated at the Savannah Agricultural Research Institute (SARI) trial sites at Nyankpala in the 2005 cropping season for their combining ability. The list of entries for the trials is presented in Table 2.

Table 1: Code name, pedigree and some agronomic description of the parental inbred lines used in a 10-parent diallel crosses in 2004

Inbred Lines	Code Name	Pedigree	Grain colour	Plant height (cm)	Gestation period (days)
TZISTR 101	P1	TZL Comp.1 C4 SI-37-1-B-B-B	White	146.00	90
TZISTR 102	P2	TZL Comp.1 C4 SI-37-5-B-B-B	White	115.00	90
TZISTR 108	P3	Z. Diplo. BC4-472-2-1-1-2-1-B-1-B-B-B-B	White	128.50	90
TZISTR 111	P4	Acr 97 Syn-Y-S1-79-B-B-B	Yellow	121.50	90
TZISTR 112	P5	Syn-W-S2-99-B-B-B	Yellow	114.00	90
TZISTR 113	P6	TZE Comp5-Y-21-1-1-2-#-B-B-B-B	Yellow	126.50	90
TZISTR 114	P7	TZE Comp5-Y-20-1-1-3-#-2-B-B-B-B	Yellow	111.50	90
TZISTR 115	P8	TZE Comp5-Y-C7-S3-55-B-B-B	Yellow	112.00	90
TZISTR 116	P9	TZE Comp5-Y-C7-S3-56-B-B-B	Yellow	118.00	90
TZISTR 117	P10	TZE Comp5-Y-C7-S3-150-B-B-B	Yellow	132.00	90

Table 2: List of Genotypes evaluated for their combining ability

Entry	Genotype	Entry	Genotype	Entry	Genotype	Entry	Genotype	Entry	Genotype
1	P_1P_2	12	P_2P_5	23	P_3P_9	34	P_5P_9	45	P_9P_{10}
2	P_1P_3	13	P_2P_6	24	P_3P_{10}	35	P_5P_{10}	46	P_1
3	P_1P_4	14	P_2P_7	25	P_4P_5	36	P_6P_7	47	P_2
4	P_1P_5	15	P_2P_8	26	P_4P_6	37	P_6P_8	48	P_3
5	P_1P_6	16	P_2P_9	27	P_4P_7	38	P_6P_9	49	P_4
6	P_1P_7	17	P_2P_{10}	28	P_4P_8	39	P_6P_{10}	50	P_5
7	P_1P_8	18	P_3P_4	29	P_4P_9	40	P_7P_8	51	P_6
8	P_1P_9	19	P_3P_5	30	P_4P_{10}	41	P_7P_9	52	P_7
9	P_1P_{10}	20	P_3P_6	31	P_5P_6	42	P_7P_{10}	53	P_8
10	P_2P_3	21	P_3P_7	32	P_5P_7	43	P_8P_9	54	P_9
11	P_2P_4	22	P_3P_8	33	P_5P_8	44	P_8P_{10}	55	P_{10}

3.2 Collection and preservation of *Striga* seed.

Maize and sorghum fields infested by *Striga hermonthica* were identified during the months of October and November 2004, in the Northern region of Ghana when the seed had not yet matured. These fields were inspected regularly until the floral heads had matured. A floral head was considered matured if all florets had completed flowering, with no visible flowers at the uppermost parts. Healthy and intact matured capsules were harvested into paper bags and put in large plastic bags to prevent the seeds from dropping before they were sent to a drying point for further drying. The capsules were removed daily for exposure to sunlight in a well-ventilated shed for adequate drying of the seeds.

When the seeds were thoroughly dried, small amounts of the harvested heads were successively spread on polythene sheeting and gently beaten with a stick until all the capsules were completely shattered and the seeds shed. The seed together with the smaller trash was passed through three sieves – 250, 180 and 150 micrometre (μm) mesh sizes. Only the material collected on the 150 μm sieve was collected as seed. The seed lot was then stored at room temperature under dry conditions until used to infest the maize field.

3.3 Experimental design

The design used for the evaluation was a randomized complete block design with two replications. Each plot consisted of a one 5 m row with 21 plants per row. The treatment design was a Griffing method 2 model 2 diallel (Griffing, 1956b). There were two environments - infested and uninfested (control) separated by a ten metre strip of land. Environment one was artificially infested with *S. hermonthica* seeds while environment two was not infested.

3.4 Field and agronomic practices

The experimental field was ploughed, harrowed and ridged before planting. A one-row plot of 5 m long represented each entry. The rows were spaced 0.75 m apart and hills at 0.25 m apart. The plots of environment one were artificially inoculated with the *S. hermonthica* seeds collected from the maize and sorghum fields in December 2004. This was accomplished by placing 1g pure *Striga* seed containing approximately 1500 germinable seeds in each planting hole. These were thoroughly mixed with soil before placing maize seed in the hole. Two maize seeds were sown per hill and were thinned to one plant per hill at three weeks after planting to obtain a target population of 53,000 plants ha^{-1}. The maize seed was dusted with a rodenticide (Nexion) to protect the seeds from rodents and birds. Carbofuran [2, 3-dihydro-2, 2-dimethylbenzofuran-7-yl methyl carbonate] was also applied at the rate of 33.3kg ha^{-1} to protect the young seedlings from cutworms and beetles. The site was protected round by a four-guard row of open pollinated maize (Okomasa)

Pre-emergence chemical weed control was practiced and consisted of an application of a combination of Pendimethalin [N-(1-ethyl propyl) – 3, 4 – dimethyl – 2, 6 – dinitrobenzenamine] and Gesaprim [2 – chloro – 4 – (ethyl amino) – 6 – (isopropyl amino) – s – triazine] at 1.5 l ha^{-1} and 1.0 l ha^{-1} active ingredient (a.i) respectively to control weeds other than *Striga*. Other weeds were hand weeded on the infested plots two days prior to *Striga* count and removed from the plots to keep the plots clean to enable accurate *Striga* count.

To allow for effective *Striga* establishment, a minimal level of nitrogen at 60 kg N ha $^{-1}$ was applied. A basal fertilizer was applied at two weeks after planting at the rate of 30 kg N ha^{-1} and 60 kg P_2O and top-dressed with sulphate of ammonia at 30 kg N ha^{-1} six weeks after planting.

3.5 Data collection.

The following data were taken:

3.5.1 **Days to flowering:** The number of days from planting to when 50% of plants produced silks was recorded as female flowering, while the number of days from planting to when 50% of the plants were shedding pollen was recorded for male flowering.

3.5.2 **Progressive plant height:** Progressive plant height was measured (in cm) every 14 days starting from 14 days after planting to when the plants seized growing. Plant height was measured from the base of the plant to the base of the uppermost leaf and averaged for five randomly selected plants per plot.

3.5.3 **Plant height:** Plant height was measured (in cm) from the base of the plant to the flag leaf node at harvest using the plants used for the progressive plant height measurement.

3.5.4 **Ear height:** Ear height was measured (in cm) from the base of the plant to the node bearing the uppermost ear at harvest using the plants used for the plant height measurement.

3.5.5 **Stalk lodging:** The actual number of plants whose stalks had broken below the ear was recorded per plot and expressed in percentages.

3.5.6 **Field weight:** all the plants of each plot were harvested. The weight of the de-husked ears was recorded in kg to two decimal places and used as the yield per plot. For each plot the total number of plants harvested and the total number of ears harvested was recorded.

3.5.7 **Percent moisture:** The moisture percent in the grain at harvest was determined using an electronic moisture metre (Wile 35).

3.5.8 **100 grains weight:** Three de-husked ears were randomly picked from each plot. These were shelled and the grains from the three ears for each plot bulked. For each plot, the weight of 100 grains was recorded in grams to two decimal places.

3.5.9 ***Striga* emergence counts (STEC):** The number of *Striga* plants that emerged per plot was recorded at 8, 10 and 12 weeks after planting and used as the STEC per plot. These were then converted to STEC per hectare.

3.5.10 **Host plant damage ratings (HDR):** Visible damage symptoms on host plants were taken at 8, 10 and 12 weeks after planting. Diseased plants were rated on a scale of 1 to 9 (1= no visible symptoms and 9 = all plants dead or dying). Details of the rating are as follows:

1 = normal plant growth, no visible symptoms.

2 = small and vague, purplish-brown leaf blotches visible.

3 = mild leaf blotching with some purplish-brown necrotic spots.

4 = extensive blotching and mild wilting; slight but noticeable stunting and reduction in ear and tassel size.

5 = extensive leaf blotching, wilting and some scorching; moderate stunting and reduction in ear and tassel size.

6 = extensive leaf scorching on about 50% of leaves with mostly gray necrotic spots; visible stunting and reduction in stem diameter, ear size and tassel size.

7 = definite leaf scorching on about 60% of leaves with mostly gray necrotic spots and leaf wilting and rolling; severe stunting and reduction in stem diameter, ear size and tassel size and often causing stalk lodging brittleness and husk opening at a late growing stage.

8 = definite leaf scorching on about 70% of leaves with extensive gray necrotic spots; reduction in stem diameter, ear size and tassel size; conspicuous stunting, leaf wilting, rolling and severe stalk lodging.

9 = complete leaf scorching of all leaves causing premature death of host plant and no ear formation

3.6 Data analysis

The data was entered into a personal computer and analyzed using statistical system analyses (SAS, 1996) after conversions of grain yield in kilograms per plot to grain yield in tons per hectare (GYLD) at 15% grain moisture using the formula below:

$$\text{GYLD} = \frac{(\mathit{fldwt} * 0.8)}{3.75} * \frac{(100 - \mathit{moist})}{85} * 10$$

where: *fldwt* is the weight of maize harvested per plot, assuming 80% shelled grain weight and the effective plot size of 3. 75 m^2; *moist* is the moisture of the grains at harvest (Kang, 1994).

The data were analyzed by environment and were combined over environments, assuming the random effects model. Genotypes and environments were all considered as random factors in the analysis. The generalized linear model (GLM) procedure (SAS, 1996) was used to test heterogeneity of variances among the genotypes and environments as described in the next section.

3.6.1 Models and analysis of variance

The linear model for entries analyzed in a randomized complete block design in one environment was:

$y_{ijk} = \mu + g_{ij} + r_i + e_{ijk}$ (Griffing, 1956a; Kang, 1994);

where y_{ijk} is the observation of entry k resulting from crossing the i^{th} and j^{th} parents, μ is the general mean, g_i (g_j) is the effect of entry k of i^{th} (j^{th}) parents, r_i is the effect of replicate i, and e_{ij} is the random error. The form of analysis of variance is presented in Table 3.

Table 3: Form of analysis of variance in one environment (Kang, 1994)

Source	df	Mean squares	Expected mean squares
Replication (r)	r-1	M1	
Genotype (g)	g-1	M2	$\sigma_e^2 + r\sigma_g^2$
Error (e)	(n-1)(g-1)	M3	σ_e^2

σ_e^2 = plot error variance, σ_g^2 = genotypic variance, r = number of replications

The combined data from the two environments for the common entries were analyzed using the model below:

$y_{ijkm} = \mu + \beta_m + r_{i(m)} + g_{ijk} + g_{ijkm} + e_{ijkm}$ (Griffing, 1956a; Kang, 1994); where y_{ijkm} is the observation of entry k resulting from crossing the i^th^ and j^th^ parents in environment m, μ is the mean of the observations, β_m is the effect of environment m, $r_{i(m)}$ is the effect of replications within environment, g_{ijk} is the effect of entries, g_{ijkm} is the effect of entries by environment interaction and e_{ijkm} is the random error. All the effects are assumed random, independent and normally distributed with zero means and variances due to each effect. The form of analysis of variance is presented in Table 4 below.

Table 4: Form of analysis of variance for the combined data (Kang, 1994)

Source	df	Mean squares	Expected mean squares
Environment (β)	$\beta - 1$	M1	
Rep. in Envir. ($r(\beta)$)	$\beta(r-1)$	M2	
Genotype (g)	$g-1$	M3	$\sigma_e^2 + r\sigma_{g\beta}^2 + r\beta\sigma_g^2$
Genotype * Envir.	$(g-1)(\beta-1)$	M4	$\sigma_e^2 + r\sigma_{g\beta}^2$
Error (e)	$\beta(g-1)(\beta-1)$	M5	σ_e^2

σ_e^2 = plot error variance, σ_g^2 = genotypic variance, r = number of replications
$\sigma_{g\beta}^2$ =genotype - environment interaction variance.

The interactive BASIC program for Griffing's Diallel Analyses (Kang, 1994) according to Griffing (1956b) Model 2 (random effects) Method 2 (parents and one set of F_1s, no reciprocal F_1s) was used to partition the genotype means into gca and sca effects. The combining ability effects and variance due to gca and sca were calculated using data across the two environments. The mathematical model used for the combining ability analysis was:

$$y_{ijk} = \mu + g_i + g_j + s_{ij} + {}^1\ m_k\ \Sigma m_k + {}^1\ m_k\ \Sigma(mv)_{ijk} + {}^1\ mc_{kl}\ \Sigma\Sigma\ e_{ijkl}$$

(Griffing, 1956a); where y_{ijk} is the observation of entry k resulting from crossing the i^{th} and j^{th} parents, μ is the mean of the observations, g_i (g_j) is the g.c.a effect for the i^{th} (j^{th}) parents, s_{ij} is the s.c.a effect for the cross between the i^{th} and j^{th} parents such that $s_{ij} = s_{ji}$, m_k is the k^{th} environment effect, $(mv)_{ijk}$ is the interaction between the ij^{th} genotype and the k^{th} environment, and e_{ijk} is the environmental effect associated with the ijk^{th} individual observation. All effects except μ are random variables. An F-test was used to test the significance of gca and sca effects. The expectations of combining ability mean squares are given in table 5 below.

Table 5: ANOVA of random effects (model 2) relative to method 2 (Kang, 1994)

Source of variance	degree of freedom	Expected mean squares
GCA	p-1	$\sigma_e^2 + m\sigma_{sca}^2 + m\,(p+2)\,\sigma_{gca}^2$
SCA	p (p-1)/2	$\sigma_e^2 + m\sigma_{sca}^2$
Error		σ_e^2

Where: p = number of parents; m = number of environments; σ_e^2 = epistatic variance
σ_{sca}^2 = specific combining ability variance; σ_{gca}^2 = general combining ability variance.

The relative importance of gca and sca effects was assessed by the ratio of the variances of random effects (Baker, 1978),

$$2[\Sigma g_i^2/n - 1]/\,[2(\Sigma g_i^2/n - 1) + \Sigma\Sigma s_{ij}^2/n\,(n-3)/2];$$

where $\Sigma g_i^2/n - 1$ is the variance of gca effects and $\Sigma\Sigma s_{ij}^2/n\,(n-3)/2$ is the variance of sca effects.

Heritability values for the various characters were estimated following the procedures by Griffing (1956b). The broad-sense heritability (h_b) and the narrow-sense heritability (h_n) were respectively estimated as:

$$h_b = \frac{\sigma_A^2 + \sigma_D^2}{\sigma_P^2} \quad \text{and} \quad h_n = \frac{\sigma_A^2}{\sigma_A^2 + \sigma_D^2 + \sigma_e^2}$$

where σ_A^2 is the additive variance [which = $2(\sigma_{gca}^2)$]; σ_D^2 is the dominance variance [which = (σ_{sca}^2)] and σ_P^2 is the phenotypic variance [which = $\sigma_A^2 + \sigma_D^2 + \sigma_e^2$]

High-parent heterosis (%) was estimated as:

$$\text{Heterosis} = 100\,[(F_1 - HP)/HP]$$

Where F_1 was the hybrid mean and HP was the high-parent mean for each cross.

3.7 Identifying suitable inbred lines

In an effort to identify suitable inbred lines to be used for commercial single cross hybrids, a rank sum was calculated by ranking the grain yield, *Striga* count, 100 grains weight, plant height, ear height, days to silking and days to anthesis. The best 10 hybrids were selected based on the rank sum values calculated by summing the ranks of each genotype.

3.8 Correlations among traits

The degree of relationship between any two traits was determined by Pearson correlation coefficients using Mstatc 2. After determining the linear associations between two traits, partial correlation was used to determine whether or not the association between any two traits was real holding the third trait constant. Correlation coefficients range in value from -1 (a perfect negative relationship) to +1 (a perfect positive relationship).

CHAPTER FOUR

4.0 RESULTS

4.1 Means of growth and yield characters in the uninfested environments

4.1.1 Grain yield

The analyses of variance showed significant differences ($p < 0.01$) among the genotypes for grain yield per hectare (Appendix 1). Mean grain yield ranged from 1.20 t/ha to 6.23 t/ha for hybrids and from 1.17 t/ha to 2.80 t/ha for inbreds.

There was no significant difference ($p < 0.05$) in grain yield between hybrids P_1P_2, P_1P_3, P_1P_9, P_2P_9, P_3P_8, P_3P_9, P_3P_{10}, and P_7P_{10} (Table 6). Grain yields of these hybrids were significantly higher than the grain yields of the rest of the hybrids. On the other hand, grain yields of P_1P_8, P_4P_5, P_4P_6, P_5P_9, P_6P_8, P_6P_9, P_6P_{10}, P_7P_8, and P_8P_9 were significantly lower than the grain yields of the rest of the hybrids. Grain yields of these hybrids were not significantly different ($p< 0.05$) from grain yields of the inbreds. Among the inbreds, there was no significant difference in grain yield except for between inbreds P_2 (P_8) and inbreds P_4 (P_9).

4.1.2 100 grains weight

There was no significant difference ($p < 0.01$) among the genotypes for 100 grains weight (Appendix 1). However there were significant differences ($p < 0.01$)

among replications for 100 grains weight. Mean 100 grains weight ranged from 19.50 g to 24.99 g for hybrids and from 16.20 g to 23.09 g for inbreds. Average weight of 100 grains was 21.48 g (Table 6)

4.1.3 Plant height

There were significant differences ($p < 0.01$) among genotypes and replications for plant height (Appendix 1). Average plant height was 148.90 cm. Plant height ranged from 113.00 cm to176.50 cm for hybrids and from 113.50 cm to156.50 cm for inbreds (Table 6)

Analysis of means of plant height for differences among entries as determined by the Least significant difference (Lsd) method revealed that there were significant differences ($p< 0.05$) between hybrids and between inbreds (Table 6). Plant height of hybrids P_1P_4, P_1P_7, P_1P_{10}, P_6P_{10} and P_7P_{10}, were not significantly different ($p< 0.05$). These hybrids were significantly taller than the rest of the hybrids while P_9P_{10} and P_8P_9 were significantly shorter. Inbred line P_1 was significantly different ($p< 0.05$) from all other inbreds. It was significantly taller than the rest of the inbreds.

4.1.4 Ear height

The analyses of variance showed significant differences ($p < 0.01$) among the genotypes for ear height (Appendix 1). Mean ear height ranged from 47.00 cm to 84.00 cm for hybrids and from 36.00 cm to 58.00 cm for inbreds. Overall average ear height was 61.89 cm.

There were no significant differences ($p < 0.05$) between hybrids P_1P_3, P_1P_{10} and P_6P_{10} nor between hybrids P_1P_4, P_1P_5, P_1P_7, P_2P_5, P_5P_9, P_7P_{10}, P_8P_{10} and P_9P_{10} for ear height as determined by the Lsd (Table 6). Ear heights of hybrids P_1P_3, P_1P_{10} and P_6P_{10} were significantly higher than ear heights all other hybrids. Ear heights of inbred lines P_4, P_5 and P_9 were not significantly different ($p < 0.05$). Ear height of inbred line P_{10} was significantly higher than ear heights of all other inbred lines.

4.1.5 Days to 50% anthesis

The analyses of variance indicated that genotypes were significantly different ($p < 0.01$) for days to 50% anthesis (Appendix 1). Mean days to 50% anthesis ranged from 55.00 days to 70.50 days for hybrids and from 57.00 days to 67.00 days for inbreds with an overall average of 61.26 days.

There were no significant differences ($p < 0.05$) between hybrids P_4P_5, P_5P_{10}, P_6P_7, P_7P_8, P_7P_{10}, P_9P_{10}, and P_7P_{10} for days to 50% anthesis (Table 6). These hybrids shed their pollen later than all other hybrids while hybrids P_2P_8, P_2P_9, P_3P_6, P_3P_{10}, P_4P_{10} and P_3 shed their pollen earlier.

4.1.6 Days to 50% silking

The analyses of variance for the traits measured in the uninfested environment showed significant differences ($p < 0.01$) among the genotypes and replicates for days to 50% silking (Appendix 1). Overall mean days to 50%

silking was 61.96 days. Mean days to 50% silking for hybrids ranged from 55.50 days to 72.00 days and from 50.50 days to 69.50 days for inbreds (Table 6).

There was no significant difference ($p< 0.05$) in days to silking among the crosses of P_1, except for P_1P_8 and P_1P_{10}. Similarly except for hybrid P_3P_4, there was no significant difference in days to silking among the crosses of P_3 (Table 6). There were no significant differences ($p< 0.05$) between hybrids P_1P_8, P_4P_5 P_4P_8, P_4P_9, P_5P_6, P_5P_{10}, P_7P_8, P_7P_{10}, P_8P_9 and P_9P_{10} for days to silking. Similarly there were no significant differences ($p< 0.05$) between inbreds P_1, P_2, P_4, P_8 P_4P_8, P_4P_9, nor between inbreds P_6, P_7, P_9 and P_{10} for days to silking (Table 6).

4.1.7 Stalk lodging

Stalk lodging was not significantly different ($p < 0.05$) among genotypes and replications (Appendix 1). Mean stalk lodging for hybrids ranged from 0.00% to 3.25% and from 0.00% to 2.94% for inbreds. Overall mean percentage stalk lodging was 2.30% (Table 6).

4.1.8 Plant stand

The analyses of variance indicated no significant difference ($p < 0.05$) among genotypes for plant stand (Appendix 1). Mean plant stand per plot ranged from 19.00 plants to 20.00 plants for both hybrids and inbreds. Overall average number of plants per plot was 19.50 (Table 6).

Table 6: Means of grain yield, 100 grains weight, plant height, ear height, days to 50% silking, days to 50% anthesis (Dts), stalk lodging and plant stand in the uninfested environment

Entries	Grain yield (t/h)	100 grain weight (g)	Plant height (cm)	Ear height (cm)	Days to anthesis	Days to silking	Stalk lodging (%)	Plant stand
P_1P_2	4.94 ebdacf	20.57 abcd	144.50 nm	61.00 lmkpjonq	56.50 poqn	57.50 jklmn	0.00	20.00
P_1P_3	5.64 ab	23.63 ab	169.00 fdec	79.00 bac	58.00 lpmoqn	58.00 jklmn	0.00	19.50
P_1P_4	4.53 ebdhigcf	23.83 ab	174.50 ba	76.50 bdc	60.00 likmojn	61.00 ghijk	0.00	20.00
P_1P_5	4.38 ebjdhigcf	22.99 abc	171.50 bdec	74.00 fbedc	59.50 lpkmojn	60.00 hijklm	0.00	20.00
P_1P_6	4.50 ebdhigcf	23.00 abc	172.50 bac	66.00 fgkjhi	58.50 lpmoqn	59.50 ijklmn	2.77	20.00
P_1P_7	4.01 lekbjdhigcfm	23.65 ab	176.50 a	74.50 fbedc	59.00 lpkmoqn	59.50 ijklmn	0.00	20.00
P_1P_8	2.70 snrxwtvqopum	20.43 abcd	157.50 jkhi	50.00 uwv	64.00 eidfhcg	65.50 bcdef	2.77	20.00
P_1P_9	6.23 a	24.99 a	160.00 jkhig	64.00 lmkjhi	61.00 likmhjg	61.00 ghijk	0.00	19.50
P_1P_{10}	3.87 leknjdhigofm	20.09 abcd	175.50 ba	84.00 a	61.00 likmhjg	61.50 fghij	0.00	19.00

Table 6: continued

P_2P_3	4.65 ebdacf	21.60 abcd	144.00 nm	59.50 lmkpronq	57.50 pmoqn	58.50 jklmn	0.00	20.00
P_2P_4	3.65 leknjdhigqopfm	20.65 abcd	145.50 nlm	47.00 wv	60.50 likmhjn	61.50 fghij	2.50	19.50
P_2P_5	4.87 ebdacf	21.95 abcd	165.00 fheg	74.00 fbedc	58.50 lpmoqn	59.50 ijklmn	0.00	20.00
P_2P_6	4.73 ebdacf	21.37 abcd	165.00 fheg	74.00 fgedc	60.00 likmojn	60.50 ghijkl	2.77	20.00
P_2P_7	3.62 leknjdhigqopfm	21.70 abcd	163.50 fhig	61.50 lmkpjonq	58.00 lpmoqn	59.00 ijklmn	0.00	19.50
P_2P_8	4.76 ebdacf	22.60 abcd	163.50 fhig	66.00 lgkjhi	55.50 pq	56.00 mn	0.00	20.00
P_2P_9	5.60 bac	24.22 ab	157.00 jkhi	66.00 lgkjhi	56.00 poq	56.00 mn	2.00	20.00
P_2P_{10}	4.68 ebdacf	22.56 abcd	152.50 klm	53.00 tusrv	57.50 pmoqn	58.00 jklmn	3.14	19.50
P_3P_4	4.72 ebdacf	20.27 abcd	159.00 jkhig	72.50 fgedh	63.00 eikfhjg	64.00 defgh	0.00	19.50
P_3P_5	4.33 lekbjdhigcf	20.78 abcd	159.50 jkhig	66.00 lgkjhi	57.00 pmoqn	57.00 klmn	0.00	20.00
P_3P_6	3.81 leknjdhigofm	20.79 abcd	167.00 fdec	69.00 fgehi	55.50 pq	56.50 lmn	0.00	20.00
P_3P_7	4.17 lekbjdhigcfm	20.50 abcd	162.00 jfhig	59.00 lmpronq	57.00 pmoqn	58.00 jklmn	0.00	19.50
P_3P_8	5.10 ebdac	19.70 bcd	163.50 fhig	65.50 lgkjhi	57.00 pmoqn	56.50 lmn	0.00	19.00

Table 6: continued

P_3P_9	5.08 ebdac	23.33 ab	155.00 jki	63.00 lmkjoni	58.00 lpmoqn	58.00 jklmn	2.50	20.00
P_3P_{10}	5.11 ebdac	22.30 abcd	163.50 fhig	69.50 fgedhi	56.00 poq	56.50 lmn	2.50	19.50
P_4P_5	2.14 srxwtvqu	20.46 abcd	157.50 jkhi	61.50 lmkpjonq	67.00 ebdac	67.50 bcd	0.00	20.00
P_4P_6	2.68 snrxwtvqopum	20.49 abcd	134.50 poq	55.00 tusrq	60.00 likmojn	60.00 hijklm	0.00	19.00
P_4P_7	3.84 leknjdhigofm	24.61 ab	144.50 nm	56.00 tusproq	60.00 likmojn	60.50 ghijkl	0.00	19.00
P_4P_8	3.35 lsknjrhitgqopfm	20.98 abcd	140.00 no	51.00 tuv	64.50 ebdfhcg	65.50 bcdef	0.00	19.50
P_4P_9	2.92 lsknjrtvqopum	21.26 abcd	151.50 klm	56.50 tmspronq	66.00 ebdfc	67.00 bcde	0.00	19.50
P_4P_{10}	3.59 leknjdhigqopfm	20.90 abcd	151.50 klm	56.50 tuspronq	55.00 q	55.50 n	1.00	20.00
P_5P_6	3.95 leknjdhigofm	22.14 abcd	140.50 no	51.50 tuv	65.50 ebdfc	66.00 bcde	0.00	19.50
P_5P_7	2.99 lsknjritvqopum	23.74 ab	156.00 jki	67.50 fgejhi	59.50 lpkmojn	60.50 ghijkl	3.16	20.00
P_5P_8	3.32 lsknjrhitgqopm	21.53 abcd	144.00 nm	51.50 tuv	62.00 likfhjg	63.00 efghi	0.00	19.50
P_5P_9	2.19 srxwtvqu	23.86 ab	135.00 po	75.00 bedc	63.00 eikfhjg	64.00 defgh	0.00	20.00
P_5P_{10}	3.52 leknjdhigqopfm	23.98 ab	167.00 fdec	59.00 lmpronq	66.50 ebdac	67.00 bcde	0.00	20.00

Table 6: continued

P_6P_7	2.50 snrxwtvqopu	20.74 abcd	139.50 no	63.50 lmkjni	70.50 a	72.00 a	0.00	19.50
P_6P_8	1.68 xwvu	19.50 bcd	126.00 trsq	53.50 tusrv	63.50 eidfhjg	64.00 defgh	3.25	20.00
P_6P_9	1.80 xwtvu	20.51 abcd	133.50 proq	65.50 lgkjhi	60.00 likmojn	61.00 ghijk	0.00	20.00
P_6P_{10}	2.58 snrxwtvqopum	23.34 ab	174.50 ba	80.50 ba	60.00 likmojn	61.00 ghijk	2.33	19.50
P_7P_8	2.37 srxwtvqopu	22.83 abc	130.00 prsq	69.50 fgedhi	68.00 bac	68.50 abc	0.00	20.00
P_7P_9	3.21 lsknjrhitqopum	21.78 abcd	125.00 trs	59.50 lmkpronq	62.00 likfhjg	63.00 efghi	0.00	20.00
P_7P_{10}	5.19 bdac	22.89 abc	176.00 a	75.50 bedc	67.50 bdac	68.00 abcd	0.00	19.50
P_8P_9	1.20 xw	19.53 bcd	119.00 tvu	59.00 lmpronq	64.50 ebdfhcg	65.50 bcdef	0.00	19.50
P_8P_{10}	3.45 leknjdhigqopfm	23.90 ab	161.50 jfhig	75.50 bedc	59.50 lpkmojn	60.00 hijklm	0.00	20.00
P_9P_{10}	4.12 lekbjdhigcfm	23.65 ab	113.00 v	75.50 bedc	68.50 ba	69.00 ab	0.00	19.50
P_1	2.34 srxwtvqpu	22.46 abcd	156.50 jki	52.00 tusv	62.00 likfhjg	61.00 ghijk	2.90	19.00
P_2	2.78 lsnrwtvqopum	16.46 d	121.00 tvu	49.50 uwv	60.00 likmojn	60.50 ghijkl	0.00	20.00
P_3	2.75 lsnrxwtvqopum	16.20 d	132.50 proq	49.50 uwv	57.00 pmoqn	56.50 lmn	1.00	20.00

Table 6: continued

P_4	1.17 x	17.38 d	122.50 tsu	43.00 xw	63.00 eikfhjg	64.00 defgh	0.00	20.00
P_5	2.01 srxwtvu	17.86 cd	121.50 tvsu	36.00 x	63.00 eikfhjg	64.00 defgh	0.00	19.50
P_6	1.85 sxwtvu	19.55 bcd	126.00 trsq	55.00 tusrq	64.50 ebdfhcg	65.50 bcdef	0.00	20.00
P_7	2.25 srxwtvqpu	18.06 cd	115.50 vu	55.50 tusprq	66.50 ebdac	69.50 ab	2.94	20.00
P_8	2.80 lsknrwtvqopum	20.26 abcd	113.50 v	55.50 tusprq	64.00 eidfhcg	64.50 cdefg	0.00	19.50
P_9	1.17 x	19.89 abcd	125.50 trs	37.50 x	65.00 ebdfcg	66.50 bcde	0.00	19.50
P_{10}	1.61 xwv	23.09 abc	132.00 proq	58.00 lmspronq	67.00 ebdac	67.50 bcd	0.00	20.00
CV	23.19	11.99	2.87	5.91	4.05	3.57	16.17	12.35
Mean	3.51	21.48	148.90	61.89	61.26	61.96	2.30	19.50
$Lsd_{(0.05)}$	1.60	5.26	8.52	7.35	4.28	4.43	3.44	3.09

Means within the same column followed by the same letter are not significantly different at 0.05 probability level as determined by the Lsd method.

4.2 Means of growth and yield characters in the infested environments

4.2.1 Grain yield

The analysis of variance for grain yield per hectare indicated significant differences ($p < 0.01$) among genotypes and among replicates (Appendix 2). Mean grain yield ranged from 1.99 t/ha to 4.99 t/ha for hybrids and from 0.67 t/ha to 2.53 t/ha for inbreds.

Analysis of grain yield per hectare means to locate differences among hybrids and inbreds showed no significant difference ($p < 0.05$) in grain yield per hectare between all crosses of P_1 except P_1P_8 and between all crosses of P_2 except P_2P_5 and P_2P_7. Grain yields per hectare of hybrids P_1P_2, P_1P_3, P_1P_4, P_1P_5, P_1P_6, P_1P_9, P_1P_{10}, P_2P_4, P_2P_5, P_3P_9, P_3P_{10}, and P_7P_{10} were significantly higher than the grain yields per hectare of the rest of the hybrids (Table 7). Among the inbred lines, there was no significant difference in grain yield per hectare except for P_4, P_7 and P_9.

4.2.2 100 grains weight

The analysis of variance indicated significant difference among genotypes ($p < 0.01$) and among replicates ($p < 0.05$) for 100 grains weight (Appendix 2). Mean 100 grains weight ranged from 17.97 g to 27.46 g for hybrids and from 16.20 g to 23.77 g for inbreds. Average weight of 100 grains was 22.39 g (Table 7)

There was no significant difference ($p < 0.05$) in 100 grains weight between hybrids P_1P_4, P_1P_5, P_1P_6, P_1P_9, P_1P_{10}, P_4P_7, P_5P_9 and P_8P_{10}. Mean weights of 100 grains of these hybrids were significantly higher than the mean weights of 100 grains of the rest of the hybrids. Except for P_{10}, there was no significant difference ($p < 0.05$) in 100 grains weight between all other inbreds (Table 7).

4.2.3 Plant height

There were significant differences ($p < 0.01$) among genotypes for plant height (Appendix 2). Overall average plant height was 141.18 cm. Plant height of hybrids ranged from 110.50 cm to176.00 cm while that of the inbreds ranged from 106.50 cm to132.50 cm (Table 7)

Analysis of means of plant height for differences among hybrids and inbreds (as determined by the Lsd method) revealed significant differences ($p< 0.05$) between hybrids and between inbreds (Table 7). Plant heights of hybrids P_1P_4, P_1P_5, P_1P_6 P_1P_7, P_1P_{10}, P_3P_6, P_6P_{10} and P_7P_{10}, were not significantly different ($p< 0.05$). Inbred lines P_2, P_5, P_6, P_7, P_8 and P_9 did not also differ significantly ($p< 0.05$) in plant height. As seen in Table 7, heights of inbred lines P_1 and P_{10} were not significantly different ($p< 0.05$) from heights of some hybrids such as P_1P_2, P_2P_3, P_2P_9, P_2P_{10}, P_4P_8, P_5P_6, P_5P_8 and P_6P_9.

4.2.4 Ear height

The analyses of variance showed significant differences ($p < 0.01$) among genotypes and among replicates for ear height (Appendix 2). Mean ear height ranged from 53.00 cm to 79.00 cm for hybrids and from 34.50 cm to 51.50 cm for inbreds. Overall average ear height was 56.96 cm.

There was neither significant difference ($p< 0.05$) between ear heights of hybrids P_1P_3, P_1P_6, P_1P_7, P_1P_{10} and P_6P_{10} nor between ear heights of hybrids P_1P_4, and P_1P_5, as determined by the Lsd (Table 7). Ear height of hybrid P_6P_{10} was significantly higher than ear height of all other hybrids except for hybrids P_1P_3, P_1P_6, P_1P_7, and P_1P_{10}. Ear heights of inbred lines P_4, P_5, P_6, and P_9 were significantly lower ($p < 0.05$) than ear heights of inbred lines P_1, P_2, P_3, P_7, P_8 and P_{10}. Ear height of inbred line P_{10} was significantly higher than ear heights of all other inbred lines.

4.2.5 Days to 50% anthesis

The analyses of variance indicated that genotypes were significantly different ($p < 0.01$) among themselves for days to 50% anthesis (Appendix 2). Mean days to 50% anthesis ranged from 57.00 days to 69.00 days for hybrids and from 58.00 days to 67.50 days for inbreds with an overall average of 61.44 days.

There were no significant differences ($p< 0.05$) between hybrids P_4P_5, P_5P_{10}, P_7P_8, P_9P_{10}, P_7 and P_{10} for days to 50% anthesis (Table 7). There were also no significant differences ($p< 0.05$) in days to 50% anthesis among crosses of P_2 and crosses of P_3 except for cross P_3P_4. Again crosses of P_1 were not statistically different from each other for days to 50% anthesis except for cross P_1P_{10}. Hybrids P_4P_5, P_5P_{10}, P_7P_8, P_9P_{10}, P_7 and P_{10} shed their pollen later than all other hybrids while hybrids such as P_1P_3, P_1P_6, P_2P_3, P_2P_4, P_2P_9 P_3P_5, P_3P_{10}, P_2, P_3 and P_8 shed their pollen earlier (Table 7).

4.2.6 Days to 50% silking

The analyses of variance for the traits measured in the infested environment showed significant differences ($p < 0.01$) among genotypes and among replicates for days to 50% silking (Appendix 2). Overall mean days to 50% silking was 62.39 days. Mean days to 50% silking for hybrids ranged from 57.50 days to 71.00 days and from 60.00 days to 68.50 days for inbreds (Table 7).

There were no significant differences ($p< 0.05$) among the crosses of P_2 for days to 50% silking. Similarly there was no significant difference ($p< 0.05$) in days to 50% silking among the crosses of P_3 except for cross P_3P_4, (Table 7) Among the crosses of P_1, crosses P_1P_3, P_1P_4 and P_1P_6 were significantly different ($p< 0.05$) from P_1P_{10}. Inbred lines P_1, P_5, P_9 and P_{10} were significantly different ($p< 0.05$) from inbred lines P_2, P_3, P_7, and P_8 for days to 50% silking (Table 7).

4.2.7 Stalk lodging

Stalk lodging was significantly different ($p < 0.01$) among genotypes (Appendix 2). Mean stalk lodging for hybrids ranged from 0.00% to 15.79% and from 0.00% to 2.77% for inbreds. Overall mean percentage stalk lodging was 2.54%.

As seen from Table 7, hybrids P_2P_3, P_2P_4, P_2P_7, P_3P_8, P_4P_{10} and P_5P_7 were not statistically different ($p < 0.05$) from each other but were statistically different ($p < 0.05$) from all other hybrids for stalk lodging. Similarly, all these other hybrids were not significantly different ($p < 0.05$) from each other for stalk lodging.

4.2.8 Plant stand

The analyses of variance indicated significant difference ($p < 0.01$) among genotypes for plant stand (Appendix 2). Mean plant stand per plot ranged from 15.00 plants to 20.00 plants for both hybrids and inbreds. Overall average number of plants per plot was 16.85.

From Table 7, inbred lines P_2 and P_6 were significantly different ($p < 0.05$) from inbred lines P_4 and P_9. Hybrids P_1P_7, P_1P_8, P_1P_{10}, P_2P_{10}, P_3P_4, P_3P_5, P_3P_8, P_4P_5, P_4P_8, P_6P_7, P_6P_8, P_6P_{10}, P_7P_8, P_7P_9, P_8P_9 and P_8P_{10} were not significantly different ($p < 0.05$) from each other for plant stand but they were significantly different ($p < 0.05$) from hybrids P_1P_2, P_1P_5, P_2P_3, P_2P_5, P_2P_9, and P_5P_7 for plant stand (Table 7).

Table 7: Means of grain yield, 100 grains weight, plant height, ear height, days to 50% silking, days to 50% anthesis stalk lodging and plant stand in the infested environment

Entry	Grain yield (t/ha)	100 grains weight (g)	Plant height (cm)	Ear height (cm)	Days to anthesis	Days to silking	Stalk lodging (%)	Plant stand
P_1P_2	4.32 ebdacf	20.57 tnsjkmroqlp	137.00 lojmnkpi	61.50 gfijhk	60.50 fkjiehg	61.50 fjihkg	3.00 c	20.00 a
P_1P_3	4.86 ba	23.63 ebdfhcg	157.50 edfc	74.00 bac	59.00 kjih	59.00 jik	2.63 c	19.00 ab
P_1P_4	4.62 bdac	26.55 ba	175.00 ba	71.00 bdec	58.50 kji	59.00 jik	1.11 c	17.00 ab
P_1P_5	4.39 ebdacf	26.89 ba	173.00 bac	71.00 bdec	61.00 fkjdiehg	62.00 fjeihkg	2.63 c	20.00 a
P_1P_6	4.75 bac	27.30 ba	176.00 a	72.50 bdac	58.50 kji	58.50 jik	2.71 c	17.50 ab
P_1P_7	3.75 ebdhgcf	23.65 ebdfcg	166.50 bdac	75.00 ba	62.00 fkjdiehcg	62.50 fjeidhkg	0.00 c	15.00 b
P_1P_8	1.99 kjnrlpqom	20.43 tnsjkmroqlp	152.00 egdfc	55.00 nmpqjlok	62.00 fkjdiehcg	63.00 fjeidhcg	2.00 c	15.00 b
P_1P_9	4.78 bac	24.99 ba	149.50 egdfhi	57.50 nmijlok	60.00 fkjihg	60.50 jihkg	2.77 c	19.00 ab
P_1P_{10}	4.53 ebdac	27.46 a	176.00 a	76.00 ba	65.00 fbdec	66.50 fbedc	2.94 c	15.00 b
P_2P_3	3.53 kejbidhgcf	21.60 njkmiohlp	134.50 lomnkp	51.50 npqrtos	57.50 kj	58.50 jik	8.78 ba	20.00 a

Table 7: continued

P_2P_4	4.85 ba	23.72 ebdfcg	147.50 lgjmkhi	43.50 w	57.50 kj	58.50 jik	10.38 ba	19.00 ab
P_2P_5	4.99 a	21.95 njkmiohlg	158.50 ebdac	60.00 gfijhk	61.00 fkjdiehg	61.50 fjihkg	2.76 c	20.00 a
P_2P_6	3.91 ebdhgcf	21.37 nsjkmroqlp	141.50 lgjmnkhi	60.00 gfijhk	58.50 kji	59.50 jik	1.47 c	18.00 ab
P_2P_7	3.35 kejidhlgcf	21.70 njkmiohlp	147.50 egjfhi	61.50 gfijhk	59.00 kjih	59.50 jik	15.79 a	19.50 ab
P_2P_8	3.99 ebdhgcf	21.76 njkmiohlp	156.50 ebdfc	53.00 nmpqrtos	59.50 kjihg	60.50 jihkg	0.00 c	18.00 ab
P_2P_9	4.04 ebdhgcf	23.56 ejkdifhg	137.50 lojmnkhi	53.00 nmpqrtos	57.50 kj	57.50 k	0.00 c	20.00 a
P_2P_{10}	3.84 ebdhgcf	22.56 njkmifhlg	138.50 lojmnkhi	51.00 pqrtos	59.50 kjihg	60.50 jihkg	2.00 c	15.00 b
P_3P_4	3.98 ebdhgcf	20.27 tnsjkmroqlp	145.00 lgjfkhi	59.00 gmijhk	62.50 fbjdiehcg	63.50 fbeidhcg	3.50 c	15.00 b
P_3P_5	3.56 kejbidhgcf	20.78 njkmifhlg	144.00 lgjmfkhi	60.00 gmijhk	57.00 k	58.00 jk	1.00 c	15.00 b
P_3P_6	3.95 ebdhgcf	20.79 njkmiohl	169.50 bdac	66.50 gfde	57.00 k	57.50 k	0.00 c	16.00 ab
P_3P_7	3.48 kejbidhgcf	20.50 tnsjkmroqlp	159.50 ebdc	57.50 nmpjlok	57.00 k	57.50 k	3.84 c	15.50 ab
P_3P_8	2.46 kejnihlgpqofm	19.70 tnsjkmroql	158.50 ebdc	65.00 gfieh	58.50 kji	59.50 jik	15.38 a	15.00 b
P_3P_9	4.57 ebdac	23.33 ejkdifhg	148.00 egjfhi	62.50 gfijh	57.00 k	58.00 jk	1.69 c	15.50 ab

Table 7: continued

P_3P_{10}	4.64 bdac	22.30 njkmiohlg	158.50 ebdc	61.00 gfijhk	58.00kji	58.00 jk	2.94 c	19.00 ab
P_4P_5	2.22 kjni,hlpqom	20.46 tnsjkmroqlp	159.00 ebdc	53.50 nmpqrlok	69.00 a	71.00 a	0.00 c	15.00 b
P_4P_6	2.54 kejnidhlgpqofm	20.49 tnsjkmroqlp	129.00 roqnp	50.50 upqrts	60.50 fkjiehg	61.50 fjihkg	2.94 c	17.00 ab
P_4P_7	2.26 kjnihlpqom	24.61 bac	140.00 lgjmnkhi	54.50 nmpqrlok	61.50 fkjdiehg	61.50 fjihkg	2.57 c	16.00 ab
P_4P_8	1.29 rspqo	20.98 nsjkmroqlp	134.00 lomnp	47.00 uv	62.00 fkjdiehcg	63.00 fjeidhcg	2.57 c	15.00 b
P_4P_9	2.07 kjnirlpqom	21.26 nsjkmroqlp	143.50 lgjmkhi	50.50 upqrts	65.00 fbdec	67.50 bdc	0.00 c	15.50 ab
P_4P_{10}	2.64 kejnidhlgpofm	20.90 njkmiohl	143.50 lgjmkhi	50.50 uqrts	58.50 kji	63.00 fjeidhcg	8.73 ba	16.00 ab
P_5P_6	2.61 kejnidhlgpofm	19.35 tnsmroqp	136.00 lojmnkp	51.00 upqrts	63.00 fbdiehcg	63.00 fjeidhcg	0.00 c	15.50 ab
P_5P_7	3.75 ebdhgcf	23.12 ejkifhlg	158.00 ebdc	56.50 nmpjlok	59.50 kjihg	60.00 jihk	8.72 ba	20.00 a
P_5P_8	1.67 nrspqom	21.53 nsjkmroqlp	136.00 lojmnkp	50.50 uqrts	64.50 fbdecg	66.00 fbedc	0.00 c	15.50 ab
P_5P_9	1.71 nrspqom	23.86 bdac	131.50 oqmnp	62.50 gfijh	64.50 fbdecg	65.00 fbedhcg	0.00 c	16.00 ab
P_5P_{10}	2.95 kejnidhlgfm	23.80 ebdfcg	139.50 lgjmnkhi	61.00 gfijhk	66.00 bdac	66.50 fbedc	2.63 c	18.00 ab
P_6P_7	1.21 rspq	18.35 tsrq	137.50 lojmnkhi	58.00 nmijlhk	69.50 fbdecg	65.50 fbedcg	1.00 c	15.00 b

Table 7: continued

P_6P_8	1.73 nrspqom	17.97 tsr	127.00 roqp	51.50 npqrtos	63.00 fbdiehcg	63.50 fbeidhcg	0.00 c	15.00 b
P_6P_9	2.41 kejnihlgpqofm	22.42 njkmiohlg	136.00 lojmnkp	58.50 mijlhk	62.00 fkjdiehcg	62.00 fjeihkg	2.27 c	16.00 ab
P_6P_{10}	3.07 kejidhlgcfm	23.53 ejkdifh,g	175.50 ba	79.00 a	61.50 fkjdiehg	62.50 fjeidhkg	0.00 c	15.00 b
P_7P_8	2.32 kjnihlgpqom	19.31 tnsroqp	126.00 roqp	66.50 gfde	67.00 bac	68.00 bac	0.00 c	15.00 b
P_7P_9	1.20 rspq	21.78 njkmiohlp	117.50 rts	53.00 npqrtos	64.00 fbdehcg	65.00 fbedhcg	0.00 c	15.00 b
P_7P_{10}	4.24 ebdacf	22.89 njkmifhlg	163.00 bdac	67.00 gfdec	62.00 fkjdiehcg	67.00 bedc	0.00 c	19.50 ab
P_8P_9	1.45 nrspqo	20.81 njkmiohl	122.00 rts	53.50 nmpqrlos	62.50 fbjdiehcg	63.00 fjeidhcg	0.00 c	15.00 b
P_8P_{10}	1.52 nrspqom	23.90 bac	152.00 egdfc	65.50 gfdeh	64.50 fbdecg	65.50 fbedcg	0.00 c	15.00 b
P_9P_{10}	2.96 kejnidhlgfm	23.65 ebdfcg	110.50 ts	67.50 fdec	66.00 bdac	67.00 bedc	2.63 c	15.50 ab
P_1	1.87 nrlpqom	20.76 tnskmroqlp	135.50 lojmnkp	48.50 ut	65.50 bdec	66.50 fbedc	0.00 c	17.00 ab
P_2	2.38 kjnihlgpqofm	16.46 tsr	109.00 ts	49.00 urts	59.00 kjih	60.50 jihkg	2.63 c	20.00 a
P_3	1.45 nrspqo	16.20 t	124.50 rqp	49.00 uts	58.00 kji	58.50 jik	2.63 c	18.50 ab
P_4	0.67 rs	17.38 tsr	121.00 rqp	43.50 w	61.50 fkjdiehg	62.50 fjeidhkg	2.77 c	15.00 b

Table 7: continued

P_5	1.39 nrspqo	17.78 tsr	106.50 t	34.00 w	65.50 bdec	67.00 bedc	0.00 c	19.50 ab
P_6	2.53 kejnidhlgpqofm	17.72 tsr	127.00 rts	46.00 wv	61.50 fkjdiehg	62.50 fjeidhkg	0.00 c	20.00 a
P_7	0.99 rsq	18.06 tsrq	107.50 t	49.50 urts	67.50 ba	68.50 ba	2.57 c	17.00 ab
P_8	2.09 kjnirlpqom	20.26 tnsjkmroql	111.00 ts	49.50 urts	58.50 kji	60.00 jihk	3.26 c	19.50 ab
P_9	0.98 rsq	19.89 tnsjkmroql	110.00 ts	34.50 w	65.00 fbdec	66.00 fbedc	0.00 c	15.00 b
P_{10}	1.64 nrspqom	23.77 ebdfcg	132.50 lojmnkp	51.50 pqrtos	66.00 bdac	66.00 fbedc	2.63 c	18.50 ab
CV	30.11	7.59	4.62	6.52	3.48	4.06	12.38	8.35
Mean	2.94	22.39	141.18	56.96	61.44	62.39	2.54	16.85
$Lsd_{(0.05)}$	1.58	3.45	12.90	7.39	5.00	5.09	4.69	4.87

Means within the same column followed by the same letter are not significantly different at 0.05 probability level as determined by the Lsd method.

4.3 Means of *Striga* emergence count and *Striga* host plant damage rating

4.3.1 *Striga* emergence count

Significant differences ($p < 0.01$) were observed for *Striga* count at twelve weeks after planting among the genotypes. *S. hermonthica* plants were first observed at 8 weeks after planting. The highest number of emerged *Striga* plants was observed at 12 weeks after planting. The number of emerged *Striga* plants observed at 12 weeks after planting ranged from 16 to 24 plants per plot with an average of 20.29 plants per plot (Table 8).

Table 8: Mean *Striga* emergence count per plot of diallel crosses among the ten parents at twelve weeks after planting§

Parent	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
P_1	21.00	19.50	16.00	21.50	21.00	19.50	24.00	18.50	18.50	18.50
P_2		22.00	22.00	19.00	23.00	23.00	22.50	19.50	21.00	24.00
P_3			21.00	22.00	18.50	18.50	16.00	17.50	22.50	17.50
P_4				18.50	20.00	20.50	22.50	21.50	17.50	22.00
P_5					17.50	16.00	20.00	22.00	19.50	21.50
P_6						18.50	19.00	22.00	19.00	23.00
P_7							20.00	1900	21.00	22.00
P_8								19.00	22.50	23.50
P_9									18.00	21.50
P_{10}										21.50

§ Values along the diagonal represent parental means, and values above the diagonal represent F_1 hybrid means. Overall mean = 20.29; LSD $_{(0.05)}$ =1.41

4.3.2 *Striga* host plant damage rating

There were no significant differences ($P< 0.05$) among genotypes for *Striga* host plant damage rating (HDR). Mean HDR at twelve weeks after planting ranged from 2.00 to 3.50 with an average of 3.12 for hybrids and 3.15 for inbred lines (Table 9).

Table 9: Mean *Striga* host plant damage rating (1 – 9 scale) for diallel crosses among the ten parents at twelve weeks after planting§

Parent	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
P_1	3.50	3.50	3.50	3.50	3.50	3.50	3.00	3.50	3.50	2.00
P_2		3.50	3.50	3.50	3.00	3.50	3.50	2.50	3.00	2.50
P_3			3.50	3.50	3.00	3.00	3.50	3.00	3.50	2.50
P_4				3.00	3.50	3.50	3.50	3.50	3.00	3.50
P_5					3.50	3.50	3.00	3.50	3.50	2.00
P_6						2.50	2.50	3.50	3.50	3.00
P_7							3.50	3.50	3.50	3.00
P_8								3.50	3.50	3.50
P_9									2.50	2.00
P_{10}										2.50

§ Values along the diagonal represent parental means, and values above the diagonal represent F_1 hybrid means. Overall mean = 3.13; $LSD_{(0.05)} = 1.41$

4.4 Analysis of data across environments

When the data from the two environments were combined and analyzed, significant differences ($p < 0.01$) were observed among the genotypes for grain yield per hectare, 100 grains weight, days to flowering, plant height, plant stand and ear height (Appendix 4). Genotype x environment interaction effect was significant for only ear height. The environment effects were significant ($p < 0.01$) for grain yield per hectare, plant stand, plant height and ear height. The replication effects were significant ($p < 0.01$) for grain yield per hectare, 100 grains weight, days to flowering and ear height.

4.4.1 Comparison of means of traits evaluated in the uninfested and infested environments

The means of the traits calculated for entries evaluated in the different environments are presented in Table 10. Mean grain yields as influenced by *Striga* infestation was significantly different ($p < 0.01$) from mean grain yields of the uninfested environment. In the uninfested environment, yields averaged 3.51 ton/ha over all entries compared to 2.94 ton/ha under *Striga* infestation. Thirteen hybrids in the infested environment seem to have their mean grain yields higher than their counterparts in the uninfested environment. However subjecting the mean grain yields of the two environments to the t-test revealed that only four of these hybrids (P_1P_{10}, P_2P_4, P_5P_7 and P_6P_9) in the infested environment really had their mean grain yields higher than their counterparts in the uninfested environment (Table 10). Apart from these thirteen hybrids, yields in the uninfested environment were higher than yields in the infested environment for all other hybrids. Similarly, except for two parents (P_6 and P_{10}), grain yields of parents in the uninfested environment were higher than grain yields of parents in the infested environment.

The crosses P_1 x P_9, P_1 x P_3, P_2 x P_9, P_7 x P_{10}, P_3 x P_{10}, P_3 x P_8 and P_3 x P_9 in the uninfested environment had yields (6.23, 5.64, 5.60, 5.19, 5.11, 5.10, and 5.08 t/ha respectively) above the achievable yield of 5.0 t/ha for Ghana (FASDEP, 2002). These same crosses in the infested environment had yields ranging from 2.46 t/ha to 4.99 t/ha, all higher than the average maize yield of 1.5 t/ha for Ghana (FASDEP, 2002).

Yield losses due to *Striga* infestation ranged from 0.14 t/ha to 2.64 t/ha for hybrids and from 0.19 t/ha to 1.30 t/ha for parents. Mean grain yield loss over all entries was 0.59 t/ha representing 16.81% reduction in yield due to *Striga* infestation (Table 11).

Mean 100 grains weight as influenced by *Striga* infestation was not significantly different ($p < 0.05$) from mean 100 grains weight of the uninfested environment. In the uninfested environment, 100 grains weight averaged 2.48 g over all entries compared to 2.38 g under *Striga* infestation. Weight losses due to *Striga* infestation ranged from 0.09 g to 3.54 g for hybrids and from 0.08 g to 3.43 g for inbreds. Mean 100 grains weight loss over all entries was 0.83 g due to *Striga* infestation (Table 11).

The mean plant height in the uninfested environment was significantly different ($p < 0.01$) from the mean plant height in the infested environment. The overall average maize plant height in the uninfested and *Striga* infested environments were 148.90 cm and 141.18 cm respectively (Table 7). Averagely, plants in the uninfested environment were taller than those in the infested environment. Reduction in plant height due to *Striga* infestation ranged from 2.00cm to 27.50 cm for hybrids and from 1.50 cm to 21.00 cm for inbreds. On the overall average, there was a 5.25% reduction in maize plant height due to *Striga* infestation.

Overall mean ear height in the infested environment was significantly different ($p < 0.01$) from the overall mean ear height in the uninfested environment. Ear heights averaged 56.96 cm over all entries under *Striga* infestation compared to 61.89 cm in the uninfested environment. All entries in the uninfested environment (except for entries P_1P_2, P_1P_6, P_1P_7, P_1P_8 and P_5P_{10}) exhibited higher ear heights than entries in the infested environment. Reduction in ear height due to *Striga* infestation ranged from 0.00 cm to 14.00 cm for hybrids and from 0.50 cm to 9.00 cm for inbreds. On the overall average, reduction in ear height due to *Striga* infestation was 4.79 cm (Table 11).

Striga infestation did not have significant influence on flowering among the genotypes. The number of days from planting to 50% silking averaged 62.39 days in the infested environment compared to 61.96 days in the uninfested environment. Similarly, the number of days from planting to 50% anthesis averaged 61.44 days and 61.26 days in the infested and uninfested environments respectively. In the uninfested environment, 52.72 % of the entries flowered

4.9 Selection index by ranking method

Rank sum values based on performance of diallel F_1's under *S. hermonthica* infestation is presented in Table 18. The rank sums revealed that nine hybrids out of the best ten hybrids had either P_1 or P_3 as parents (Table 18). Two hybrids each out of these ten hybrids had P_4, P_6, P_9 and P_{10} as parents while a hybrid each had P_2 and P_5 as parents. P_8 was a predominant parent in the worst ten hybrids. Three hybrids each had P_4, P_5, P_6, P_7 and P_9 as parents.

Table 10: Means of grain yield, 100 grains weight, plant height, ear height, days to 50% silking and days to 50% anthesis in the uninfested (uninf) and infested environments compared

Entry	Grain yield (t/ha)		100 grains weight (g)		Plant height (cm)		Ear height (cm)		Days to silking		Days to anthesis	
	Uninf	Infested	Uninf	Infested	Uninf	Infested	Uninf	Infested	Uninf	Infested	Uninf	Infested
P_1P_2	4.94 a	4.32 b	20.92	20.57	144.50 a	137.00 b	61.50 a	61.00 a	57.50	61.50	56.50	60.50
P_1P_3	5.64 a	4.86 b	25.79	23.63	169.00 a	157.50 b	74.00 a	79.00 b	58.00	59.00	58.00	59.00
P_1P_4	4.53 a	4.62 a	23.83	26.55	174.50 a	175.00 a	71.00 a	76.50 b	61.00	59.00	60.00	58.50
P_1P_5	4.38 a	4.39 a	22.99	26.89	171.50 a	173.00 a	71.00 a	74.00 a	60.00	62.00	59.50	61.00
P_1P_6	4.50 a	4.75 a	23.00	27.30	172.50 a	176.00 a	72.50 a	66.00 b	59.50	58.50	58.50	58.50
P_1P_7	4.01 a	3.75 a	29.76	28.65	176.50 a	166.50 b	75.00 a	74.50 a	59.50	62.50	59.00	62.00
P_1P_8	2.70 a	1.99 b	22.36	20.43	157.50 a	152.00 b	55.00 a	50.00 b	65.50	63.00	64.00	62.00
P_1P_9	6.23 a	4.78 b	27.83	24.99	160.00 a	149.50 b	57.50 a	64.00 b	61.00	60.50	61.00	60.00
P_1P_{10}	3.87 a	4.53 b	20.09	27.46	175.50 a	176.00 a	76.00 a	84.00 b	61.50	66.50	61.00	65.00
P_2P_3	4.65 a	3.53 b	21.96	21.60	144.00 a	134.50 b	51.50 a	59.50 b	58.50	58.50	57.50	57.50

Table 10: continued

P_2P_4	3.65 a	4.85 b	20.65	23.72	145.50 a	147.50 a	43.50 a	47.00 a	61.50	58.50	60.50	57.50
P_2P_5	4.87 a	4.99 a	23.23	21.95	165.00 a	158.50 a	60.00 a	74.00 b	59.50	61.50	58.50	61.00
P_2P_6	4.73 a	3.91 b	24.21	21.37	165.00 a	141.50 b	60.00 a	74.00 b	60.50	59.50	60.00	58.50
P_2P_7	3.62 a	3.35 a	22.21	21.70	163.50 a	147.50 b	61.50 a	61.50 a	59.00	59.50	58.00	59.00
P_2P_8	4.76 a	3.99 b	22.60	21.76	163.50 a	156.50 b	53.00 a	66.00 b	56.00	60.50	55.50	59.50
P_2P_9	5.60 a	4.04 b	24.22	23.56	157.00 a	137.50 b	53.00 a	66.00 b	56.00	57.50	56.00	57.50
P_2P_{10}	4.68 a	3.84 b	22.65	22.56	152.50 a	138.50 b	51.00 a	53.00 a	58.00	60.50	57.50	59.50
P_3P_4	4.72 a	3.98 b	20.81	20.27	159.00 a	145.00 b	59.00 a	72.50 b	64.00	63.50	63.00	62.50
P_3P_5	4.33 a	3.56 b	22.74	20.78	159.50 a	144.00 b	60.00 a	66.00 a	57.00	58.00	57.00	57.00
P_3P_6	3.81 a	3.95 a	22.26	20.79	167.00 a	169.50 a	66.50 a	69.00 a	56.50	57.50	55.50	57.00
P_3P_7	4.17 a	3.48 b	23.26	20.50	162.00 a	159.50 a	57.50 a	59.00 a	58.00	57.50	57.00	57.00
P_3P_8	5.10 a	2.46 b	23.24	19.70	163.50 a	158.50 b	65.00 a	65.50 a	56.50	59.50	57.00	58.50
P_3P_9	5.08 a	4.57 a	25.13	23.33	155.00 a	148.00 b	62.50 a	63.00 a	58.00	58.00	58.00	57.00

Table 10: continued

P_3P_{10}	5.11 a	4.64 a	23.84	22.30	163.50 a	158.50 b	61.00 a	69.50 b	56.50	58.00	56.00	58.00
P_4P_5	2.14 a	2.22 a	18.74	20.46	157.50 a	159.00 a	35.50 a	61.50 b	67.50	71.00	67.00	69.00
P_4P_6	2.68 a	2.54 a	21.30	20.49	134.50 a	129.00 b	50.50 a	55.00 a	60.00	61.50	60.00	60.50
P_4P_7	3.84 a	2.26 b	25.89	24.61	144.50 a	140.00 a	54.50 a	56.00 a	60.50	61.50	60.00	61.50
P_4P_8	3.35 a	1.29 b	21.20	20.98	140.00 a	134.00 b	47.00 a	51.00 a	65.50	63.00	64.50	62.00
P_4P_9	2.92 a	2.07 b	22.72	21.26	151.50 a	143.50 a	50.50 a	56.50 a	67.00	67.50	66.00	65.00
P_4P_{10}	3.59 a	2.64 b	22.27	20.90	151.50 a	143.50 b	50.50 a	56.50 a	55.50	63.00	55.00	58.50
P_5P_6	3.95 a	2.61 b	22.14	19.35	140.50 a	136.00 a	51.00 a	51.50 a	66.00	63.00	65.50	63.00
P_5P_7	2.99 a	3.75 b	23.74	23.12	156.00 a	158.00 a	56.50 a	67.50 b	60.50	60.00	59.50	59.50
P_5P_8	3.32 a	1.67 b	23.17	21.53	144.00 a	136.00 b	50.50 a	51.50 a	63.00	66.00	62.00	64.50
P_5P_9	2.19 a	1.71 a	25.21	23.86	135.00 a	131.50 a	62.50 a	75.00 b	64.00	65.00	63.00	64.50
P_5P_{10}	3.52 a	2.95 a	23.98	23.80	167.00 a	139.50 b	61.00 a	59.00 a	67.00	66.50	66.50	66.00
P_6P_7	2.50 a	1.21 b	20.74	18.35	139.50 a	137.50 a	58.00 a	63.50 b	72.00	65.50	70.50	69.50

Table 10: continued

P_6P_8	1.68 a	1.73 a	19.50	17.97	126.00 a	127.00 a	51.50 a	53.50 a	64.00	63.50	63.50	63.00
P_6P_9	1.80 a	2.41 b	20.51	22.42	133.50 a	136.00 a	58.50 a	65.50 b	61.00	62.00	60.00	62.00
P_6P_{10}	2.58 a	3.07 a	23.34	23.53	174.50 a	175.50 a	79.00 a	80.50 a	61.00	62.50	60.00	61.50
P_7P_8	2.37 a	2.32 a	22.83	19.31	130.00 a	126.00 a	66.50 a	69.50 a	68.50	68.00	68.00	67.00
P_7P_9	3.21 a	1.20 b	22.77	21.78	125.00 a	117.50 b	53.00 a	59.50 b	63.00	65.00	62.00	64.00
P_7P_{10}	5.19 a	4.24 b	25.14	22.89	176.00 a	163.00 b	67.00 a	75.50 b	68.00	67.00	67.50	62.00
P_8P_9	1.20 a	1.45 a	19.53	20.81	119.00 a	122.00 a	53.50 a	59.00 b	65.50	63.00	64.50	62.50
P_8P_{10}	3.45 a	1.52 b	24.11	23.90	161.50 a	152.00 b	65.50 a	75.50 b	60.00	65.50	59.50	64.50
P_9P_{10}	4.12 a	2.96 b	25.36	23.65	113.00 a	110.50 a	67.50 a	75.50 b	69.00	67.00	68.50	66.00
P_1	2.34 a	1.87 a	22.46	20.76	156.50 a	135.50 b	48.50 a	52.00 a	61.00	66.50	62.00	65.50
P_2	2.78 a	2.38 a	18.20	16.46	121.00 a	109.00 b	49.00 a	49.50 a	60.50	60.50	60.00	59.00
P_3	2.75 a	1.45 b	18.44	16.20	132.50 a	124.50 b	49.00 a	49.50 a	56.50	58.50	57.00	58.00
P_4	1.17 a	0.67 a	19.38	17.38	122.50 a	121.00 a	34.50 a	43.00 a	64.00	62.50	63.00	61.50

Table 10: continued

P_5	2.01 a	1.39 b	17.86	17.78	121.50 a	106.50 b	34.00 a	36.00 a	64.00	67.00	63.00	65.50
P_6	1.85 a	2.53 b	19.55	17.72	126.00 a	127.00 a	46.00 a	55.00 b	65.50	62.50	64.50	61.50
P_7	2.25 a	0.99 b	19.19	18.06	115.50 a	107.50 b	49.50 a	55.50 a	69.50	68.50	66.50	67.50
P_8	2.80 a	2.09 b	21.15	20.26	113.50 a	111.00 a	49.50 a	55.50 a	64.50	60.00	64.00	58.50
P_9	1.17 a	0.98 a	23.32	19.89	125.50 a	110.00 b	34.50 a	37.50 a	66.50	66.00	65.00	65.00
P_{10}	1.61 a	1.64 a	23.09	23.77	132.00 a	132.50 a	51.50 a	58.00 b	67.50	66.00	67.00	66.00
CV	23.19	30.11	11.99	7.59	2.87	4.62	6.52	5.91	3.57	4.06	4.05	3.48
Mean	3.51 **	2.94 **	22.48	22.39	148.90 **	141.18 **	56.63 **	61.89 **	61.96	62.39	61.26	61.44

** = Significant at 0.01 probability level; Means within the same trait followed by the same letter are not significantly different at 0.05 probability level as determined by the t-test.

Table 11: Differences between the uninfested and infested environments in mean values for grain yield, 100 grains weight, plant height, ear height, days to 50% silking, days to 50% anthesis, percentage stalk lodging and plant stand ('plus sign' = gain in mean and 'minus sign' = loss in mean due to *Striga* infestation)

Genotype	Grain yield (t/ha)	100 grains weight (g)	Plant height (cm)	Ear height (cm)	Days to 50% silking	Days to 50% anthesis	Stalk lodging	Plant stand
P_1P_2	-0.62	-0.35	-7.50	0.50	4.00	4.50	3.00	0.00
P_1P_3	-0.78	-2.16	-11.50	-5.00	1.00	1.00	2.63	0.50
P_1P_4	0.09	2.72	0.50	-5.50	-2.00	-1.50	1.11	3.00
P_1P_5	0.01	3.90	1.50	-3.00	2.00	1.50	2.63	0.00
P_1P_6	0.25	4.30	3.50	6.50	-1.00	0.00	-0.06	2.50
P_1P_7	-0.26	-1.11	-10.00	0.50	3.00	3.00	-0.00	5.00
P_1P_8	-0.71	-1.93	-5.50	5.00	-2.50	-2.00	-0.77	5.00
P_1P_9	-1.45	-2.84	-10.50	-6.50	-0.50	-1.00	2.77	0.50
P_1P_{10}	0.66	7.37	0.50	-8.00	5.00	4.00	2.94	4.00

Table 11: continued

P_2P_3	-1.12	-0.36	-9.50	-8.00	0.00	0.00	8.78	0.00
P_2P_4	1.20	3.07	2.00	-3.50	-3.00	-3.00	7.88	-0.50
P_2P_5	0.12	-1.28	3.50	-14.00	2.00	2.50	2.76	0.00
P_2P_6	-0.82	-2.84	-23.50	-14.00	-1.00	-1.50	-1.30	2.00
P_2P_7	-0.27	-0.51	-6.00	-0.00	0.50	1.00	15.79	0.00
P_2P_8	-0.77	-0.84	-7.00	-13.00	4.50	4.00	0.00	2.00
P_2P_9	-1.56	-0.66	-19.50	-13.00	1.50	1.50	-2.00	0.00
P_2P_{10}	-0.84	-0.09	-14.00	-2.00	2.50	2.00	1.14	4.50
P_3P_4	-0.74	-0.54	-14.00	-13.50	-0.50	-0.50	3.50	4.50
P_3P_5	-0.77	-1.96	-15.50	-6.00	1.00	0.00	1.00	-5.00
P_3P_6	0.14	-1.47	2.50	-2.50	1.00	1.50	0.00	4.00
P_3P_7	-0.69	-2.76	-2.50	-1.50	-0.50	0.00	3.84	4.00
P_3P_8	-2.64	-3.54	-5.00	-0.50	3.00	1.50	15.38	4.00

Table 11: continued

P_3P_9	-0.51	-1.80	-7.00	-0.50	0.00	-1.00	-0.81	4.50
P_3P_{10}	-0.47	-1.54	-5.00	-8.50	2.50	2.00	0.44	-0.50
P_4P_5	0.08	1.72	1.50	-8.00	3.50	2.00	0.00	5.00
P_4P_6	-0.14	-0.81	-5.50	-4.50	1.50	0.50	2.94	2.00
P_4P_7	-1.58	-1.28	-4.50	-1.50	1.00	1.50	2.57	3.00
P_4P_8	-2.06	-0.22	-6.00	-4.00	-2.50	-2.50	2.57	4.50
P_4P_9	-0.85	-1.46	-3.50	-6.00	0.50	-1.00	0.00	4.00
P_4P_{10}	-0.95	-1.37	-8.00	-6.00	7.50	3.50	7.73	4.00
P_5P_6	-1.34	-2.79	-4.50	-0.50	-3.00	-2.50	0.00	4.00
P_5P_7	0.74	-0.62	2.00	-11.00	-0.50	0.00	5.56	0.00
P_5P_8	-1.65	-1.64	-8.00	-1.00	3.00	2.50	0.00	4.00
P_5P_9	-0.48	-1.35	-3.50	-12.50	1.00	1.50	0.00	4.00
P_5P_{10}	-0.57	-0.18	-27.50	2.00	1.50	-0.50	2.63	2.00

Table 11: continued

P_6P_7	-1.29	-2.39	-2.00	-5.50	-6.50	-1.00	1.00	4.50
P_6P_8	0.05	-1.53	1.00	-2.00	-0.50	-0.50	-3.25	5.00
P_6P_9	0.61	1.91	2.50	-7.00	1.00	2.00	2.27	4.00
P_6P_{10}	0.49	0.19	1.00	-1.50	1.50	1.50	-2.33	-4.50
P_7P_8	-0.05	-3.52	-4.00	-3.00	-0.50	-1.00	0.00	5.00
P_7P_9	-2.01	-0.99	-7.50	-6.50	2.00	-2.00	0.00	5.00
P_7P_{10}	-0.95	-2.25	-13.00	-8.50	-1.00	-5.50	0.00	0.00
P_8P_9	0.25	1.28	3.00	-5.50	-2.50	-2.00	0.00	4.50
P_8P_{10}	-1.93	-0.21	-9.50	-10.00	5.50	5.00	0.00	5.00
P_9P_{10}	-1.16	-1.71	-2.50	-8.50	-2.00	-2.50	2.63	4.00
P_1	-0.47	-1.70	-21.00	-3.50	5.50	3.50	-2.90	2.00
P_2	-0.04	-1.74	-12.00	-0.50	0.00	-1.00	2.63	0.00
P_3	-1.30	-2.24	-8.00	-0.50	2.00	1.00	1.63	1.50

Table 11: continued

P_4	-0.50	-2.00	-1.50	0.50	-1.50	-1.50	2.77	5.00
P_5	-0.62	-0.08	-15.00	-2.00	3.00	2.50	0.00	0.00
P_6	0.68	-1.83	1.00	-9.00	3.00	-3.00	0.00	0.00
P_7	-1.26	-1.13	-8.00	-6.00	-1.00	1.00	-0.37	3.00
P_8	-0.71	-0.89	-2.50	-6.00	-4.50	-5.50	3.26	0.00
P_9	-0.19	-3.43	-15.50	-3.00	-0.50	0.00	0.00	4.50
P_{10}	0.03	0.68	0.50	-6.50	-1.50	-1.00	2.63	1.50
Mean	-0.59	-0.83	-6.18	-4.79	0.43	0.18	1.90	2.75

4.4.2 Progressive plant height (cm)

The mean progressive plant heights for the infested and uninfested environments are presented in Figure 1. From the mean progressive plant heights, similar growth patterns were observed for the different environments – a steady growth rate for the first 28 days after planting, then a sharp rate from 28 days after planting to 56 days after planting which steadied again between 56 days after planting and 84 days after planting, after which growth ceased.

For the first 28 days after planting the plants in the uninfested environment had the faster growth rate (0.79 cm per day) relative to the growth rate of the plants in the infested environment (0.71 cm per day). From 28 days after planting to 56 days after planting and from 56 days after planting to 84 days after planting the growth rates of the plants in the infested environment (3.46 cm per day and 1.65 cm per day respectively) were faster than the growth rates of the plants in the uninfested environment (3.34 cm per day and 1.64 cm per day respectively). However, at the time plants ceased growth, plants in the uninfested environment were generally taller than plants in the infested environment. The growth patterns of the five best performing F_1s in the infested and uninfested environments are presented in Figures 2 and 3.

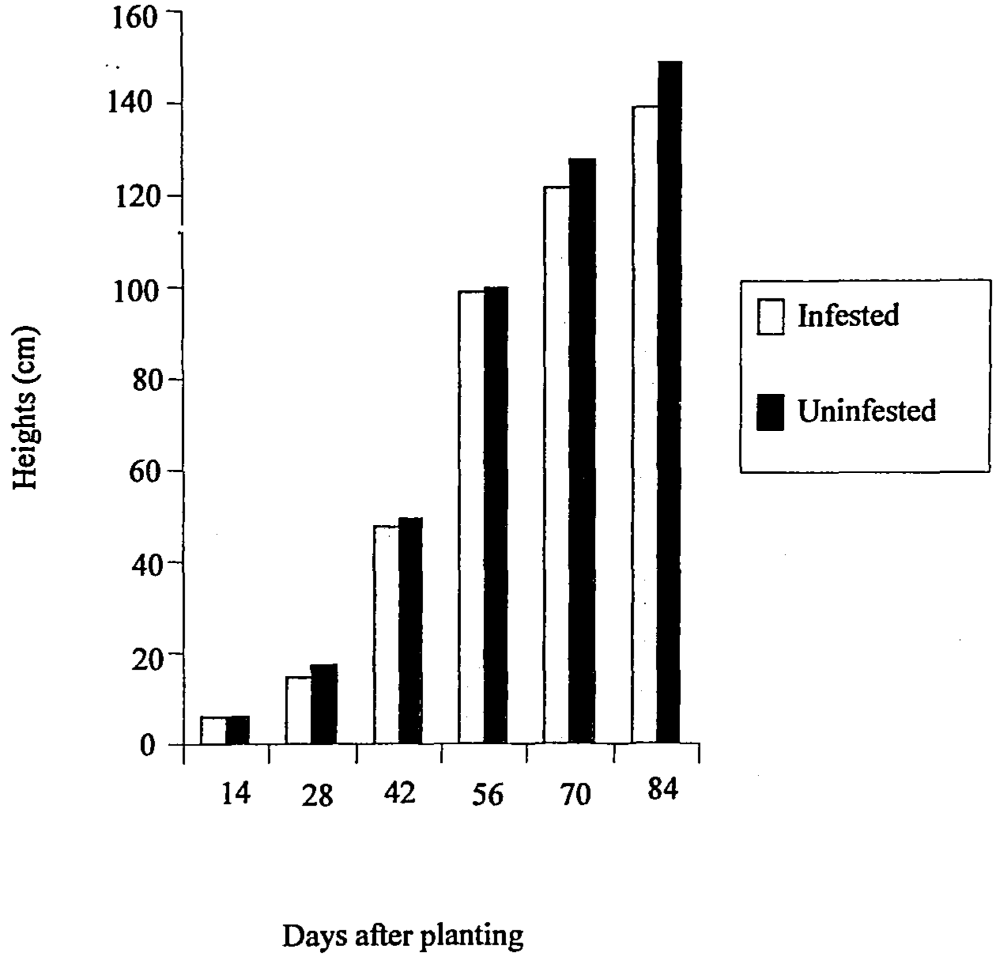

Figure 1: Mean progressive plant height in the infested and uninfested environments

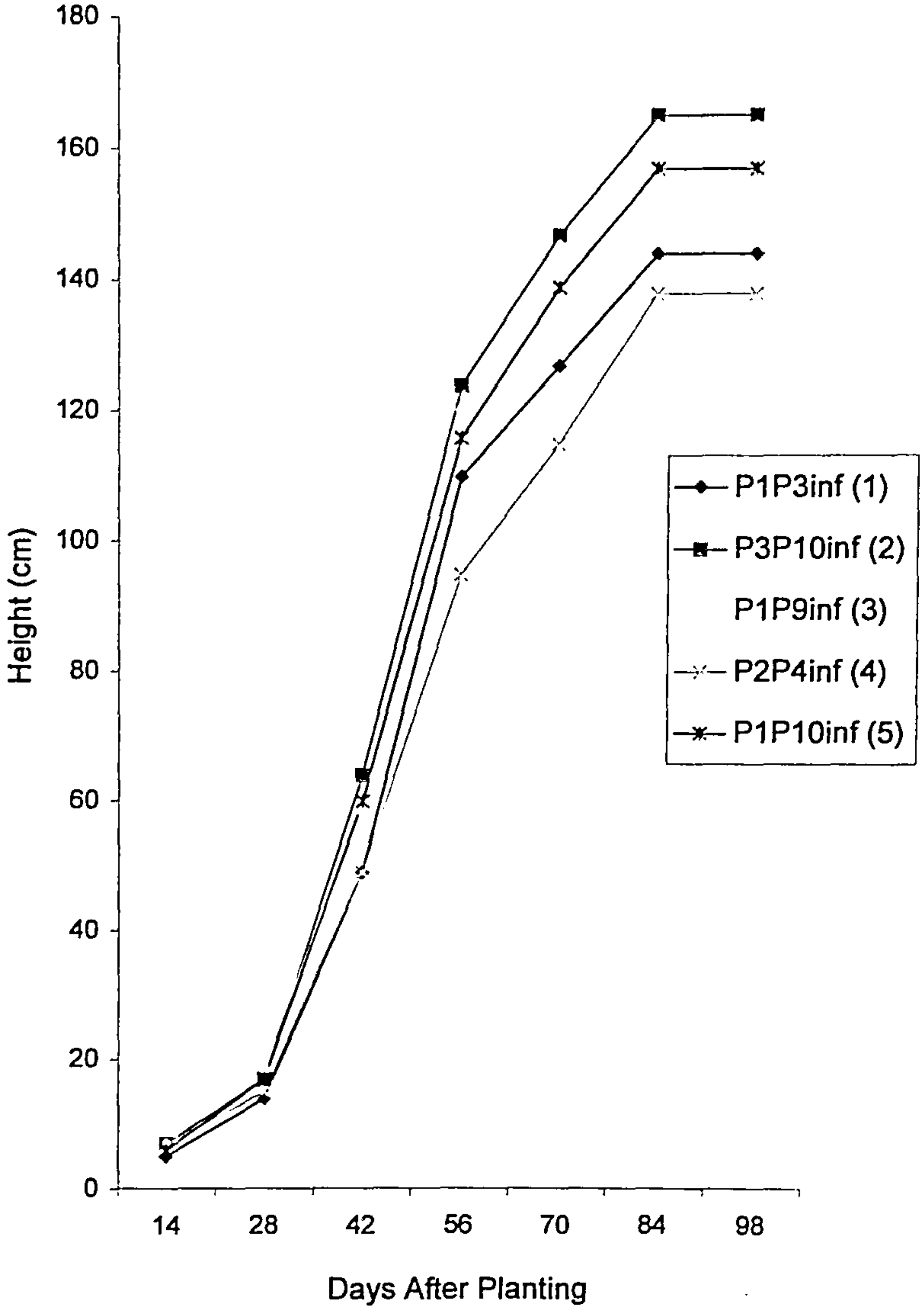

Figure 2: Growth Patterns of the Five Best Performing F_1s in the Infested Environment; inf = infested

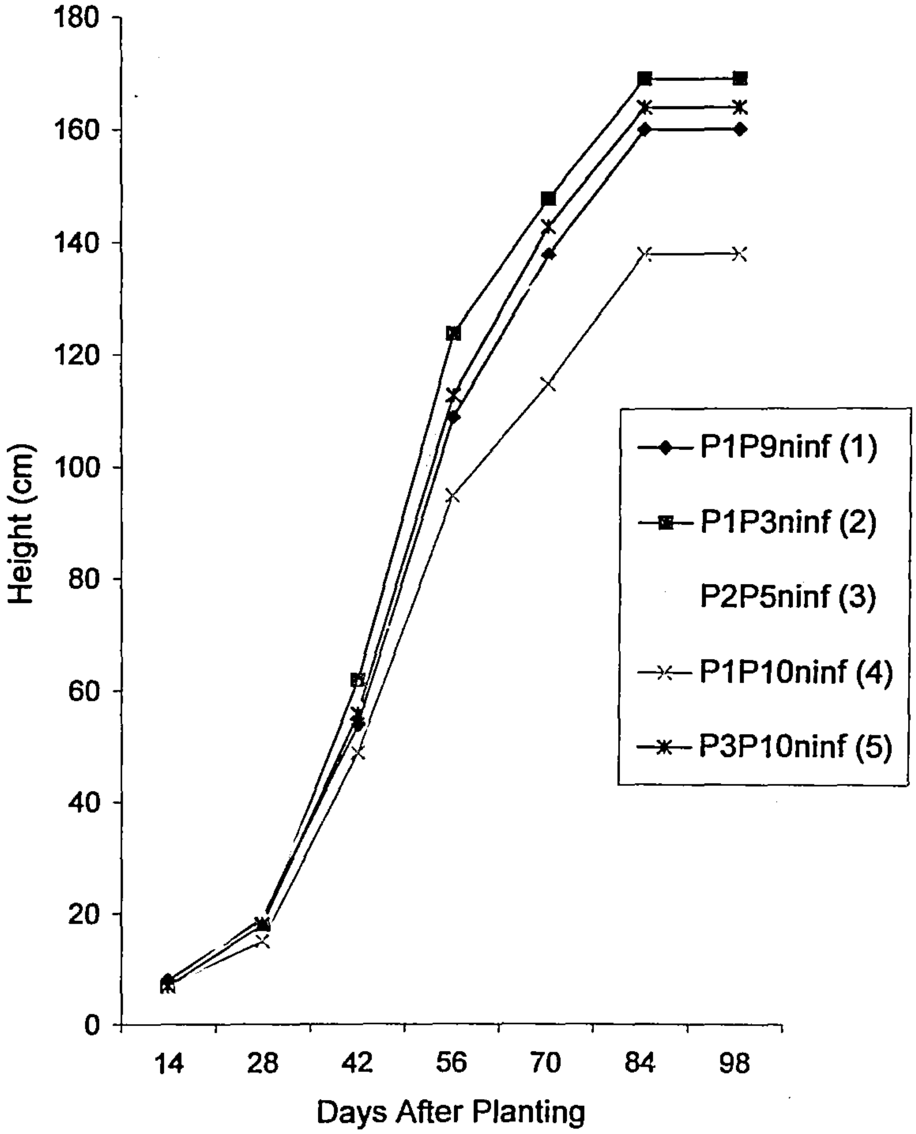

Figure 3: Growth Patterns of the Five Best Performing F_1s in the Uninfested Environment; ninf = uninfested

4.5 Combining ability

When the genotype sum of squares was partitioned into general combining ability (gca) and specific combining ability (sca) effects, both effects were found to be significant ($p < 0.01$) for grain yield, days to male and female flowering and plant height. The mean sums of squares due to gca effects were two to five times higher than those due to sca effects (Appendix 5).

4.5.1 General combining ability

Estimates of gca effects of parents are presented in Table 12. P_2 had the highest gca effects for grain yield per hectare. P_1 had the highest positive value of gca for plant height while P_7 had the highest gca effects for days to silking and to anthesis. P_2 exhibited negative values of gca for all characters except for grain yield.

The performance of parents across the two environments indicated their combining ability (Tables 12). P_2 and P_1 had the highest parental values for yield and plant height respectively and corresponding high combining ability effects. The inbred lines P_1, P_2 and P_3 did not only exhibited the greatest effects of gca for grain yield, but P_1 and P_3 again exhibited high positive gca effects for plant height. Their cross combinations and crosses in which they were involved were the most productive hybrids. One of the parental inbred lines (P_1) of the highest yielding single-cross (P_1 x P_9) exhibited the second highest sca value for yield.

The gca effects for *Striga* resistance under *Striga hermonthica* were generally negative (Table 14). P_1, P_4, and P_9 had positive gca effects, P_4 having the highest gca effect of 1.05.

Table 12: General combining ability effects for yield, plant height and days to 50% silking and anthesis across the two environments for the ten parents

Parents	Grain yield	Plant height	Days to silking	Days to anthesis
P_1	0.53	15.25	-0.75	-0.50
P_2	0.67	-1.67	-2.62	-2.60
P_3	0.52	6.77	-3.60	-3.25
P_4	-0.50	-3.25	0.71	0.46
P_5	-0.18	-1.06	1.36	1.36
P_6	-0.27	-0.83	0.05	0.13
P_7	-0.15	-1.81	1.78	1.46
P_8	-0.44	-6.50	0.69	0.67
P_9	-0.28	-12.85	1.09	1.11
P_{10}	0.10	5.96	1.30	1.15
S.E $_{(gi)}$	±0.03	±1.20	±0.27	±0.23
S.E $_{(gi-gj)}$	±0.06	±2.66	±0.60	±0.51
Lsd $_{(gi-gj)\ 0.05}$	0.43	2.73	1.30	1.19
0.01	0.61	3.90	1.86	1.70

4.5.2 Specific combining ability

The crosses P_1 x P_9 and P_7 x P_{10} had the highest sca effects (1.74) for grain yield while P_2 x P_8 had the highest sca for plant height followed by P_6 x P_{10} (Table 13). P_4 x P_5 had the highest sca effects for both days to silking and days to anthesis. P_2 x P_{10} had negative sca values for all characters. The combinations P_1 x P_2, P_6 x P_8 and P_9 x P_{10} had high negative values of sca effects for plant height (Table 13). All the crosses involving P_3 had positive sca values for plant height and grain yield except for the crosses P_1P_3, P_2P_3 and P_3P_4.

In the *Striga hermonthica* infested environment, sca effects were significant ($p < 0.01$) for *Striga* count at 12 WAP. P_1P_6 had the highest positive sca effects (9.30) for *Striga* resistance while P_2P_9 had the highest negative sca effects (-7.53). All the crosses involving P_6, except P_1P_6, P_3P_6, P_4P_6 and P_5P_6, exhibited negative sca effects for *Striga* resistance (Table 14).

Table 13: Specific combining ability effects for grain yield, plant height and days to 50% silking and anthesis across the two environments for the 45 F_1s

F_1 Hybrids	Grain yield	Plant height	Days to silking	Days to anthesis
P_1P_2	-0.09	-16.47	0.64	0.19
P_1P_3	0.68	-2.91	0.62	0.84
P_1P_4	1.53	14.11	-2.19	-2.12
P_1P_5	0.51	10.43	-1.84	-2.02
P_1P_6	0.84	17.70	-2.52	-2.54
P_1P_7	-0.02	14.43	-2.25	-1.87

Table 13: continued

P_1P_8	-0.77	2.36	2.08	1.42
P_1P_9	1.74	8.72	-1.81	-1.52
P_1P_{10}	-0.46	7.91	1.23	0.94
P_2P_3	-0.12	-9.49	2.50	1.94
P_2P_4	0.05	5.53	-0.31	-0.27
P_2P_5	1.42	8.34	-0.46	-0.41
P_2P_6	-0.11	12.11	0.35	0.32
P_2P_7	-0.06	10.34	-2.13	-1.77
P_2P_8	1.12	24.53	-2.04	-1.98
P_2P_9	1.40	18.13	-3.94	-3.16
P_2P_{10}	-0.04	-2.43	-1.165	-1.45
P_3P_4	-0.19	4.84	4.41	4.13
P_3P_5	0.08	2.41	-2.48	-2.27
P_3P_6	0.60	14.68	-1.67	-2.04
P_3P_7	0.43	12.16	-2.65	-2.62
P_3P_8	0.67	17.09	-1.31	-1.08
P_3P_9	1.07	13.95	-1.71	-1.77
P_3P_{10}	0.73	4.63	-2.67	-2.31
P_4P_5	-1.17	12.93	5.96	5.77
P_4P_6	0.35	-7.81	-2.23	-1.75
P_4P_7	0.67	3.68	-3.71	-2.58
P_4P_8	0.23	3.11	0.62	0.71

Table 13: continued

P_4P_9	0.25	-6.78	3.23	2.52
P_4P_{10}	0.49	1.16	-4.98	-6.27
P_5P_6	0.69	-3.49	0.87	1.36
P_5P_7	0.66	12.24	-5.11	-4.73
P_5P_8	0.08	3.93	0.23	-0.18
P_5P_9	-0.61	3.53	-0.17	-0.12
P_5P_{10}	0.29	4.72	1.87	2.34
P_6P_7	-0.75	-2.49	4.70	4.50
P_6P_8	-0.62	-14.80	0.79	1.05
P_6P_9	-0.37	1.30	-1.86	-1.64
P_6P_{10}	-0.03	23.74	-1.81	-1.93
P_7P_8	-0.09	-7.32	3.56	3.96
P_7P_9	-0.39	-7.72	-1.09	-0.98
P_{7P10}	1.74	21.72	2.21	0.73
P_8P_9	-0.99	-5.78	0.25	0.32
P_8P_{10}	-0.21	13.66	-1.46	-1.23
P_9P_{10}	0.69	-24.99	3.39	3.59
S.E $_{(i,j)}$	0.33	13.55	3.08	2.58
S.E $_{(i,j)-(i,k)}$	0.71	29.27	6.65	5.57
Lsd $_{(0.05)}$	1.41	9.04	4.31	3.94
$_{(0.01)}$	2.02	12.93	6.16	5.64

Table 14: General and specific combining ability effects for *Striga* count at twelve weeks after planting for the ten parents§

Parents	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
P_1	0.98	-2.86	-1.66	-6.41	-5.53	9.30	-3.62	6.80	1.09	-4.62
P_2		-0.46	2.22	-0.53	0.84	-1.33	6.26	-6.33	-7.53	3.26
P_3			-0.67	-3.83	2.55	5.88	-6.53	2.38	3.17	-5.03
P_4				1.08	4.80	5.63	-0.78	1.13	4.42	1.72
P_5					-1.21	0.51	-0.91	-6.49	4.80	1.09
P_6						-0.63	-1.08	-.16	-6.37	-5.08
P_7							-1.79	1.92	2.72	4.01
P_8								-1.13	1.13	1.92
P_9									0.92	-1.28
P_{10}										-0.21

§ Values along the diagonal represent gca effects, and values above the diagonal represent sca effects.

4.6 Heritability

Estimates of gca and sca variance and estimates of heritability are presented in Table 15. The magnitude of σ_{sca}^2 was higher than σ_{gca}^2 for *Striga* count at 12 weeks after planting, grain yield per hectare, number of days to anthesis, number of days to silking and plant height. The narrow sense heritability (h_n^2) values were low, ranging from 0.17 for yield to 0.41 for days to silking. The broad sense heritability (h^2) values were higher ranging from 0.72 to 0.98. The ratios of gca to sca mean square components for yield per hectare and plant height were 0.20 and 0.23 respectively, and for days to silking and days to anthesis they were 0.46 and 0.43, respectively. Plant height had the highest heritability of 98% and *Striga* emergence count had the lowest of 72%. Genetic effects could account for 87% of the variation observed among genotypes for grain yield.

Table 15: Estimates of General combining ability (gca) and Specific combining ability (sca) variance and heritability for all characters

Characters	σ_{gca}^2	σ_{sca}^2	$\sigma_A^2 + \sigma_D^2 / \sigma_P^2$ (h^2)	σ_A^2 / σ_P^2 (h_n^2)	$2\sigma_G^2 / (2\sigma_G^2 + \sigma_S^2)$
STEC - 12	-1.18	28.56	0.72	-0.06	-0.09
Yield/ha	0.41	3.28	0.87	0.17	0.20
Dta	8.64	22.92	0.88	0.38	0.43
Dts	10.45	24.83	0.89	0.41	0.46
Plant ht.	153.19	1011.14	0.98	0.23	0.23

STEC – 12 = *Striga* emergence count at 12 weeks after planting; h^2 = broad sense heritability;
h_n^2 = narrow sense heritability; $2\sigma_G^2 / (2\sigma_G^2 + \sigma_S^2)$ = ratio of gca to sca mean square components
Dta = days to 50% anthesis; Dts = days to 50% silking

4.7 High-parent Heterosis (%)

Estimates of high-parent heterosis (%) are presented in Tables 16a and 16b. High-parent heterosis for grain yield was positive for all of the hybrids with the exception of P_1P_8, P_4P_5, P_4P_8, P_6P_7, P_6P_8, P_6P_9, P_7P_8 and P_8P_9. The range in high-parent heterosis for grain yield was from -46 to 139% with an average of 56% for the 45 hybrids. Similarly except for 3 hybrids (P_1P_2, P_4P_9 and P_9P_{10}), high-parent heterosis for plant height was positive for all other hybrids. It ranged from -14 to 39% with an average of 16% for the 45 hybrids. The plant height of the hybrid P_6P_8 equalled that of the high-parent. Conversely high-parent heterosis for days to flowering was negative for all of the hybrids with the exception P_1P_8, P_3P_4, P_4P_8, P_4P_9, P_6P_7, P_7P_8 and P_9P_{10}. The range in high-parent heterosis for days to flowering was from -16 to 2% with an average of -6% for the 45 hybrids. Days to flowering of the hybrids P_5P_6, P_5P_{10}, P_6P_7 and P_6P_8 equalled that of the high-parent.

Estimates of high-parent heterosis (%) for grain yield in infested and uninfested environments are presented in Table 16b. High-parent heterosis (%) for grain yield was positive for about 80% of the 45 hybrids in both the infested and uninfested environments. Hybrids in the infested environment generally had higher high-parent heterosis than hybrids in the uninfested environment. The range in high-parent heterosis for yield in the infested environment was from -52% to 215% with an average of 65% for the 45 hybrids while the range in the uninfested environment was from -57% to 166% with an average of 59% for the 45 hybrids.

Table 16a: Parental means, hybrid means and high-parent heterosis (%)* for grain yield and associated parameters across environments

Parents	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
P_1	**2.10**	4.13	4.75	4.58	3.88	4.12	3.38	2.34	5.01	3.12
	146.00	140.75	162.75	169.75	168.25	175.75	171.50	154.75	154.75	172.75
	63.75	59.50	58.50	60.00	61.00	59.00	61.00	64.25	60.75	64.00
	63.75	58.50	58.50	59.25	60.25	58.50	60.50	63.00	60.50	63.00
P_2	60	**2.58**	4.09	3.25	4.94	3.32	3.49	4.37	4.82	3.76
	-4	**115.00**	139.25	144.25	149.25	153.25	150.50	160.00	147.25	145.50
	-7	**60.50**	58.50	60.00	60.50	60.00	59.25	58.25	56.75	59.25
	-8	**59.50**	57.50	59.00	59.75	59.25	58.50	57.50	56.75	58.50
P_3	126	59	**2.10**	2.85	3.44	3.88	3.83	3.78	4.32	4.38
	11	9	**128.50**	152.00	151.75	64.25	160.75	161.00	151.50	161.00
	-8	-3	**57.50**	63.75	57.50	57.00	57.75	58.00	58.00	57.25

Table 16a: continued

P_3	-8	-3	**57.50**	62.75	57.25	56.25	57.00	57.75	57.50	57.00
P_4	118	90	38	**0.92**	1.18	2.61	3.05	2.32	2.50	3.11
	16	19	18	**121.75**	152.25	131.75	142.25	137.00	120.75	147.50
	-6	-5	1	**63.25**	60.25	60.75	61.00	64.25	67.25	59.25
	-7	-5	1	**62.25**	59.00	60.25	60.75	63.25	65.50	56.75
P_5	85	90	64	-31	**1.71**	3.28	3.36	2.49	1.95	3.23
	15	30	18	25	**114.00**	138.25	153.00	140.00	133.25	153.25
	-7	-8	-12	-8	**65.50**	64.50	60.25	64.50	64.50	66.75
	-6	-7	-11	-8	**64.25**	64.25	59.50	63.25	63.75	66.25
P_6	88	29	77	19	50	**2.19**	1.85	1.70	2.10	2.83
	20	26	28	8	14	**121.50**	138.50	121.50	131.25	172.50
	-8	-6	-11	-5	-2	**64.00**	68.75	63.75	61.50	61.75
	-8	-6	-11	-4	0	**63.00**	67.50	63.25	61.00	60.75

Table 16a: continued

P_7	66	35	82	88	97	-16	**1.62**	2.35	2.21	4.71
	18	31	25	17	34	14	**111.50**	128.00	121.25	169.50
	-12	-14	-16	-12	-12	0	**69.00**	68.25	64.00	67.50
	-10	-13	-15	-9	-11	1	**67.00**	67.50	63.00	64.75
P_8	-4	68	53	-5	2	-30	-4	**2.44**	1.32	2.48
	6	39	25	13	23	0	14	**112.25**	118.50	156.75
	1	-6	-7	2	-2	0	-1	**62.25**	64.25	62.75
	-1	-6	-6	2	-2	0	1	**61.25**	63.50	62.00
P_9	139	87	106	134	14	-4	36	-46	**1.07**	3.54
	6	25	16	-9	13	8	3	1	**117.75**	111.75
	-8	-14	-13	2	-3	-8	-7	-3	**66.25**	68.00
	-7	-13	-12	1	-3	-7	-6	-2	**65.00**	67.25

Table 16a: continued

P_{10}	41	46	109	92	89	29	191	2	119	**1.62**
	18	12	23	13	17	32	30	20	-14	**130.50**
	-4	-11	-14	-11	0	-8	-2	-6	2	**66.75**
	-5	-12	-14	-15	0	-9	-3	-7	1	**66.50**

Highlighted values are the parental means; hybrid means are above the highlighted values; high-parent heterosis (%) is below the highlighted values. The first, second, third and fourth values represent grain yield, plant height (cm), days to 50% silking and days to 50% anthesis respectively.

Table 16b: Parental means, hybrid means and high-parent heterosis* for grain yield in infested and uninfested environments

Parents	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
P_1	**1.87**	4.32	4.86	4.62	4.39	4.75	3.75	1.99	4.78	4.53
	2.34	4.94	5.64	4.53	4.38	4.50	4.01	2.70	6.23	3.87
P_2	82	**2.38**	4.53	4.85	4.99	3.91	3.35	3.99	4.04	3.84
	78	**2.78**	4.65	3.65	4.87	4.73	3.62	4.76	5.60	4.68
P_3	104	94	**1.45**	3.98	3.56	3.95	3.48	2.46	4.57	4.64
	105	94	**2.75**	4.72	4.33	3.81	4.17	5.10	5.08	5.11
P_4	85	88	58	**0.67**	2.22	2.54	2.26	1.29	2.07	2.64
	87	92	71	**1.17**	2.14	2.68	3.84	3.35	2.92	3.59
P_5	-16	101	90	90	**1.39**	2.61	3.73	1.67	1.71	2.95
	-4	166	65	67	**2.01**	3.95	2.99	3.32	2.19	3.52
P_6	101	110	55	41	68	**2.53**	1.21	1.73	2.41	3.07
	31	75	70	30	70	**1.85**	2.50	1.68	1.80	2.58

Table 16b: continued

P_7	70	61	175	146	56	140	0.99	2.32	1.20	4.24
	101	68	72	58	39	52	2.25	2.37	3.21	5.19
P_8	18	215	183	60	0	128	-38	2.09	1.45	1.52
	82	85	86	7	45	71	20	2.80	1.20	3.45
P_9	111	61	3	168	-20	23	80	-52	0.98	2.96
	150	123	97	38	19	9	75	11	1.17	4.12
P_{10}	-32	-5	21	11	21	159	-31	-27	81	1.64
	-40	-3	40	-15	43	131	-57	23	156	1.60

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* Highlighted values are the parental means; hybrid means are above the highlighted values; high-parent heterosis (%) is below the highlighted values. The upper and lower values represent infested and uninfested environments respectively.

4.8 Correlation Studies

In the infested environment, correlations between *Striga* count and agronomic traits were not significant ($p < 0.05$) and were positive for only 100 grains weight, number of days to flowering and stalk lodging. Similarly the relationship between *Striga* host plant damage rating and all other traits were not significant ($p < 0.05$) and were negative for all these traits except for stalk lodging, plant stand and *Striga* count (Table 17). The correlation between days to silking and days to anthesis was significant, positive and highest in both the infested and uninfested environments. The association between these two traits was real as the partial correlation was also significant, positive and the highest. Grain yield was significantly and negatively correlated with days to flowering but significantly and positively correlated with 100 grains weight, plant height and ear height under both environments. As seen in Table 17, the association between grain yield and days to flowering was real and negative while the association between grain yield and 100 grains weight was real and positive but weak. Again the association between grain yield and plant stand was real and positive in the infested environment. There was also a real negative association between days to flowering and stalk lodging in the infested environment.

Table 17: Correlation coefficients for grain yield, 100 grains weight (wt), plant height, ear height, number of days to 50% silking (Dts), number of days to 50% anthesis (Dta), stalk lodging, plant stand, STEC - 12 and *Striga* host plant damage rating (HDR).

Environment	Trait	100 grains wt	Plant height	Ear height	Dts	Dta	Stalk lodging	Plant stand	STEC - 12	HDR
***Striga* infested**	Grain yield	0.59**	0.48**	0.54**	-0.52**	-0.50**	0.21	0.41*	-0.15	-0.10
		0.28*		0.13	-0.48**	-0.52**	0.18	0.57**	0.01	-0.06
	100 grains wt.		0.63**	0.62**	-0.13	-0.13	0.06	0.07	0.20	-0.16
				0.30*	0.09	0.09	-0.02	0.09	0.24	-0.14
	Plant height			0.66**	-0.26*	-0.24*	0.12	-0.01	-0.01	-0.07
	Ear height				-0.24	-0.19	-0.06	-0.10	-0.12	-0.12
					0.11	0.16	-0.21	-0.12	0.20	-0.10
	Dts					0.97**	-0.33*	-0.33*	0.15	-0.18
						0.94**	-0.31*	-0.35*	0.06	-0.21

Table 17: continued

Striga infested	Dta						-0.38*	-0.36*	0.01	-0.23
							-0.36*	-0.38*	0.01	-0.26
	stalk lodging							0.29*	0.39	0.12
								0.29*	0.37	0.13
	Plant stand								-0.02	0.05
									-0.01	0.05
	STEC									0.06
										0.06
Uninfested	Grain yield	0.55**	0.15	0.43**	-0.48**	-0.46**	0.03	0.41*		
		0.34*		0.18	-0.36**	-0.34**	-0.05	-0.06		
	100 grains wt.		0.50**	0.50**	-0.20	-0.17	-0.02	-0.05		
				0.28	0.04	0.07	-0.09	-0.04		
	Plant height			0.14	-0.10	-0.11	0.11	-0.04		

Table 17: continued

Uninfested	Ear height	-0,18	-0,17	-0,08	0,09
		0,13	0,13	-0,19	0,13
	Dts		0,99**	-0,33*	-0,33*
			0,99**	-0,12	-0,08
	Dta			-0,10	-017
				-0,14	-0,13
	Stalk lodging				0,10
					0,10

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* Significant at the 0,05 probability level; ** Significant at the 0,01 probability level; STEC – 12 = Striga emergence count at 12 weeks after planting
The lower values represent partial correlation coefficients; plant height was controlled for partial correlation

4.9 Selection index by ranking method

Rank sum values based on performance of diallel F_1's under *S. hermonthica* infestation is presented in Table 18. The rank sums revealed that nine hybrids out of the best ten hybrids had either P_1 or P_3 as parents (Table 18). Two hybrids each out of these ten hybrids had P_4, P_6, P_9 and P_{10} as parents while a hybrid each had P_2 and P_5 as parents. P_8 was a predominant parent in the worst ten hybrids. Three hybrids each had P_4, P_5, P_6, P_7 and P_9 as parents.

Table 18: Rank sum values based on performance of diallel F_1's under *S. hermonthica* infestation using grain yield, *Striga* count, 100 grains weight (g), plant height (cm), ear height (cm), days to silking, and days to anthesis

Entry	Grain yield (t/ha)	Rank	*Striga* count	Rank	100 grains weight (g)	Rank	Plant height (cm)	Rank	Ear height (cm)	Rank	Days to silking	Rank	Days to anthesis	Rank	Rank sum
P_1P_6	4.75	5	19.50	16	27.30	2	176.00	1	72.50	5	58.50	7	58.50	10	46
P_1P_3	4.86	2	16.00	1	23.63	13	157.50	15	74.00	4	59.00	10	59.00	14	59
P_1P_4	4.62	7	21.50	25	26.55	4	175.00	4	71.00	6	59.00	11	58.50	9	66
P3P_{10}	4.64	6	17.50	5	22.30	21	158.50	13	61.00	18	58.00	6	58.00	8	72
P_3P_6	3.95	16	18.50	11	20.79	33	169.50	6	66.50	10	57.50	2	57.00	2	80
P_1P_5	4.39	10	21.00	22	26.89	3	173.00	5	71.00	7	62.00	23	61.00	22	92
P_1P_9	4.78	4	18.50	8	24.99	5	149.50	19	57.50	26	60.50	16	60.00	19	97
P_1P_{10}	4.53	9	18.50	9	27.46	1	176.00	2	76.00	2	66.50	39	65.00	39	101

Table 18: continued

P_3P_6	4.57	8	22.50	36	23.33	16	148.00	20	62.50	14	58.00	5	57.00	4	103
P_2P_4	4.85	3	19.00	12	23.72	10	147.50	21	43.50	45	58.50	9	57.50	6	106
P_3P_5	3.56	21	18.50	10	20.78	34	144.00	24	60.00	22	58.00	4	57.00	1	116
P_2P_9	4.04	13	21.00	23	23.56	14	137.50	31	53.00	34	57.50	1	57.50	7	123
P_3P_7	3.48	23	16.00	2	20.50	36	159.50	9	57.50	27	57.50	3	57.00	3	123
P_3P_8	2.46	31	17.50	4	19.70	41	158.50	12	65.00	13	59.50	14	58.50	12	127
P_5P_7	3.75	20	20.00	20	23.12	17	158.00	14	56.50	28	60.00	15	59.50	18	132
P_1P_7	3.75	19	24.00	43	23.65	11	166.50	7	75.00	3	62.50	25	62.00	26	134
P_2P_5	4.99	1	23.00	39	21.95	22	158.50	11	60.00	20	61.50	20	61.00	23	136
P_6P_{10}	3.07	25	23.00	41	23.53	15	175.50	3	79.00	1	62.50	26	61.50	25	136
P_2P_8	3.99	14	19.50	17	21.76	24	156.50	16	53.00	33	60.50	17	59.50	16	137
P_1P_2	4.32	11	19.50	15	20.57	35	137.00	33	61.50	16	61.50	19	60.50	20	149
P_2P_7	3.35	24	22.50	35	21.70	25	147.50	22	61.50	17	59.50	13	59.00	15	151

Table 18: continued

P_7P_{10}	4.24	12	22.00	34	22.89	18	163.00	8	67.00	9	67.00	41	62.00	30	152
P_2P_6	3.91	17	23.00	40	21.37	28	141.50	27	60.00	21	59.50	12	58.50	11	156
P_2P_3	3.53	22	22.00	29	21.60	26	134.50	37	51.50	36	58.50	8	57.50	5	163
P_6P_9	2.41	32	19.00	14	22.42	20	136.00	36	58.50	24	62.00	24	62.00	29	179
P_4P_7	2.26	34	22.50	37	24.61	6	140.00	28	54.50	30	61.50	22	61.50	24	181
P_1P_8	1.99	37	18.50	7	20.43	39	152.00	17	55.00	29	63.00	27	62.00	27	183
P_2P_{10}	3.84	18	24.00	44	22.56	19	138.50	30	51.00	38	60.50	18	59.50	17	184
P_5P_9	1.71	39	19.50	18	23.86	8	131.50	39	62.50	15	65.00	34	64.50	37	190
P_5P_{10}	2.95	27	21.50	27	23.80	9	139.50	29	61.00	19	66.50	40	66.00	41	192
P_3P_4	3.98	15	22.00	30	20.27	40	145.00	23	59.00	23	63.50	32	62.50	31	194
P_8P_{10}	1.52	41	23.50	42	23.90	7	152.00	18	65.50	12	65.50	37	64.50	38	195
P_4P_{10}	2.64	28	22.00	31	20.90	31	143.50	26	50.50	42	63.00	29	58.50	13	200
P_9P_{10}	2.96	26	21.50	28	23.65	12	110.50	45	67.50	8	67.00	42	66.00	42	203

Table 18: continued

P_4P_6	2.54	30	20.50	21	20.49	37	129.00	40	50.50	40	61.50	21	60.50	21	210
P_5P_6	2.61	29	16.00	3	19.35	42	136.00	34	51.00	39	63.00	30	63.00	33	210
P_4P_9	2.07	36	17.50	6	21.26	29	143.50	25	50.50	41	67.50	43	65.00	40	220
P_4P_5	2.22	35	20.00	19	20.46	38	159.00	10	53.50	31	71.00	45	69.00	44	222
P_4P_8	1.29	43	21.50	26	20.98	30	134.00	38	47.00	44	63.00	28	62.00	28	237
P_6P_7	1.21	44	19.00	13	18.35	44	137.50	32	58.00	25	65.50	36	69.50	45	239
P_7P_9	1.20	45	21.00	24	21.78	23	117.50	44	53.00	35	65.00	35	64.00	35	241
P_8P_9	1.45	42	22.50	38	20.81	32	122.00	43	53.50	32	63.00	31	62.50	32	250
P_5P_8	1.67	40	22.00	32	21.53	27	136.00	35	50.50	43	66.00	38	64.50	36	251
P_6P_8	1.73	38	22.00	33	17.97	45	127.00	41	51.50	37	63.50	33	63.00	34	261
P_7P_8	2.32	33	1900	45	19.31	43	126.00	42	66.50	11	68.00	44	67.00	43	261

CHAPTER FIVE

5.0 DISCUSSION

5.1 Performance of single crosses

The mean plant height in the uninfested environment (control) was significantly different from the mean plant height of the *S. hermonthica* infested environment. On the average, there was a 5.25% loss in height due to *Striga* infestation. Loss in plant height and vigour has been associated with *Striga* infestation as reported by Nagawa (1991), Reda and Kebebe (1994) and Mbasa (1994). *Striga* is known to cause stunting in its host (IITA, 1991; Kim, 1991). The retardation in growth could be the effect of *Striga* attributed to suppression of internode elongation not the number of nodes or leaves per plant.

Hybrids that show low *Striga* emergence or resistance to attachment, but low tolerance to the few parasitic plants that do attach would be of little value, even in lightly infested areas. Low emergence or high resistance by itself would only go part way towards controlling the parasite. High resistance must be accompanied by good to high tolerance to be of significance. In this study, host plant damage rating (a host tolerance index) was not significant ($p < 0.05$). This suggests that the host plants were not only resistant to the few parasitic plants that did attach but were also tolerant. The low and non-significant correlation of *Striga* emergence count with grain yield (-0.15) also suggests a good tolerance of the entries in this study to *S. hermonthica* infestation.

Correlation coefficients among plant height and ear height and among days to silking and days to anthesis were all positive and significant suggesting that one could respectively use either of these traits to select for the other. The correlation between *Striga* emergence and yield was r = -0.15, indicating that only 2.25% (r^2) of the variation in grain yield was explained by variation in number of emerged *Striga*. The negative and non-significant correlation between grain yield and *Striga* emergence count suggest that the most resistant hybrids may not necessarily be the highest yielding hybrids. This was evident from the sums of the ranking, as the most resistant hybrid was not necessarily the highest yielding. This again means that in selecting for superior parents, both traits should be considered.

The correlation between plant height and number of days to flowering was low and significant (r = -0.24). This implies that the two characters are inversely correlated but weakly. Probably some of the genes controlling short plant height may be weakly linked to some of the genes controlling late flowering or the genes controlling short plant height may have some pleiotropic effect on late flowering. On the contrary, correlation between number of days to silking and number of days to anthesis was extremely high, r = 97 (infested environment) and r = 99 (uninfested environment), suggesting that the two traits may either be controlled by the same or similar genes or may have pleiotropic effect on each other or may have linkage genes.

5.2 Combining ability

Both sca and gca effects for *Striga* count at 12 weeks after planting were significant at $p < 0.01$ and $p < 0.05$, respectively. This suggests that non-additive gene action was more important than additive gene action for S. *hermonthica* emergence. That is, the genes associated with this trait have dominance genetic action. This is in agreement with Kim (1994) and Akanvou *et. al.*, (1997) who reported highly significant sca effects and a 3.5 fold ratio for sca:gca mean squares at 12 weeks after planting. The parental lines P_1, P_4 and P_9 had positive gca effects for *Striga* emergence count indicating that these parents contributed to increase *S. hermonthica* resistance in crosses. Twenty-four out of the forty-five single crosses had positive sca effects suggesting that the inbred parents involved in these crosses are genetically divergent among themselves. In descending order P_4, P_1 and P_9 were the best general combiners whilst P_1P_6, P_1P_8, P_2P_7, P_3P_6, P_4P_6, P_5P_9, P_4P_5, P_4P_9, P_7P_{10} and P_2P_{10} were the ten best specific combiners for *Striga* resistance.

Although the mean squares for sca were highly significant for all other traits measured, they were lower compared with those for gca. This indicated that the additive effects (gca) were more important than the non-additive effects (sca) for these traits. The predominance of additive over non-additive effects is relatively common for grain yield (Gama *et al.*, 1995; Beck *et al.*, 1990).

Both gca and sca effects were highly significant for grain yield, plant height and days to male and female flowering. For these traits, even though both the additive and non-additive effects are relevant non-additive gene action played a minor role. The highly significant gca effects for these traits indicate the importance of additive genetic effects in the materials studied. It also indicates that the inbred lines contributed differently in the crosses in which they were involved. Again, the highly significant sca for these traits indicated that there were hybrid combinations that had performance different from that expected only on the gca effects. The highest yielding single-cross (P_1 x P_9) showed a high sca value, and one of the lines involved in this cross exhibited a high gca value. The high sca value of this cross along with positive and high gca value from one of its inbred lines, afforded this single-cross to be the highest yielding in this set. Thus both additive and non-additive effects contributed to the high productivity of this single cross. Estimates of general combining ability for plant height ranged from -12.85 cm per plant (P_9) to 15.25 cm per plant (P_1). Lines P_8 and P_9 contributed towards reducing plant height, which is desirable, while lines P_1 and P_3 contributed to increase plant height.

Considering the interaction, the non-significance of genotype x environment interaction indicates that the gca of the inbred lines and the sca of the specific hybrid combinations were not altered by the environmental conditions (infestation and uninfestation) the hybrids were subjected to. This means that the choice of the best parent can be based on the average gca effects obtained across the environments. That is, parental lines selected for hybrids at one environment could be used for another environment.

The parental lines P_1, P_2, P_3 and P_{10} had positive gca effects, indicating that these parents contributed to increase yield in crosses. In descending order, P_2,

P_1, P_3 and P_{10} were the best general combiners for grain yield. The top ten single crosses in terms of yield had these lines as parents and all had positive sca effects except crosses P_1 x P_2 and P_1 x P_{10}. This indicated that both additive and non-additive effects were important in the genetic control of grain yield for the top ten single crosses. This is in agreement with Nass *et. al.* (2000) and Aguiar *et. al.*, (2003) who reported that for grain yield of maize, the additive and non-additive effects contribute quite similarly for the control of this character. In descending order P_1P_9, P_7P_{10}, P_1P_4, P_2P_5, P_2P_9, P_2P_8, P_3P_9, P_1P_6, P_3P_{10} and P_9P_{10} were the best ten specific combiners for grain yield.

The magnitude of σ_{sca}^2 was higher than σ_{gca}^2 for *Striga* count at 12 weeks after planting, grain yield per hectare, number of days to anthesis, number of days to silking and plant height. The higher values of σ_{sca}^2 indicate the presence of non-additive gene action for all these characters. This is supported by the low values of the ratios of the gca to sca components of variance. The closer this ratio is to 1, the greater the predictability based on gca alone, anything less than 1 indicates that non-additivity gene effects are more important than additivity gene effects in controlling the inheritance of these traits. Thus, the relatively low values of the ratios of the gca to sca components of variance implies that sca plays a major role in predicting the F_1 hybrid performance. In other words reliance on the performance of the F_1 hybrids is effective in selecting superior parents. Again it can be inferred from the low values of the ratios of the gca to sca components of variance that the inbred lines had a narrow genetic base.

The broad-sense heritability (h^2) values for *Striga* count at 12 weeks after planting, grain yield per hectare, number of days to anthesis, number of days to silking and for plant height were higher than the narrow sense heritability (h_n^2). Considering the variability observed among genotypes in their ability to prevent attachment of the parasite to their roots, 72% could be accounted for by genetic effects. The relatively low narrow sense heritability (h_n^2) estimates suggest that non-additive effects were important in the genetic control of these traits and that sca plays a greater role in selecting superior parents. It also indicates that dominant desirable characters can easily be transferred from the inbred lines to the single-cross hybrids.

5.3 High – Parent Heterosis

High-parent heterosis (%) for yield of the forty-five (45) hybrids in the infested environment was greater than high-parent heterosis for yield of the 45 hybrids in the uninfested environment. This suggests that non-additive effects (dominance and epistasis) contributed more for the control of the grain yield trait in the infested environment. It also suggests that a significant portion of *Striga* resistance is derived from gene complexes as thought by Kim *et al.*, (1998), which may be best exploited in hybrid combination where disruption through segregation would be minimized. It thus indicates that epistsis played a great role in inheritance of resistance to *S. hermonthica* (Adetimirin *et al.*, 2001). Also these results indicate that heterosis provided resistance to *S. hermonthica* emergence. In other words, non-additive gene action was more important than additive gene action for resistance to *S. hermonthica* emergence as reported by Kim (1994). Similarly, Kling *et al*., (2000) reported that in maize heterosis provided tolerance to *S. hermonthica* that was reflected in higher grain yield and reduced ear rot.

5.4 Selection of superior inbred lines for single cross hybrid development

The use of a combination of host plant damage rating and *Striga* emergence count has been recommended for selecting resistant genotypes in maize (Haussmann *et al*., 2000) especially when very susceptible materials are used. This is because such materials can suffer more damage even when a few *Striga* plants attach. In this study however resistant inbred lines were used. The non-significant difference (0.05) in host plant damage rating among genotypes observed in this study suggests that this morphological character cannot be used to discriminate among genotypes in the selection of superior parents.

From the study, parents P_1, P_4 and P_9 contributed to increase *Striga* resistance and parents P_1, P_2, P_3 and P_{10} contributed to increase grain yield in crosses. Parent P_1 thus contributed to both increase in *Striga* resistance and grain production. In terms of grain yield, 100 grains weight, plant height and days to flowering, parents P_1, P_2 and P_3 were predominant parents in the best 10 hybrids whilst P_1 and P_3 were predominant parents in terms of *Striga* emergence count.

Correlation coefficient between grain yield and *Striga* count was negative (-0.15) and non-significant. This suggests that either of these traits cannot be used to select superior parents for the other. This was evident from the ranked mean scores of STEC-12 as the highest grain-yielding hybrid was not the most resistant.

It was even not among the best ten hybrids. Selecting superior parents thus calls for the inclusion of both traits. Considering the ranked sums of the following traits - grain yield, *Striga* count, 100 grains weight, plant height, ear height, days to silking, and days to anthesis - nine out of the best 10 hybrids identified had either P_1 or P_3 as a parent

On the basis of the above observations P_1, P_3 and P_2 in descending order have been identified as superior parents from this study for single-cross hybrid development. They represent inbred lines TZISTR 101, TZISTR 108 and TZISTR 102 respectively.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

Results of this study indicate that two different types of gene actions (non-additive and additive) are responsible for the traits measured. Both gca and sca were highly significant for grain yield, plant height, days to flowering and *Striga* emergence counts. This confirms that both additive and non-additive effects are important in the genetic control of grain yield in maize. Though both gca and sca were significant for *Striga* emergence counts, non-additive gene action played a major role in *Striga* emergence. Thus, non-additive gene action played an important role in the inheritance of *S. hermonthica* resistance.

Parents P_1 and P_2 had the highest gca values for plant height (15.25) and grain yield (0.67) respectively while parent P_7 had the highest gca values for both number of days to anthesis (1.46) and number of days to silking (1.78). Hybrids P_1P_9 and P_7P_{10} had the highest sca effects for grain yield per hectare (1.74) while P_2P_8 had the highest sca effects for plant height (24.53) and P_4P_5 the highest sca effects for both number of days to anthesis (5.77) and number of days to silking (5.96).

The broad-sense heritability values for *Striga* count at 12 weeks after planting, grain yield per hectare, number of days to anthesis, number of days to silking and plant height were higher than the narrow-sense heritability values indicating that non-additive gene action played a major role in the inheritance of these characters. It thus means that desirable characters can easily be transferred from the inbred lines to the single-cross hybrids.

From the results of this study, inbred lines TZISTR 101, TZISTR 108 and TZISTR 102 were found to have good general combining abilities for *Striga* resistance. Therefore, they should be employed in maize breeding programmes to improve the levels of hybrids resistance to *Striga*.

Considering the level of *Striga* resistance of the single-cross hybrids as evidence from the results of the *Striga* emergence counts, the hybrid (host plant) resistance alone is not expected to be efficacious for the control of the parasite. The host plant resistance will only reduce the *Striga* attack and not completely eliminate seed production. It is thus recommended that the cultivation of hybrids developed from the results of this study be combined with other control methods especially maize-legume rotation or mixtures. Of particular importance will be the rotation of the hybrids with farmers' acceptable legumes that will in addition to the improvement in soil productivity will also stimulate abortive *S. hermonthica* seed germination. It is also recommended that a bigger replication number and evaluating the hybrids in different locations be considered in similar future work.

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APPENDICES

Appendix 1: Analysis of variance of parameters measured in the uninfested environment.

Source of variation	df	Grain yield (t/ha)	100-grain weight (gm)	Days to silking	Days to anthesis	Anthesis-silking interval	Plant stand	Plant height	Ear height	Percentage lodging
Replication	1	1818.34	1137.24**	67.24**	62.63**	0.08	0.45	112.01*	199.13**	0.79
Genotype	54	3161.03**	8.17	34.01**	30.39**	0.69	12.06	741.66**	232.45**	33.42
Error	54	634.99	6.64	4.88	4.55	0.53	8.46	18.06	13.59	38.52
C.V		23.19	11.99	3.57	3.48	10.64	16.11	2.87	6.52	36.17
S.E		7.97	2.58	2.21	2.13	0.73	2.91	4.25	3.69	6.21
Mean		3.44	21.48	61.95	61.26	0.68	18.06	148.01	56.53	1.72

*; **; = Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 2: Analysis of variance of parameters measured in the infested environment.

Source of variation	df	Grain yield (t/ha)	100-grain weight (gm)	Days to silking	Days to anthesis	Anthesis-silking interval	Plant stand	Plant height	Ear height	Percentage lodging
Replication	1	21255.44**	20.10*	112.01**	106.04**	0.08	17.60	4.81	76.95*	113.83
Genotype	54	2345.96**	15.55**	24.63**	21.28**	1.63	26.39	637.53**	230.00**	71.20
Error	54	620.81	2.96	6.44	6.22	1.75	12.53	41.40	13.42	33.69
C.V		30.11	7.59	4.06	4.05	13.85	22.35	4.62	5.91	12.38
S.E		7.88	1.72	2.54	2.49	1.32	3.54	6.43	3.66	5.80
Mean		2.62	22.66	62.50	61.55	0.95	15.84	139.26	62.00	4.69

*; **; = Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 3: Analysis of variance of *Striga* emergence counts and Host plant damage rating.

Source of variation	df	STEC - 8	STEC - 10	STEC - 12	HDR - 8	HDR - 10	HDR - 12
Replication	1	7.65	40.81	13.18	0.74	1.54	0.74
Genotype	54	4.51	12.31	8.70**	0.46	0.55	0.61
Error	54	6.20	9.18	11.85	0.33	0.55	0.50
C.V		49.00	25.00	16.96	22.94	26.52	21.45
S.E		0.34	0.41	0.46	0.57	0.74	0.70
Mean		5.08	12.12	20.29	2.50	2.81	3.28
		(13551.52)	(32557.58)	(54109.09)			

** = Significant at 0.01 probability level. Values in parentheses are for mean Striga count per hectare.
STEC-8, 10 & 12 = Striga emergence count at 8, 10 & 12 weeks after planting.
HDR-8, 10 & 12 = Host plant damage rating at 8, 10 & 12 weeks after planting.

Appendix 4: Analysis of variance of parameters measured across environments.

Source of variation	df	Grain yield (t/ha)	100-grain weight (gm)	Days to silking	Days to anthesis	Anthesis-silking interval	Plant stand	Plant height	Ear height	Percentage lodging
Replication	1	17753.77**	427.48**	176.40**	165.82**	0.16	11.82	35.20	261.82**	66.81
Environment (E)	1	36955.12**	76.08*	16.91	4.37	4.09	272.84	4206.56**	1647.29**	486.06
Genotype (G)	54	4727.77**	19.69**	51.39**	45.60**	1.19	29.23	1347.27**	427.17**	58.43
G x E	54	779.21	4.03	7.26	6.07	1.14	9.22	31.92	35.29**	46.20
Error	109	670.95	11.45	5.63	5.36	1.13	10.46	30.21	13.15	36.21
C.V		27.07	15.33	3.81	3.77	13.85	19.08	3.83	6.20	18.79
S.E		8.19	3.38	2.37	2.32	1.32	3.23	5.50	3.68	6.02
Mean		3.03	22.07	62.22	61.40	0.95	16.95	143.64	59.26	3.20

*; **; - Significant at the 0.05 and 0.01 probability levels respectively.

Appendix 5: Analysis of variance of diallel single crosses.

Source of variation	df	Grain yield (t/ha)	Days to silking	Days to anthesis	Plant height	*Striga* count 12 WAP
Environment (E)	1	36.96**	4206.64**	16.91	4.40	---------------
Genotypes (G)	54	4.72**	1347.26**	51.39**	45.60**	36.39**
G.C.A	9	8.80**	2879.19**	155.89**	132.04**	24.12*
S.C.A	45	3.91**	1040.64**	30.49**	28.31**	38.84**
G x E	54	0.78	31.93	7.26	6.07	-----------------
Error	108	0.63	29.73	5.66	5.39	10.28

*; **; = Significant at the 0.05 and 0.01 probability levels respectively; 12 WAP = 12 weeks after planting