COMBINING ABILITY FOR YIELD OF IMIDAZOLINONE RESISTANT MAIZE INBRED LINES UNDER ARTIFICIAL AND NATURAL STRIGA INFESTATION

BY

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DECLARATION

I, IGNATH HILDEUS RWIZA, do hereby declare that this dissertation represents my own work and that, to the best of my knowledge, it has not been previously submitted for the award of a degree at this or any other University.

Signature.....

Date.....29.06.2007.....

APPROVAL

This dissertation of IGNATH HILDEUS RWIZA is approved as fulfilling part of the requirements for the award of the degree of Masters of Science in Agronomy by the University of Zambia.

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ABSTRACT

Striga hermonthica (Del.) Beth popularly known as witchweed infests cereal crops particularly maize (*Zea mays* L.) leading to severe reductions in yields, thereby compounding the food insecurity of thousands of households in sub-Saharan Africa region. In Tanzania, maize is grown on about 2 million hectares but the yield obtained is very low. It is estimated at 1.3 tons ha^{-1}. Various control measures against striga that have been used so far are not effective because the damage occurs before the weed emerges, therefore, an appropriate control strategy has to be effective in the soil before emergence. One promising strategy in suppressing striga parasitism has been the use of imidazolinone resistant maize varieties where the seed is coated with imazapyr herbicide. A study was carried out to investigate the inheritance of this trait in maize populations. Ninety three testcrosses based on three testers; CML373-IR/CML393-IR (tester A), CML202-IR/CML395-IR (tester B) and IR OPV(Synthesis 2000-IR) (tester C) were evaluated under natural and artificial striga infestation conditions in the Lake zone of Tanzania and Kisumu-Kenya in the 2006 season using alpha (0,1) lattice design. Grain yield was used as a proxy to maize resistance to imazapyr herbicide such that resistant materials were suitable candidates in striga infested areas with the use of the herbicide. The results from the study showed differences in both General Combining Ability (GCA) and Specific Combining Ability (SCA) effects for grain yield. GCA effects ranged from -0.57 to 0.78. SCA effects were different within each tester. The SCA effects with tester A, ranged from -0.67 to 0.58, with tester B from -0.70 to 0.32 and with tester C from -0.62 to 0.80. The contribution of GCA and SCA to entry sums of squares for grain yield was relatively higher for GCA than for SCA at 38 and 32 percent, respectively. This suggested that the additive gene effects were the more important source of variation on herbicide resistance.

DEDICATION

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CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crops in the world. It is used as food as well as feed in developing and developed countries, respectively (FAO, 1980). Yields in industrialised countries are more than 8 tons ha^{-1}, while in the developing countries these are less than 3 tons ha^{-1} (Pingali, 2001). Yields of 1.5 tons ha^{-1} for Kenya, 1.3 tons ha^{-1} for Tanzania and 1.2 tons ha^{-1} for Uganda have also reported. In Africa, maize production is mostly under rain-fed conditions, where 95% is produced by small and medium-scale farmers, who own less than ten hectares (Heisey and Mwangi, 1997).

Maize production in East Africa is mostly done by small-scale resource poor farmers who are mostly faced by various maize production problems including biological, environmental and physical stresses.

In Tanzania, more than 80% of the population depends on maize as a major food crop (GoT, 2002). The annual per capita consumption of maize is estimated at 112.5 kg, while the national maize consumption is approximately three million tons per year (Kaliba *et al.*, 2000). Maize contributes 60 percent of dietary calories to Tanzanian consumers (FSD, 1992).

An average of two million hectares of maize are grown in the high potential areas of the country, such as Southern highlands, Lake and Northern zones (Moshi *et al.*, 1990). The authors also stated that, although the yield is relatively higher in the Southern highlands, the country average yield is about 1.3 tons ha^{-1}. The low yields

are due to several factors which include striga weed infestation, low soil fertility, drought, diseases and pests.

Striga weed (*Striga hermonthica*) is the major contributing factor to yield reduction with yields of zero being possible (De Groote and Wangare, 2002). The damage occurs after the striga weeds have attached themselves to the host plant where they draw water and nutrients (Kanampiu *et al.*, 2001).

The weed affects negatively the livelihood of more than 100 million people in Africa and inflicts a crop damage totalling approximately 7 billion US dollars annually on the African economy (Berner *et al.*, 1995). The increase in maize production, therefore, has to come from intensified production on current maize fields through the adoption of productivity-enhancing technologies.

1.1 Strategies for striga control

Control measures that have been used have been based on agronomic strategies and these included: a) Hand weeding and throwing the weeds far away from the field or burning them; This practice has been done since the colonial era but weeds have still been growing profusely, making mechanical control difficult; b) Crop rotation with cassava and potatoes; This only slows down the effect of striga as the problem persists when a crop grows. The weed seeds are not eliminated by crop rotation; c) Leaving land fallow for up two years; This has been found to be unsustainable due to increase in human population and therefore pressure on land; d) Use of mineral fertilizers; This has been found to be an expensive option to farmers; and e) The use of farm yard manure; although this helps to suppress weeds by increasing soil fertility, it promotes

growth of pigweeds (*Amaranthus hybridus*) which in turn competes fiercely with maize lowering its yield.

Recently a new strategy in suppressing striga parasitism has been tried. This involves the application of a herbicide as a seed coating on herbicide resistant maize varieties. Dressing imidazolinone resistant (IR) maize seeds with imazapyr herbicides was found to control striga and reduce striga seed bank when continuously applied on the same field for more than three seasons (Kanampiu *et al.*, 2001). The use of herbicide treated seeds does not affect the sowing of herbicide sensitive crops like beans and cowpea in intercropping, therefore; this technology can be used in traditional small-scale farmers' intercropping systems (Kanampiu *et al.*, 2002a). The development of IR-maize varieties is therefore a relevant strategy for maize production in striga infested areas.

Little information on combining ability for grain of imidazolinone resistance maize is available to enable strategic use of the trait in breeding for imidazolinone resistance maize varieties.

The objectives of the study therefore, were;

i) To determine the combining ability for yield of Imidazolinone Resistant maize (IR- maize) inbred lines under striga (*Striga hermonthica*) infestation.

ii) To identify useful IR-maize inbred lines for use in developing IR-maize varieties.

1.2 Hypothesis of the study

The imidazolinone resistant trait in maize is simply inherited, enabling development of IR-maize varieties suitable for use in striga infested areas in combination with the herbicide.

CHAPTER II

LITERATURE REVIEW

2.1.0 *Striga* spp (Witchweed)

Striga (*Striga* spp), popularly known as witchweed, is a parasitic weed that destroys cereal crops, particularly maize, leading to food insecurity in thousands of households (Woomer and Omare, 2005). The weed attaches itself to the roots of cereal crops where it sucks nutrients from the host and thereby cause various debilitating effects (Kanampiu *et al.,* 2002b). The weed feeds on sugars, mineral nutrients and water of its host and may result in complete crop loss under the worst conditions (Woomer and Omare, 2005). Two species of weed, *S. hermonthica* and *S. asiatica,* are most common in Africa (Ayensu *et al.,* 1984).

2.1.1 The origin of striga weed

Striga weed is thought to be originated in the Nuba Mountains of Sudan and Ethiopia, but is now widespread in many parts of Africa, as well as Yemen and Saudi Arabia (Musselman and Ayensu, 1984). Basically, striga is found in the tropical and subtropical regions, in the latitudes ranging between 30° S and 30° N. The species *S. asiatica* prefers sandy soils, whereas *S. hermonthica* is more common in heavy soils (Mbwaga *et al.*, 2000).

2.1.2 The life cycle of striga

Striga has a rather complicated life cycle. The plant produces abundant, very small seeds that fall to the soil, and are incorporated into the soil during tillage. The seeds

can remain dormant in the soil for up to 20 years until they are stimulated to germinate by biochemical signals from host plant roots (Woomer and Omare, 2005).

The germinating seeds penetrate the host root, and siphon off water, minerals and photosynthates for its own growth while living underground. During the process they produce toxic chemicals which result in stunting and discoloration of the host plant (Kanampiu *et al.,* 2002b). The striga shoots, once emerged from the soil, produce fleshy green stems and narrow leaves and grow up to the height of 100 cm. The weed produces numerous, small purple flowers that later form capsules containing many seeds. After the host plant dies, so too does the striga, causing the capsules to burst and the seeds to spread on the soil, and the cycle repeats itself (Woomer and Omare, 2005). The weed survives by literally sucking nutrients out of the crop and this result in crop withering and grain yield reduction.

2.1.3 The structure of striga seed, dispersal and germination process

Striga seeds are tiny in size measuring approximately 0.3mm long and 0.15mm wide depending on the species. They are dispersed by wind and water erosion, livestock, and agricultural implements such as ploughs and harrows (Mbwaga *et al.*, 2000; Woomer and Omare, 2005). The seeds can remain viable in the soil for up to 20 years in the absence of suitable host plants. The seeds are usually dormant for few months after harvest of the crop, before they acquire the capacity to germinate (Mbwaga *et al.*, 2000). For the seeds to germinate, they should be about 3 to 4 mm from the host, because they respond to the crop germination stimulants produced by young roots of the host plant.

On contact with a host root, the tip of the striga root (radicle) penetrates into the host root and establish connections. After establishment, the parasite extracts sugars and inorganic minerals from the host plant (Mbwaga *et al.*, 2000). Recent studies have shown that as a result of striga infestation, growth inhibitors in the host plant are increased and growth promoters are decreased. Young striga seedlings depend completely on the host when they are still under the ground, when they emerge above the ground they develop green leaves and produce photosynthates. However, there is a continuous flow of carbohydrates, water and minerals from the host. The two types of Striga can be differentiated morphologically. *Striga asiatica* produces bright red flowers, but morphotypes with white, yellow and pink flowers occur in some regions. *S. hermonthica*, which is known as a giant witchweed is an out crossing species with purple flowers. The weed produces massive amounts of seeds estimated to be 58,000 to 200,000 per plant (Parker and Riches, 1993).

2.2.0 Striga management

2.2.1 Conventional striga management

Woomer and Omare (2005) pointed out that striga is difficult to control in maize fields because it grows under ground and attaches on the maize roots. It is important that striga should not be permitted to produce seeds in the field and it is necessary to weed striga once or twice during the cropping season. If striga is not weeded and reaches a stage of flowering and maturity, farmers should dig a hole of about 70 cm deep in the center of a path, gather the drying striga plants and put them in the hole, burn and bury them.

It is also important to clean farm tools immediately after weeding striga infested fields to avoid spreading of the seeds to new fields. The simplest control practice is containment, implying care must be taken not to spread striga into neighbouring fields and farms. However, another option for smallholders is deep tillage to more than 50 cm. Such depth places striga seeds deep in the soil to prevent emergence and multiplication.

2.3.0 Agronomic strategies for striga control in maize fields

Research on various methods for striga control in Africa have been going on for over fifty years, and have been focused mainly on agronomic practices; these methods include: Hand weeding and hoe weeding, use of striga free seeds, early planting, intercropping of cereals with legumes, the use of trap crops in rotation with cereals, the use of organic and inorganic nitrogen fertilisers and integrated striga control techniques (Mbwaga *et al.,* 2000). Integrated control practices that focus on factors like crop rotation, tolerant varieties and soil fertility management have shown value in reducing losses, but have been poorly adopted and have failed to slow the spread of the weed (Ransom *et al.*, 2004).

Kanampiu *et al.* (2003) advanced various reasons why these methods have not been adopted. They listed these reasons as: a) Their benefits have been seen only in medium to long-term period; b) The requirement of understanding of *Striga* life-cycle, which farmers usually lack; c) They do not fit well with existing cropping systems, for example, they require land for rotation when human population pressure requires intensification of land use for higher food production; and d) While host plant

resistance exists, it is ineffective under high levels of infestation and the resultant maize grain yield increase is inadequate.

Currently the agronomic technology with promising results is the use of Push-pull. It is based on the control of stem borers together with striga weeds (Khan *et al.*, 2005). The technology is still under verification and it takes more than one season for the results to be realised as compared to IR-maize technology.

The 'push-pull' habitant management approach for managing these two important pests, the insect and the weed, was developed by the International Centre of Insect Physiology and Ecology (ICIPE) in partnership with the Kenya Ministry of Agriculture, Kenya Ministry of Livestock and Fisheries Development, and Rothamsted Research in United Kingdom. The technology involves the use of Napier grass and Desmodium legume (Silverleaf or Greenleaf desmodium) as intercrops (Khan *et al.*, 2005). Desmodium legume is planted between the rows of maize. It produces a smell or odor that repels (push) away stem borer moths from the maize crop. Napier grass (*Pennisetum purpureum*) is planted around the maize crop as a trap plant. The grass attracts (pull) stem borer moths than maize, the attracted moths lay eggs, when the eggs hatch the small larvae bore into the napier grass stems where they die due to the sticky like substance produced by the plant.

Striga is suppressed by the ground cover formed by desmodium legumes interplanted with maize plants. The results from the research conducted by Khan *et al.* (2005) showed that the chemical produced by the roots of desmodium legumes are also responsible for suppressing striga weed due to allelopathic effect. The authors also

pointed out that apart from controlling stem borers and striga weeds, the technology conserve soil and water while preserving biodiversity. In Kenya, over 2000 farmers have confirmed in on farm trials that push-pull results in a significant reduction of stem borer pests and striga infestation and leads to higher yield of maize.

2.4.0 Breeding strategies for striga control in maize fields

Having identified striga as a problem to maize production in sub-Saharan Africa, maize breeders in the National and International Agriculture Research Centres have tried to find ways of combating striga using various breeding techniques. Some of the tried ones include:

i) The screening of inbred lines for striga resistance.

Menkir *et al.* (2004) reported that the results obtained after screening lines of diverse germplasm in the field and screen house under artificial striga infestation revealed that, there were significant differences on the number of striga plants attached to the roots in the pots and the number of emerged striga plants on ridges in the screen house. The number of striga plants attached to the roots in pots was positively correlated with striga damage symptom rating ($r = 0.51$ to 0.61, $P < 0.01$) and in the field ($r = 0.76$ to 0.79, $P < 0.01$). The number of emerged striga plants in the screen house was also positively correlated with the number of emerged striga plants ($r = 0.82$ to 0.85, $P < 0.01$) in the field. Some of the inbred lines had many striga plants attached to the roots that supported few emerged striga plants; this suggested that different mechanisms of resistance to striga exist in the set of inbred lines

The authors also mentioned that there were positive General Combining Ability (GCA) values for grain yield with low values for striga damage symptom rating and

number of emerged striga plants. This situation contributed to the increase of grain yield.

ii) Assessment of reactions of diverse maize inbred lines to '*Striga hermonthica*'

The breeders at IITA also determined the extent of variation in parasite attachment to the roots of the inbred lines, the relationship between the emerged striga plants and other traits of the inbred lines. Twenty inbred lines selected for field resistance to *S. hermonthica* and five checks with known resistance, tolerance and susceptibility reactions to *S. hermonthica* were evaluated in pots, greenhouse and in the field under artificial striga infestation for three years. The results revealed that, the new inbred lines and the resistant inbred checks were least infested by *S. hermonthica* and exhibited yield losses of 0 to 37 % compared to the yields of the tolerant and the susceptible inbred checks, which were reduced by 40 to 85 %. The results also showed that sixteen new inbred lines were infested significantly by fewer striga parasites compared with the susceptible inbred check. Some of these lines also supported significantly fewer emerged striga plants and sustained lower damage symptoms and percentage yield loss compared to the susceptible inbred check. Those inbred lines can be useful in breeding programmes for developing resistant maize cultivars (Menkir, 2006).

iii) Development of imidazolinone-resistant crops for striga control

Imidazolinone herbicides control parasitic weeds by inhibiting the enzyme acetohydroxyacid synthase (AHAS) which is also called acetolactate synthase (ALS). AHAS is a critical enzyme for the biosynthesis of branched-chain amino acids in

plants (Tan *et al.*, 2004). Several variant AHAS genes conferring imidazolinone resistance were discovered in plants through mutagenesis and selection, and were used to create IR-maize (*Zea mays* L), wheat (*Triticum aestivum* L), rice (*Oryza sativa* L), oilseed rape (*Brassica napus* L) and sunflower (*Helianthus annuus* L). These crops were developed using conventional breeding methods (Tan *et al.*, 2004). Extensive research and development of this multi-trait and multi-herbicide technology have been carried out through cooperation between public and private sectors (Shaner *et al.*, 1996). To date IR-crops including maize have been developed for control of striga.

2.4.1 The Role of Imidazolinone Resistant Crops in Crop Production

IR-crops coated by imidazolinone herbicides control troublesome weeds in farmers' fields that cannot be controlled with any other herbicide; for instance; red rice (*Oryza sativa* L.) is a very difficult weed to control in cultivated rice because of its taxonomic and physiological similarities to commercial rice. It can be easily controlled by coating IR-rice with imidazolinone herbicide (Gealy *et al.*, 2003; Steele *et al.*, 2002).

Jointed goat-grass (*Aegilops cylindrica* Host) is a problematic weed in winter wheat in the United States of America. Before IR-wheat was developed, there were no herbicides that would selectively control this weed without injuring the wheat (Anderson *et al.*, 2004). Imidazolinone herbicides have demonstrated effective control of jointed goat-grass but have no selectivity to conventional wheat (Ball *et al.*, 1999). With IR-wheat, farmers can use imidazolinone herbicides to solve the problem of jointed goat-grass in wheat.

Besides weeds that other herbicides cannot control, the IR-production system also controls a broad spectrum of weeds in several crops in which IR-varieties are available. Weeds like barnyardgrass (*Echinochloa crus-galli* L) in rice and cheat weed (*Bromus secalinus* L) in wheat can also be controlled by IR-production system (Dillon *et al.,* 1999; Liscano *et al.,* 1999).

The IR-production system is a very effective tool in controlling parasitic weeds in maize. Witchweed (*Striga* spp) which is a severe problem in Africa can be effectively controlled by Imazapyr herbicide applied at a rate of 30 g AE ha^{-1} (Kanampiu *et al.,* 2001). The use of the IR production system in Kenya increased the maize harvest index by 17% in striga infested soils (Abayo *et al.,* 1998).

Aly *et al.* (2001) mentioned that the combination of imidazolinone herbicide and IR-sunflowers is an effective tool in the control of broomrape (*Orobanche* spp) in sunflower.

Since maize and rice are often rotated with soybeans, and imidazolinones are common herbicide of choice for soybeans, using IR-maize and rice in rotation with soybeans eliminates any risk of maize or rice injury resulting from carryover of residual imidazolinone herbicides from the previous year in soybeans (Shaner *et al.,* 1996).

IR-maize is cross-tolerant to all AHAS-inhibiting herbicides and can prevent maize injury caused by the interaction between AHAS-inhibiting herbicides and organophosphate insecticides (Green and Ulrich, 1993). Some growers chose IR maize hybrids specifically for this characteristic. Besides the benefits of weed control, these crops have an advantage in commercialisation with fewer regulatory hurdles

compared with transgenic herbicide resistant crops. Because IR-crops were all developed using traditional breeding methods, there is no additional regulatory restriction on their commercialisation over any other conventionally developed crop except approval from relevant authorities which review all plants with novel traits, transgenic or non-transgenic (CFIA, 1995). As a result, IR-crops are more readily accessible to farmers than transgenic herbicide tolerant crops. Within that context, combining imidazolinone herbicide with IR-maize varieties may be a practical way for African farmers in controlling striga weed (Siehl *et al.,* 1996).

2.5.0 The Concepts of Combining Ability

Sprague and Tatum (1942) explained that, combining ability is a term which involves General Combining Ability (GCA) and Specific Combining Ability (SCA) and has been extensively used in breeding of several economic crop species. They also mentioned that, GCA was relatively more important than SCA for unselected inbred lines.

Combining ability of inbred lines is the ultimate factor determining future usefulness of the lines in the population improvement. Sprague and Tatum (1942) defined the concept of combining ability, and the two expressions of GCA and SCA as having a significant impact on inbred line evaluation and population improvement in maize breeding. They defined GCA as the average performance of a line in hybrid combinations and SCA as those instances in which certain hybrid combinations are either better or poorer than would be expected on the average performance of the parent inbred lines included. They also emphasised that estimates of GCA and SCA are relative to and dependent on the particular set of inbred lines included in the

hybrids under test. Hallauer and Miranda (1988) pointed out that, the concepts of GCA and SCA became more useful in the characterisation of inbred lines in crosses and often have been included in the description of an inbred line.

2.5.1 Selection of a tester for General and Specific Combining Ability

In selection for GCA, a broad base heterogeneous population is used as a tester, which can be the parental population or any broad genetic base (synthetic or open-pollinated) variety. In all instances, genotypes are tested with a representative sample of genotypes in the tester, that is, each plant in the base population is crossed to a random sample of gametes from the tester. Each testcross, therefore, is a type of half-sib family. When the tester has a narrow genetic base, selection among testcrosses is said to be for SCA (Hallauer and Miranda, 1988).

For inbred lines evaluation, a desirable tester as was defined by Matzinger (1953) is the one which combines the greatest simplicity in use with the maximum information on the performance to be expected from tested lines when used in other combinations or grown in other environments. Rawlings and Thompson (1962) defined a good tester as the one that classifies correctly relative performance of lines and discriminates efficiently among lines under test.

For improvement of breeding populations, Hallauer (1975) advocated that there is no single tester that can completely fulfill those requirements pointed out by Matzinger (1953). The author mentioned that generally a suitable tester should include

simplicity in use, provide information that correctly classifies the relative merit of lines and maximises genetic gain.

2.5.2 Combining ability as a measure for genotype performance

Evaluation of inbred lines themselves had little value because of inconsistency of correlation between characters of the inbred and their performance in F_1 crosses. The top cross test introduced by Davis (1927) made possible the screening of inbred lines based on GCA. This procedure was shown to be effective by Jenkins and Brunson (1932) and was widely used subsequently. Han *et al.* (1991) also reported that inbred lines giving high yields in top crosses were more likely to produce better single crosses.

2.5.3 Estimation of Combining Ability

The Combining ability for inbred lines and broad based testers in Line x Tester mating design is estimated using a formula presented by Singh and Chaudhary (1985). The line x tester analysis provides information about the general and specific combining ability of the material evaluated for the trait of interest, at the same time it estimates various types of gene effects. The crossing plan involves 'l' lines and't' testers. All of these 'l' lines are crossed to each of the't' tester and therefore, line x tester (l x t) full-sib progenies are produced. These progenies along with or without parents that is, lines and testers, are tested in a replicated trial using suitable field design (Comstock and Robinson, 1948; Singh and Chaudhary, 1985; Tyagi and Lal, 2005).

The formula established by Singh and Chaudhary (1985) for estimation of the effects due to general and specific combining abilities were as follows:

(a) Estimation of General Combining ability effects:

i) Lines

$$g_i = x_{i..} / t\,r - x... / ltr$$

ii) *Testers*

$$g_t = x_{.j.} / l\,r - x... / ltr$$

where; g : general combining ability effects

x : number of crosses

l : number of lines

t : number of testers

r : number of replications

(b) Estimation of Specific Combining ability effects:

$$s_{ij} = (x_{ij} / r) - (x_{i..} / tr) - (x_{.j.} / lr) - (x... / ltr)$$

where; s_{ij} : Specific combining ability effects for cross l, x_{ij} : Grand total for cross l, x_i : Grand total of lines for cross l, x_j : Grand total of testers for cross l, $x...$: Grand total crosses, l: number of lines, t : number of testers and r : number of replications.

CHAPTER III

MATERIALS AND METHODS

3.1 Location and environmental condition

The research was conducted in Tanzania and Kenya. A total of five striga infested sites representing striga prone areas in the countries where maize is considered as a main food crop were used for research implementation (Table 1). The sites had varying types of soils, sandy loam soils in Tanzania and sandy clay loam in Kenya. During the season the Tanzania sites received low rains compared to Kenya and this affected the crop to some extent. Temperatures were high in both Tanzania and Kenya sites compared to previous seasons. This is due to inadequate rainfall and low humidity during the season.

3.2 Planting materials

Thirty one inbred lines with a range of response to striga and imidazolinone herbicide (Table 2) were crossed to three testers to obtain 93 crosses used in the study (Appendix 1). The testers used were two hybrids and an open-pollinated maize variety. Hybrid testers were categorised into two different heterotic groups namely: 'Heterotic group A' (CML 373-IR/CML 393-IR) and 'Heterotic group B' (CML 202-IR/CML 395 IR). The open-pollinated tester was in the 'heterotic group C' (IR OPV (Synthesis 2000-IR). During research implementation three commercial maize varieties which are less tolerant to striga were used as checks.

3.3 Experimental design

The crosses were planted in an alpha (0, 1) lattice design with three replications. A one row plot of 5 m long, 0.75 m apart was planted in Tanzania and eleven hills of twenty two plants were used. In Kenya a plot of two rows, 5 m long, 0.75 m apart was planted. Planting was done by hand on 20th February 2006 in Tanzania and 11th April 2006 in Kenya.

3.4 Striga seeds inoculation

Striga seeds mixed with fine sand in the proportion of 25.5 g. of seeds to 1000 g. of sand were applied into the planting holes as inoculant for artificial striga infested fields.

3.5 Cultural practices

Cultural operations such as weeding, fertiliser application and insecticide application, to control stem borer, were done leaving striga weeds undisturbed. Phosphate fertiliser was applied after land preparation at a rate of 40 kg P_2O_5 ha^{-1} while nitrogen fertiliser was applied as side dressing at a rate of 100 kg N ha^{-1}. Harvesting was done manually in mid-June for Tanzania sites and late August for Kenya sites.

Table 1. Locations and coordinates for experimental sites

NO:	NAME	MANAGEMENT (STRIGA)	ALTITUDE (M. A.S.L)	LONGITUDE	LATITUDE
1	Ukiriguru-Sengerema (SA)-Tanzania	Artificial infestation	1230	E 33.047	S 2.733
2	Ukiriguru-Sengerema (SB)-Tanzania	Natural infestation	1228	E 33.056	S 2.746
3	Ukiriguru-Nyashimba (NA)-Tanzania	Artificial infestation	1201	E 33.072	S 2.794
4	Ukiriguru-Nyashimba (NB)-Tanzania	Natural infestation	1211	E 33.061	S 2.776
5	Kibos (KB)-Kenya	Artificial infestation	1310	E 34.816	S 2.339

Table 2. List of inbred lines

LINE NO.	PEDIGREE	LINE NO.	PEDIGREE	LINE NO.	PEDIGREE
1	CML247-IR(BC0)-B-B-B-108	11	CML373-IR(BC0)-B-B-38-B	21	CML445-IR(BC0)-B-B-117-B
2	CML247-IR(BC0)-B-B-B-110	12	CML373-IR(BC0)-B-B-55-B	22	CML445-IR(BC0)-B-B-23-B
3	CML247-IR(BC0)-B-B-B-46	13	CML373-IR(BC0)-B-B-70-B	23	CML445-IR(BC0)-B-B-37-B
4	CML247-IR(BC0)-B-B-B-99	14	CML373-IR(BC0)-B-B-93-B	24	CML445-IR(BC0)-B-B-5-B
5	CML312-IR(BC0)-B-B-B-60	15	CML384-IR(BC0)-B-B-B-126	25	CML445-IR(BC0)-B-B-60-B
6	CML312-IR(BC0)-B-B-B-65	16	CML390-IR(BC0)-B-B-6-B	26	CML78-IR(BC0)-B-B-B-123
7	CML312-IR(BC0)-B-B-B-67	17	CML395-IR(BC0)-B-B-41-B	27	CML78-IR(BC0)-B-B-B-129
8	CML312-IR(BC0)-B-B-B-79	18	CML444-IR(BC0)-B-B-131-B	28	CML78-IR(BC0)-B-B-B-130
9	CML312-IR(BC0)-B-B-B-92	19	CML444-IR(BC0)-B-B-154-B	29	CML78-IR(BC0)-B-B-B-26
10	CML373-IR(BC0)-B-B-180-B	20	CML444-IR(BC0)-B-B-158-B	30	CML78-IR(BC0)-B-B-B-62
				31	CML78-IR(BC0)-B-B-B-7

3.6 Data collection

Traits assessed during research implementation were:

i) *Relative Grain Yield: The percentage of the mean grain yield of the trial* values above 100% indicate above average performance, while below 100% indicate below average performance.

ii) Rank Average: Average rank for grain yield across all trials.

iii) Rank Standard deviation: Standard deviation of rank for grain yield across all trials, small values indicate stable performance while large values indicate variable performance.

iv) Grain yield: Shelled grain weight per plot adjusted to 12.5% grain moisture and converted to tons per hectare.

v) Anthesis date: Number of days after planting when 50% of the plants shed pollen.

vi) Anthesis Silking Interval (ASI): Determined by (i) measuring the number of days after planting when 50% of the plants shed pollen (anthesis date = AD) and show silks (silking date = SD), respectively, and (ii) calculating: ASI = SD –AD.

vii) Plant height: The height between the base of a plant to the insertion of the first tassel branch of the same plant.

viii) Ear height: The height between the base of a plant to the insertion of the top ear of the same plant.

ix) *P. sorghi*: Score for the severity of common rust (*Puccinia sorghi*) symptoms rated on a scale from 1 (= clean, no infection) to 5 (= severely infected)

x) *E. turcicum*: Score for the severity of northern leaf blight (*Exserohilum turcicum*) symptoms rated on a scale from 1 (= clean, no infection) to 5 (= severely infected).

xi) Striga count: Number of striga emerged or found in a plot at 6, 8, 10 and 12 weeks after planting, then calculated to number of striga in a m^2.

3.7 Data analysis

The agronomic data were analysed using Statistical Analysis System (SAS), while GCA and SCA effects were estimated using a formula presented by Singh and Chaudhary (1985). The analysis of variance was done assuming a randomised complete block design. Environments were considered as random effects and entries as fixed effects. The variances for GCA (σ^2_{gca}), SCA (σ^2_{sca}) and error were calculated from expected mean squares of the analysis of variance. The error variances (σ^2_e) are equal to mean squares of error.

CHAPTER IV

RESULTS

4.1 General

In Tanzania the rains started late and they were poorly distributed compared to previous seasons. A total of 381 mm rainfall was recorded during the long rains, being the lowest comparing to the past 25 years where the mean rainfall was 511.9 mm. This was contrary to Kibos in Kenya where a total of 1199.9 mm rainfall was recorded during the season. Uneven distribution of the rains in Tanzania resulted to drought stress on the experiments. The maximum temperature recorded during the season ranged from 28°C to 30.9°C where as the minimum ranged from 15.6°C to 21.8°C. The temperature was higher compared to previous seasons.

4.2 Grain yield and plant characteristics

Significant difference ($P < 0.01$) was revealed among 5 sites for Grain yield (GY) (Appendix 1). The means for grain yield over all sites ranged from 0.8 tons ha^{-1} to 3.1 tons ha^{-1}. Test crosses CML78-IR(BC0)-B-B-B-7/TESTER C, CML445-IR(BC0)-B-B-23-B/TESTER A and CML78-IR(BC0)-B-B-B-7/TESTER A produced high mean grain yields of 3.1, 3.1 and 2.9 tons ha^{-1}, respectively. The lowest means were obtained from test crosses CML78-IR(BC0)-B-B-B-62/TESTER B, CML373-IR(BC0)-B-B-38-B/TESTER A and CML395-IR(BC0)-B-B-41-B/TESTER B, they produced 0.9, 0.9 and 0.8 tones ha^{-1}, respectively. Local check the means for grain yield ranged from 1.5 to 2.3 tons ha^{-1} (Appendix 1).

Significant differences were also realised on the Anthesis date (AD) ($P < 0.01$), Ear height ($P < 0.01$) at five sites and Plant height (PH) ($P < 0.05$) at four sites (Appendix 1). Testcrosses CML78-IR(BC0)-B-B-B-26/TESTER C, CML445-IR(BC0)-B-B-60-B/TESTER C and CML78-IR(BC0)-B-B-B-62/TESTER C were the earliest to shed pollen compared to the others. They reached 50% pollen shed at 63.0, 63.3 and 63.4 days respectively. Test crosses CML312-IR(BC0)-B-B-B-92/TESTER B, CML373-IR(BC0)-B-B-93-B/TESTER B and CML312-IR(BC0)-B-B-B-60/TESTER B were the latest to reach 50% pollen shed, they reached that stage at 72.5, 72.7 and 73.3 days, respectively (Appendix 1). Two checks (check 1 and 3) were the earliest to reach 50% pollen shed compared to the crosses, they reached pollen shed stage at 60.4 and 62.4 days after planting. Check 2 reached 50% pollen shed at 63.4 days (Appendix 1).

Considering the height of the crosses, CML312-IR(BC0)-B-B-B-65/TESTER B, CML78-IR(BC0)-B-B-B-7/TESTER B and CML78-IR(BC0)-B-B-B-62/TESTER B were the shortest compared to others, a height of 158.4 cm, 158.8 cm and 160.4 cm., respectively was obtained. The tallest crosses were CML395-IR(BC0)-B-B-41-B/TESTER A, CML444-IR(BC0)-B-B-158-B/TESTER C and CML395-IR(BC0)-B-B-41-B/TESTER C with a height of 205.5 cm, 210.1 cm and 222.4 cm., respectively. As for the checks, the shortest height was 175.5 cm and tallest was 184.3 cm (Appendix 1).

The shortest ear height was obtained in testcrosses CML78-IR(BC0)-B-B-B-62/TESTER B, CML373-IR(BC0)-B-B-38-B/TESTER B and CML312-IR(BC0)-B-B-B-65/TESTER B with a height of 62.3 cm, 64.5 cm and 66.9 cm. While the tallest

were CML444-IR(BC0)-B-B-158-B/TESTER A, CML444-IR(BC0)-B-B-158-B/TESTER C and CML395-IR(BC0)-B-B-41-B/TESTER C with a height of 93.4 cm, 95.6 cm and 99.9 cm., respectively. The ear height for the checks ranged from 73.4 cm to 76.2 cm (Appendix 1).

4.3 Diseases

The leaf rust (*Puccinia sorghi*) was significant ($P < 0.01$) at four sites (Appendix 1). Seven testcrosses scored 1.0 which was the lowest score, some of the crosses include: CML445-IR(BC0)-B-B-60-B/TESTER C, CML445-IR(BC0)-B-B-60-B/TESTER A and CML247-IR(BC0)-B-B-B-99/TESTER A. The highest score of 1.9 and 1.8 was obtained in crosses CML373-IR(BC0)-B-B-93-B/TESTER C and CML373-IR(BC0)-B-B-38-B/TESTER C, respectively. The scores for the checks ranged from 1.2 to 1.8 (Appendix 1)

Northern leaf blight (*Exserohilum turcicum*) was significant ($P < 0.05$) at two sites (Appendix 1). Testcrosses CML373-IR(BC0)-B-B-70-B/TESTER B, CML395-IR(BC0)-B-B-41-B/TESTER B and CML390-IR(BC0)-B-B-6-B/TESTER B scored the lowest, a score of 1.6, 1.7 and 1.9 was obtained. Crosses CML247-IR(BC0)B-B-B-99/TESTER C, CML444-IR(BC0)-B-B-131-B/TESTER A and CML444-IR(BC0)-B-B-158-B/TESTER A scored as high as the checks, they scored 3.0, 3.0 and 2.9, respectively. Scores for the checks ranged from 2.4 to 3.0 (Appendix 1).

4.4 Striga count

The differences on striga attack among genotypes were significant ($P < 0.01$) at 8^{th}, 10^{th} and 12^{th} weeks after planting (Appendix 1), there was no significant difference at

6th weeks. Testcrosses CML247-IR(BC0)-B-B-B-46/TESTER A was infested at 8th weeks, a striga count of 0.1 was obtained. CML78-IR(BC0)-B-B-B-130/TESTER B, CML312-IR(BC0)-B-B-B-60/TESTER C and CML445-IR(BC0)-B-B-37-B/TESTER A were infested at 10 weeks after planting, striga counts of 0.4 and 0.3 respectively were obtained, other crosses were less or free from striga infestation.

At 12 weeks after planting seven crosses were free from striga infestation, some of the crosses include: CML78-IR(BC0)-B-B-B-7/TESTER A, CML78-IR(BC0)-B-B-B-129/TESTER A and CML312-IR(BC0)-B-B-B-79/TESTER A. The crosses that were highly infested were CML445-IR(BC0)-B-B-117-B/TESTER A, CML247-IR(BC0)-B-B-B-99/TESTER A and CML373-IR(BC0)-B-B-93-B/TESTER A with striga counts of 1.1, 0.9 and 0.6, respectively. The checks were highly infested compared to testcrosses. The striga count at 6th weeks ranged from 1.1 to 2.1, at 8th weeks 3.6 to 6.7, at 10th weeks 5.5 to 9.2 and at 12th weeks 5.8 to 11.6 (Appendix 1)

4.5 Combined Analysis

4.5.1 GCA and SCA mean squares

The line and tester mean squares (GCA) were significantly different ($P < 0.01$) for grain yield. The G x E interaction (tester x location) was also significant at ($P < 0.01$) (Table 3). The grain yield was not significant for G x E (line x location) interaction. The SCA mean squares for Line x Tester were significantly different ($P < 0.01$) for grain yield. The mean squares were not significant for G x E (Line x Tester x Location).

Table 3. Combined Analysis of Variance for grain yield (GY) (t/ha) across 5 sites in Tanzania and Kenya

SOURCE OF VARIATION	DF	MS	F
Location	4	80.98	**
Line	30	1.81	**
Line x Location	120	0.28	ns
Tester	2	21.41	**
Tester x Location	8	0.85	**
Line x Tester	60	0.75	**
Line x Tester x Location	240	0.23	ns
Error	755	0.47	
Total	1219		
σ^2_{gca}		0.55	
σ^2_{sca}		0.14	

** (P<0.01); ns = not significant; DF: Degrees of Freedom; MS: Mean square; F: F-value

4.5.2 General Combining Ability (GCA) effects

Twelve (12) lines L3, L4, L15, L21, L22, L23, L24, L25, L27, L29, L30 and L31 had positive GCA for grain yield (GY). Lines L 29, 22 and 31 had highest positive GCA with values of 0.78, 0.57 and 0.52 respectively, while L30, L15 and L3 were the lowest (Table 4). The negative GCA for grain yield were obtained in a number of lines L1, L2, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L16, L17, L18 L19, L20, L26 and L28. With the lowest being L14, L11 and L17 with GCA values of -0.57, -0.43 and -0.35, respectively.

4.5.3 Specific Combining Ability (SCA) effects

Under tester A, 14 lines; L1, L6, L8, L14, L17, L18, L19, L20, L22, L23, L24, L27, L30 and L31 had positive SCA effects for grain yield. L19, L8 and L30 expressed higher values of 0.53, 0.57 and 0.58, respectively (Table 5). Seventeen (17) lines; L2, L3, L4, L5, L7, L9, L10, L11, L12, L13, L15, L16, L21, L25, L26, L28 and L29 had negative SCA effects (Table 5). The lines which expressed the lowest SCA effects were L12, L15 and L11 with the values of -0.46, -0.54 and -0.67, respectively.

For tester B, 21 lines; L2, L3, L4, L7, L8, L9, L12, L13, L14, L15, L16, L19, L21, L22, L23, L24, L25, L26, L27, L28 and L29 had positive SCA effects for grain yield. Lines L23, L3, L26 and L9 had high values of 0.32, 0.29, 0.24 and 0.23, respectively. Ten (10) lines; L1, L5, L6, L10, L11, L17, L18, L20, L30 and L31 had negative SCA effects, the lines with the lowest SCA effects were L30, L31, L17 and L6 with values of -0.70, -0.50, -0.31 and -0.27, respectively.

Regarding tester C, 16 lines; L5, L6, L10, L11, L12, L13, L15, L16, L17, L20, L21, L25, L28, L29, L30 and L31 had positive SCA effects for grain yield. Lines L11, L15, L10 and L5 had high values of 0.80, 0.50, 0.33 and 0.31, respectively. Fifteen (15) lines; L1, L2, L3, L4, L7, L8, L9, L14, L18, L19, L22, L23, L24, L26 and L27 had negative SCA effects. The lowest were L8, L19, L24 and L27 with values of -0.62, -0.56, -0.44 and -0.41, respectively.

Table 4. GCA effects for Grain Yield (GY)

LINE NO.	PEDIGREE	GY (T/HA)
L1	CML247-IR(BC0)-B-B-B-108	-0.18
L2	CML247-IR(BC0)-B-B-B-110	-0.09
L3	CML247-IR(BC0)-B-B-B-46	0.04
L4	CML247-IR(BC0)-B-B-B-99	0.31
L5	CML312-IR(BC0)-B-B-B-60	-0.20
L6	CML312-IR(BC0)-B-B-B-65	-0.05
L7	CML312-IR(BC0)-B-B-B-67	-0.24
L8	CML312-IR(BC0)-B-B-B-79	-0.24
L9	CML312-IR(BC0)-B-B-B-92	-0.09
L10	CML373-IR(BC0)-B-B-180-B	-0.22
L11	CML373-IR(BC0)-B-B-38-B	-0.43
L12	CML373-IR(BC0)-B-B-55-B	-0.01
L13	CML373-IR(BC0)-B-B-70-B	-0.20
L14	CML373-IR(BC0)-B-B-93-B	-0.57
L15	CML384-IR(BC0)-B-B-B-126	0.05
L16	CML390-IR(BC0)-B-B-6-B	-0.13
L17	CML395-IR(BC0)-B-B-41-B	-0.35
L18	CML444-IR(BC0)-B-B-131-B	-0.12
L19	CML444-IR(BC0)-B-B-154-B	-0.21
L20	CML444-IR(BC0)-B-B-158-B	-0.13
L21	CML445-IR(BC0)-B-B-117-B	0.46
L22	CML445-IR(BC0)-B-B-23-B	0.57
L23	CML445-IR(BC0)-B-B-37-B	0.22
L24	CML445-IR(BC0)-B-B-5-B	0.40
L25	CML445-IR(BC0)-B-B-60-B	0.30
L26	CML78-IR(BC0)-B-B-B-123	-0.31
L27	CML78-IR(BC0)-B-B-B-129	0.25
L28	CML78-IR(BC0)-B-B-B-130	-0.18
L29	CML78-IR(BC0)-B-B-B-26	0.78
L30	CML78-IR(BC0)-B-B-B-62	0.07
L31	CML78-IR(BC0)-B-B-B-7	0.52
Mean		0.00
$LSD_{(0.05)}$		0.02

Table 5. SCA effects for Grain Yield (GY) (t/ha) and heterotic groups for hybrid and open pollinated testers.

LINE NO.	PEDIGREE	SCA EFFECTS		
		CML373-IR/CML393-IR (Heterotic group A)	CML202-IR/CML395-IR (Heterotic group B)	IR OPV(Synthesis 2000- (Heterotic group C)
L1	CML247-IR(BC0)-B-B-B-108	0.21	-0.18	-0.03
L2	CML247-IR(BC0)-B-B-B-110	-0.06	0.08	-0.03
L3	CML247-IR(BC0)-B-B-B-46	-0.12	0.29	-0.17
L4	CML247-IR(BC0)-B-B-B-99	-0.02	0.13	-0.11
L5	CML312-IR(BC0)-B-B-B-60	-0.13	-0.18	0.31
L6	CML312-IR(BC0)-B-B-B-65	0.12	-0.27	0.15
L7	CML312-IR(BC0)-B-B-B-67	-0.08	0.12	-0.03
L8	CML312-IR(BC0)-B-B-B-79	0.57	0.05	-0.62
L9	CML312-IR(BC0)-B-B-B-92	-0.18	0.23	-0.04
L10	CML373-IR(BC0)-B-B-180-B	-0.12	-0.21	0.33
L11	CML373-IR(BC0)-B-B-38-B	-0.67	-0.13	0.80
L12	CML373-IR(BC0)-B-B-55-B	-0.46	0.16	0.30
L13	CML373-IR(BC0)-B-B-70-B	-0.22	0.10	0.13
L14	CML373-IR(BC0)-B-B-93-B	0.20	0.14	-0.34
L15	CML384-IR(BC0)-B-B-B-126	-0.54	0.04	0.50
L16	CML390-IR(BC0)-B-B-6-B	-0.20	0.03	0.17
L17	CML395-IR(BC0)-B-B-41-B	0.12	-0.31	0.19
L18	CML444-IR(BC0)-B-B-131-B	0.16	-0.04	-0.12
L19	CML444-IR(BC0)-B-B-154-B	0.53	0.03	-0.56
L20	CML444-IR(BC0)-B-B-158-B	0.14	-0.13	0.00
L21	CML445-IR(BC0)-B-B-117-B	-0.28	0.14	0.14
L22	CML445-IR(BC0)-B-B-23-B	0.25	0.06	-0.32
L23	CML445-IR(BC0)-B-B-37-B	0.05	0.32	-0.37
L24	CML445-IR(BC0)-B-B-5-B	0.32	0.12	-0.44
L25	CML445-IR(BC0)-B-B-60-B	-0.13	0.04	0.09
L26	CML78-IR(BC0)-B-B-B-123	-0.20	0.24	-0.04
L27	CML78-IR(BC0)-B-B-B-129	0.26	0.14	-0.41
L28	CML78-IR(BC0)-B-B-B-130	-0.21	0.02	0.19
L29	CML78-IR(BC0)-B-B-B-26	-0.23	0.18	0.05
L30	CML78-IR(BC0)-B-B-B-62	0.58	-0.70	0.12
L31	CML78-IR(BC0)-B-B-B-7	0.35	-0.50	0.15
Mean		0.00	0.00	0.00
$LSD_{(0.05)}$		0.04	0.04	0.04

4.6 Analysis of variance for the sites

The mean squares for GCA for the lines were significantly different ($P < 0.01$) for grain yield at Ukiriguru-Sengerema A, Nyashimba A and Kibos sites (Appendices 2, 3, 4, 5 and 6). The significant difference ($P < 0.01$) for mean squares for GCA for testers was obtained at all five sites.

The SCA (line x tester) mean squares were significantly different ($P < 0.01$) for grain yield at Ukiriguru-Sengerema B, Nyashimba B and Kibos sites. They were not significant at Sengerema A and Nyashimba A.

CHAPTER V

DISSCUSSION

The study looked into the combing ability for yield of IR-maize inbred lines so as to identify the useful lines for use in developing IR-maize varieties. Grain yield was the key trait for assessing their performance under striga infestations. The agronomic traits like Anthesis date, Anthesis Silking Interval, Plant and Ear height, were not discussed in the present study because they were not much important in the determination of IR-maize inbred lines performance and resistance to imidazolinone herbicide. The data collected can be used in future when developing IR-maize varieties.

5.1 Grain yield and plant characteristics

Significant differences among testcrosses across all sites were observed for grain yield ranging from 0.8 to 3.1 tons ha^{-1}. The checks expressed lower grain yield compared to some of the crosses, the yield of 1.5 to 2.3 tons ha^{-1} being obtained (Appendix 1). The differences were observed between testcrosses across testers and within testers suggesting that the inbred lines had different contributions to yielding ability in their hybrid combinations and indeed the testers were not equally suitable as parents in hybrid combinations.

Similar results were reported by Diallo (2005) evaluating 320 testcrosses under striga in Kenya. He identified sixteen testcrosses that gave yields above 9 tons ha^{-1} and yielded significantly higher than most checks. He noted that hybrids that gave higher performance were the ones that also showed higher resistance to the prevailing

stresses such as ear rot, GLS, *Puccinia sorghi, Exserohilum turcicum* and striga. He concluded that, it is the best option for poor resource farmers who are faced with striga problem on their farms.

5.2 Disease infection

Results from the current study showed that, testcrosses were significantly different ($P < 0.01$) for their reaction to *P. sorghi* at four sites. Crosses CML445-IR(BC0)-B-B-60-B/TESTER C, CML445-IR(BC0)-B-B-60-B/TESTER A and CML247-IR(BC0)-B-B-B-99/TESTER A scored 1.0, this was the lowest score. The highest score of 1.9 and 1.8 were obtained in crosses CML373-IR(BC0)-B-B-93-B/TESTER C and CML373-IR(BC0)-B-B-38-B/TESTER C, respectively. The scores recorded from the checks ranged from 1.2 to 1.8 (Appendix 1). This suggests that, most of the testcrosses were resistant to *P. sorghi*. As was noted by Diallo (2005) such testcrosses give better performance.

Similarly, significant ($P < 0.05$) differences in the incidence of *E. turcicum* among crosses assessed were observed. (Appendix 1). The low scores of 1.6, 1.7 and 1.9 were obtained from crosses CML373-IR(BC0)-B-B-70-B/TESTER B, CML395-IR(BC0)-B-B-41-B/TESTER B and CML390-IR(BC0)-B-B-6-B/TESTER B, respectively. Some of the crosses like CML247-IR(BC0)B-B-B-99/TESTER C, CML444-IR(BC0)-B-B-131-B/TESTER A and CML444-IR(BC0)-B-B-158-B/TESTER A, scored highly 3.0, 3.0 and 2.9, respectively similar to checks with scores ranging from 2.4 to 3.0 (Appendix 1). These results strongly suggests differences in the reaction to *E. turcicum*, though the disease had no effect on grain yield.

Differences among testcrosses for all measured agronomic characteristics at all five sites (Appendix 1) were observed highlighting the variability in the material used in the study for these characteristics.

5.3 Striga count

Striga (*Striga hermonthica*) is a major contributing factor to maize yield reduction, it attaches itself to the host plant where it causes damage by drawing out water and nutrients (De Groote and Wangare, 2002). In this study striga counts, as an indication of the resistance to imidazolinone herbicide and therefore 'resistant' to the pest, varied among testcrosses.

Differences among testcrosses for striga infestation was significant at the 8th, 10th and 12th week after planting, but not at earlier stages. At the 8th week testcross CML247-IR(BC0)-B-B-B-46/TESTER A, was the only one with significant count of 0.1 (Appendix 1). By the 10th week, three testcrosses, CML78-IR(BC0)-B-B-B-130/TESTER B, CML312-IR(BC0)-B-B-B-60/TESTER C and CML445-IR(BC0)-B-B-37-B/TESTER A, were significantly infested with mean counts of 0.4, 0.3 and 0.3, respectively. The situation at 12th week was almost similar with only two testcrosses, CML445-IR(BC0)-B-B-117-B/TESTER A and CML247-IR(BC0)-B-B-B-99/TESTER A, showing significant mean striga counts of 1.1 and 0.9, respectively (Appendix 1). This indicates how the test crosses had different levels of resistance to imidazolinone herbicide. The variation in herbicide resistance resulted in different levels of striga infestation.

5.4 Combining ability

The study focused on GCA and SCA for striga tolerance in maize inbred lines, and grain yield was used as the trait proxying the tolerance. The analysis across sites showed significant effects ($P < 0.01$) for GCA, SCA and GCA x location (Table 3). Previous research done by Kaya (2004) showed that, GCA and SCA effects were significant for all traits under the study. The significance of GCA and SCA effects for the traits showed the importance of both additive and non-additive gene effects. The significant SCA effects detected in the traits imply the contribution of non-additive gene effects to the phenotypic variation among the hybrids. Sakila *et al.* (2000) observed the same differences on the lines, testers and line x tester interactions.

Everett *et al.* (1995) evaluated the optimal combining ability patterns among promising populations for inbred lines development in tropical mid-altitude zones and detected highly significant differences for GCA, SCA and GCA x environment interaction. From the results, they suggested the need of selecting different parental lines for hybrid development for specific environment.

5.4.1 General Combining Ability (GCA)

Significant positive GCA effects for grain yield (GY) were observed in twelve inbred lines (Table 4). Lines 29 and 22 were the best general combiners expressing grain yield increase of +0.78 and +0.57 tons ha^{-1}, respectively. The poorest line was L14 with a yield reduction of -0.57 tons ha^{-1}. The positive GCA effects indicate that, the additive gene effects contributed to the increase of grain yield. Similar results were reported by Nass *et al.* (2000), where a line with large positive GCA and another with negative GCA were identified. In their study more than half of the lines had positive

GCA effects, indicating that on average these lines contributed to grain yield increase. They also pointed out that, genetically, the GCA effects from one environment contain the average GCA effects and GCA x Environment interaction. As a result, when estimates of GCA x Environment interaction are near to zero, the average GCA effects will approach the GCA effects obtained for each environment. Therefore, the selection of the best parents based on the average GCA effects can be done if there is interest in single cross hybrids adapted to all environments.

The estimation of variance due to general combining ability (σ^2gca) and specific combining ability (σ^2sca) showed that, the former was higher (0.55) than the latter (0.14) for grain yield (Table 3). This indicated a predominantly additive gene action for this trait. The variance of 0.55 and 0.14 were estimated for GCA and SCA, respectively (Table 3). The SCA variances are used to determine the homogeneity of which inbred lines transmit yielding abilities to the progenies. Relative magnitudes of GCA and SCA variances are useful in identifying superior lines. According to Griffing (1956), the ideal SCA variance is one. High SCA variance designate high variability in transmitting yielding ability to the progenies, where as, low SCA variance indicates less variability in transmitting yielding ability. The inbred lines assessed had lower SCA variance (0.14), this imply that, the lines had less variation in transmitting yielding ability. On the basis of the above, comparing the magnitudes of GCA and SCA variances, lines 3, 4, 15, 21, 22, 23, 24, 25, 27, 29, 30 and 31 were identified as superior lines.

Non-significant difference for the GCA x E interactions (Table 3) implies that the contribution of additive genes to expression of grain yield is the same in the different

environments where the testcrosses were evaluated. However, testing lines at different sites is important because it ensures selection of correct inbred lines, which are stable in their performance under targeted stress across locations. Scott (1967) mentioned that, in the absence of significant GCA x E interaction it is advisable to select stable genotypes.

The contribution of GCA sum of squares to entry total sums of squares for grain yield was relatively higher than from the SCA, 38% against 32%. This suggests that, the additive gene effects were more important than the non-additive gene effects for this set of entries, and were the main source of variation in inbred lines on striga resistance. Similar results were reported by Nass *et al.* (2000), the hybrids which expressed higher grain yields than the hybrid checks, the contributions of the GCA and SCA were approximately 58% and 44%, respectively. These results showed that for the best single crosses, both GCA and SCA effects were important for the grain yield but GCA effects were more important than the SCA effects due to predominant additive gene effects. Beck *et al.* (1989) also mentioned that, high proportion of GCA sums of squares compared to SCA sums of squares for grain yield indicates the importance of additive gene effects against non-additive gene effects for the trait of interest.

5.4.2 Specific Combining Ability (SCA)

The highly significant positive SCA effects were expressed in 14 lines with tester heterotic group A, 21 lines with tester heterotic group B and 16 lines with tester heterotic group C. The highest effects were observed in line L30 (heterotic group A), L23 (heterotic group B) and L11 (heterotic group C) with yield increase of 0.58, 0.32

and 0.80 tons ha^{-1}, respectively (Table 5). The positive SCA effects imply that, the variation on yield among inbred lines contributed by non-additive gene effects. Nass *et al.* (2000) also reported the highly significant positive and negative SCA effects. The largest positive and negative SCA effects for grain yield from their study were observed in L5 x L8 and L6 x L7 crosses, respectively. Therefore, the positive GCA and SCA effects expressed by the lines showed that, the variation among inbred lines on grain yield was due to both additive and non-additive gene effects, but additive gene effects were more predominant than non-additive gene effects. These findings agree with a study conducted by Garay *et al.* (1996) who found additive and non-additive gene effects for grain yield. This signifies that the differences on grain yield among inbred lines were caused by both gene effects.

SCA (line x tester) mean squares for grain yield were significantly different at ($P < 0.01$). The interactions among line, tester and locations (line x tester x environment) did not show significant difference for grain yield (Table 3). The significance of SCA mean squares for grain yield implies that, there are variations in the trait that are controlled by non-additive genes, and these can enable identification of promising crosses basing on SCA effects.

SCA x Environment (E) interaction shows how the lines express themselves on their performance under different locations. The present study showed that, the SCA x E interaction had no influence on grain yield change within lines. This implies that, the difference in yield performance had not been influenced by non-additive gene effects and locations. Kaya (2004) also reported that, from the study, the Hybrid x Environment interactions were not significantly different across locations. The non-

significant Genotype x Environment (G x E) interactions imply the possibility of evaluating genotypes without diverse environmental conditions influencing the traits.

CHAPTER VI

CONCLUSION

Selection of superior inbred lines that are resistant to imidazolinone herbicide should not be based on agronomic characters even if they are significant. The emphasis will be on grain yield expressed by the lines.

From the study twelve inbred lines including lines 3, 4, 15, 21, 22, 23, 24, 25, 27, 29, 30 and 31 were identified as potential lines for grain yield, the crosses developed from these lines produced high yields.

It is concluded from the study that, both GCA effects (additive gene effects) and SCA effects (non-additive gene effects) were involved in governing inheritance of grain yield in IR-maize inbred lines assessed, however, additive gene effects were predominant.

6.1 RECOMMENDATIONS

The study recommends that, twelve inbred lines (3, 4, 15, 21, 22, 23, 24, 25, 27, 29, 30 and 31) that expressed high performance under striga environment can be used in developing imidazolinone resistant maize varieties through application of appropriate selection methods, such as backcross selection and recurrent selection that efficiently pyramid desirable alleles for the trait.

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Appendix 1. Mean Grain Yield (GY) (t/ha) and other important agronomic characters of IR-maize test crosses tested across 5 sites

Entry	Pedigree	Across			Acr	UK. S.A	UK. S.B	UK. N.A	UK. N.B	KBS	Anth	ASI	Plt	Ear	P.	E	Striga	Striga			
		RelGY	Rank		GY	GY	GY	GY	GY	GY	Date		hgt	hgt	sorg	turc	Avg	6wks	8wks	10wks	12wks
		%	Avg	Std Dev	t/ha	t/ha	t/ha	t/ha	t/ha	t/ha	d	d	cm	cm	1-5	1-5	#sqm	#sqm	#sqm	#sqm	#sqm
88	CML78-IR(BC0)-B-B-B-7/TESTERC	170	9	9	3.1	2.9	3.45	2.44	1.81	4.77	64.3	7.7	198.6	81.8	1.6	2.6	0.0	0.0	0.0	0.0	0.1
12	CML445-IR(BC0)-B-B-23-B/TESTERA	165	6	2	3.1	3.1	3.46	1.64	2.51	4.97	63.9	6.6	189.7	78.0	1.1	2.6	0.0	0.0	0.0	0.0	0.2
26	CML78-IR(BC0)-B-B-B-7/TESTERA	162	14	11	2.9	2.3	2.68	2.39	2.29	4.88	65.0	7.8	196.6	83.8	1.2	2.7	- 0.0	0.0	0.0	0.0	0.0
28	CML78-IR(BC0)-B-B-B-62/TESTERA	158	18	21	2.8	3.4	2.23	1.87	2.91	3.54	64.8	6.1	192.8	76.9	1.6	2.4	0.0	0.0	0.0	0.0	0.1
87	CML384-IR(BC0)-B-B-B-126/TESTERC	154	10	6	2.9	3.3	2.76	1.58	2.41	4.33	63.7	4.1	188.6	82.8	1.7	2.8	0.1	0.0	0.0	0.2	0.3
68	CML373-IR(BC0)-B-B-38-B/TESTERC	151	11	9	2.9	2.6	2.45	1.69	2.30	5.44	63.7	5.0	202.9	81.7	1.8	2.5	0.0	0.0	0.0	0.0	0.1
11	CML445-IR(BC0)-B-B-5-B/TESTERA	150	9	5	2.9	2.7	2.82	1.47	2.21	5.47	65.0	6.0	183.0	77.2	1.2	2.3	0.0	0.0	0.0	0.0	0.1
89	CML78-IR(BC0)-B-B-B-26/TESTERC	150	14	12	2.8	3.6	2.72	1.40	2.39	3.93	63.0	6.7	201.0	79.5	1.4	2.6	0.0	0.0	0.0	0.0	0.1
77	CML445-IR(BC0)-B-B-117-B/TESTERC	150	13	13	2.9	2.9	3.49	1.63	1.62	4.64	65.9	5.0	194.5	87.1	1.4	2.6	0.0	0.0	0.0	0.0	0.1
76	CML445-IR(BC0)-B-B-60-B/TESTERC	148	11	6	2.9	2.9	2.70	1.28	2.36	5.25	63.3	5.6	199.7	82.9	1.0	2.4	0.1	0.0	0.0	0.1	0.2
30	CML78-IR(BC0)-B-B-B-129/TESTERA	147	16	13	2.7	2.2	2.46	1.69	2.63	4.53	66.1	5.2	190.1	76.6	1.4	2.3	- 0.0	0.0	0.0	0.0	0.0
27	CML78-IR(BC0)-B-B-B-26/TESTERA	142	16	14	2.7	3.0	2.06	1.54	2.06	5.03	64.1	5.5	196.2	76.8	1.4	2.5	0.0	0.0	0.0	0.1	0.1
58	CML78-IR(BC0)-B-B-B-26/TESTERB	140	18	18	2.6	3.0	2.88	1.66	1.46	4.15	67.9	7.7	192.4	77.3	1.1	2.2	0.1	0.0	0.0	0.0	0.2
84	CML247-IR(BC0)-B-B-B-99/TESTERC	133	22	10	2.5	2.5	2.12	1.52	2.10	4.27	66.9	5.9	185.4	77.8	1.3	3.0	0.0	0.0	0.0	0.0	0.1
69	CML373-IR(BC0)-B-B-55-B/TESTERC	132	21	10	2.6	2.7	2.38	1.09	1.95	5.10	66.3	5.5	197.7	91.0	1.7	2.6	0.0	0.0	0.0	0.0	0.2
90	CML78-IR(BC0)-B-B-B-62/TESTERC	131	20	8	2.6	2.6	2.38	1.38	1.69	4.67	63.4	6.1	200.3	77.9	1.5	2.6	0.1	0.0	0.0	0.0	0.2

14	CML445-IR(BC0)-B-B-60-B/TESTERA	128	25	12	2.4	2.7	1.98	1.39	1.95	4.08	64.9	6.6	176.9	69.8	1.0	2.5	0.0	0.0	0.0	0.0	0.1
22	CML247-IR(BC0)-B-B-B-99/TESTERA	126	29	15	2.4	2.0	2.23	1.26	2.41	3.87	69.0	4.8	186.1	78.5	1.0	2.6	0.2	0.0	0.0	0.1	0.9
15	CML445-IR(BC0)-B-B-117-B/TESTERA	126	26	9	2.4	2.2	2.35	1.24	2.16	3.98	65.9	5.7	192.0	84.6	1.2	2.5	0.3	0.0	0.0	0.1	1.1
13	CML445-IR(BC0)-B-B-37-B/TESTERA	125	32	25	2.4	2.9	1.68	0.91	2.67	3.76	66.6	5.1	189.3	81.7	1.2	2.2	0.2	0.0	0.0	0.3	0.4
72	CML373-IR(BC0)-B-B-180-B/TESTERC	121	27	12	2.4	2.7	2.50	0.98	1.74	3.91	67.6	3.9	173.9	77.7	1.7	2.2	-0.1	0.0	0.0	-0.1	-0.2
43	CML445-IR(BC0)-B-B-23-B/TESTERB	121	30	17	2.3	2.5	1.70	1.28	1.97	4.04	69.0	5.2	189.2	81.5	1.2	2.6	0.0	0.0	0.0	0.0	0.1
64	CML390-IR(BC0)-B-B-6-B/TESTERC	118	35	21	2.1	1.9	2.59	1.41	1.71	3.05	66.1	4.9	202.4	92.5	1.3	2.2	0.0	0.0	0.0	0.0	0.1
46	CML445-IR(BC0)-B-B-117-B/TESTERB	118	30	14	2.3	2.6	2.57	0.98	1.44	4.20	69.6	6.1	190.1	84.1	1.2	2.5	0.1	0.0	0.0	0.0	0.2
74	CML445-IR(BC0)-B-B-23-B/TESTERC	117	35	23	2.4	2.2	1.92	1.35	1.15	5.25	64.6	5.6	180.6	70.3	1.4	2.1	0.0	0.0	0.0	0.0	0.1
23	CML247-IR(BC0)-B-B-B-108/TESTERA	117	36	21	2.1	2.2	2.43	1.18	2.03	2.82	68.0	5.0	177.8	75.1	1.3	2.3	0.1	0.0	0.0	0.0	0.2
4	CML444-IR(BC0)-B-B-154-B/TESTERA	115	38	24	2.3	1.7	3.56	0.77	1.72	3.61	68.4	3.1	183.0	78.6	1.6	2.7	0.1	0.0	0.0	0.1	0.4
1	CML395-IR(BC0)-B-B-41-B/TESTERA	115	45	29	2.0	1.8	1.50	1.14	2.92	2.79	67.2	6.4	205.0	92.3	1.7	2.4	0.0	0.0	0.0	0.0	0.1
78	CML312-IR(BC0)-B-B-B-60/TESTERC	115	32	19	2.3	2.4	2.92	0.84	1.37	4.03	67.2	6.7	188.7	79.4	1.5	2.3	0.2	0.0	0.0	0.3	0.4
70	CML373-IR(BC0)-B-B-70-B/TESTERC	113	40	25	2.1	2.5	1.84	1.65	1.05	3.35	66.6	6.3	187.8	78.6	1.7	2.2	0.0	0.0	0.0	0.0	0.2
93	CML78-IR(BC0)-B-B-B-130/TESTERC	113	37	8	2.2	2.1	1.98	1.20	1.59	3.96	66.4	6.8	180.7	76.3	1.5	2.4	0.1	0.0	0.0	0.0	0.2
19	CML312-IR(BC0)-B-B-B-79/TESTERA	112	39	25	2.3	1.7	3.16	0.74	1.52	4.33	67.9	8.1	195.2	92.5	1.3	2.7	-0.0	0.0	0.0	-0.1	0.0
73	CML445-IR(BC0)-B-B-5-B/TESTERC	111	38	17	2.1	2.3	2.30	0.80	1.98	3.20	65.6	6.9	200.3	87.1	1.4	2.5	0.0	0.0	0.0	0.0	0.1
3	CML444-IR(BC0)-B-B-131-B/TESTERA	110	39	30	1.9	2.3	2.60	1.13	1.78	1.81	65.9	8.2	197.4	91.7	1.3	3.0	0.0	0.0	0.0	0.0	0.2
79	CML312-IR(BC0)-B-B-B-65/TESTERC	109	38	30	2.2	2.5	2.81	0.46	1.68	3.61	66.9	7.9	174.8	79.9	1.2	2.8	0.0	0.0	0.0	0.0	0.1
67	CML444-IR(BC0)-B-B-158-B/TESTERC	108	40	25	2.1	2.7	1.23	1.14	1.67	3.57	63.9	7.8	210.1	95.6	1.5	2.6	0.1	0.0	0.0	0.1	0.3
75	CML445-IR(BC0)-B-B-37-B/TESTERC	108	38	30	2.1	2.5	0.96	1.05	1.77	4.38	66.2	4.3	203.2	85.1	1.1	2.6	0.0	0.0	0.0	0.0	0.2
44	CML445-IR(BC0)-B-B-37-B/TESTERB	108	42	22	2.1	2.0	2.35	0.61	2.15	3.54	69.8	6.1	192.8	82.0	1.2	2.6	0.1	0.0	0.0	0.1	0.4
86	CML247-IR(BC0)-B-B-B-110/TESTERC	108	41	11	2.0	2.3	1.83	1.16	1.56	3.35	65.6	6.0	179.7	75.2	1.5	2.6	0.0	0.0	0.0	0.0	0.1
92	CML78-IR(BC0)-B-B-B-129/TESTERC	107	43	21	2.0	2.3	1.39	1.37	1.49	3.32	65.5	5.4	190.7	79.3	1.2	2.3	0.0	0.0	0.0	0.0	0.1
5	CML444-IR(BC0)-B-B-158-B/TESTERA	106	43	21	2.0	2.3	2.10	0.69	2.08	3.00	67.3	6.7	198.5	93.4	1.1	2.9	0.0	0.0	0.0	0.0	0.2
96	Local Check3	106	41	32	2.3	1.7	2.50	0.51	1.55	5.26	62.4	7.0	184.3	76.2	1.3	2.4	3.5	1.1	3.6	5.5	5.8
17	CML312-IR(BC0)-B-B-B-65/TESTERA	106	41	27	2.2	1.8	2.05	0.53	2.01	4.60	67.2	7.1	177.9	77.0	1.3	2.3	0.0	0.0	0.0	0.0	0.1

83	CML247-IR(BC0)-B-B-B-46/TESTERC	105	41	19	2.1	1.8	2.04	1.22	1.09	4.35	67.3	4.8	187.0	75.9	1.7	2.7	0.0	0.0	0.0	0.0	0.0
61	CML78-IR(BC0)-B-B-B-129/TESTERB	105	42	20	2.1	2.2	2.84	0.87	1.16	3.30	69.9	5.1	174.9	73.9	1.2	2.3	0.0	0.0	0.0	0.0	0.1
42	CML445-IR(BC0)-B-B-5-B/TESTERB	104	44	7	2.0	2.1	1.95	1.09	1.36	3.47	69.0	7.5	185.2	86.3	1.1	2.0	0.0	0.0	0.0	0.0	0.1
80	CML312-IR(BC0)-B-B-B-67/TESTERC	104	44	23	1.9	2.4	2.27	1.18	1.07	2.79	67.3	5.9	193.9	82.1	1.5	2.7	0.0	0.0	0.0	0.0	0.1
85	CML247-IR(BC0)-B-B-B-108/TESTERC	102	44	14	2.0	2.4	1.73	1.03	1.23	3.67	67.0	6.0	188.4	78.2	1.4	2.7	0.0	0.0	0.0	0.0	0.1
53	CML247-IR(BC0)-B-B-B-99/TESTERB	100	45	21	2.1	1.6	2.11	0.93	1.19	4.56	71.6	4.4	188.0	73.9	1.3	2.3	0.1	0.0	0.0	0.1	0.2
65	CML444-IR(BC0)-B-B-131-B/TESTERC	100	46	10	2.0	2.2	1.89	0.83	1.29	3.86	64.8	6.9	190.8	78.5	1.4	2.2	0.0	0.0	0.0	0.0	0.2
24	CML247-IR(BC0)-B-B-B-110/TESTERA	99	47	27	2.0	1.0	1.95	1.20	1.26	4.34	68.0	6.1	172.1	74.6	1.1	2.6	0.1	0.0	0.0	0.1	0.3
63	CML395-IR(BC0)-B-B-41-B/TESTERC	99	44	24	2.1	2.0	2.28	0.88	0.71	4.58	68.3	6.8	222.4	99.9	1.7	2.3	0.1	0.0	0.0	0.1	0.2
21	CML247-IR(BC0)-B-B-B-46/TESTERA	97	50	25	2.0	1.4	2.65	0.69	1.42	3.66	67.0	4.7	189.6	78.6	1.2	2.2	0.1	0.0	0.1	0.1	0.5
91	CML78-IR(BC0)-B-B-B-123/TESTERC	96	50	14	1.9	2.1	1.40	1.08	1.19	3.58	65.8	5.5	200.2	79.7	1.4	2.3	-0.0	0.0	0.0	-0.1	-0.1
52	CML247-IR(BC0)-B-B-B-46/TESTERB	96	53	14	1.8	2.1	1.80	1.08	1.04	3.13	71.2	4.3	188.0	78.9	1.2	2.4	0.1	0.0	0.0	0.0	0.4
82	CML312-IR(BC0)-B-B-B-92/TESTERC	94	48	25	2.0	2.2	2.15	0.26	1.55	3.87	67.4	5.6	196.5	85.9	1.3	2.7	0.1	0.0	0.0	0.0	0.2
29	CML78-IR(BC0)-B-B-B-123/TESTERA	93	57	25	1.7	1.5	1.20	1.03	1.91	2.97	67.6	5.2	189.5	75.9	1.7	2.2	0.1	0.0	0.0	0.1	0.2
18	CML312-IR(BC0)-B-B-B-67/TESTERA	92	55	15	1.7	1.8	1.93	0.99	1.39	2.39	68.2	4.1	188.5	81.5	1.3	2.4	0.0	0.0	0.0	0.0	0.2
2	CML390-IR(BC0)-B-B-6-B/TESTERA	91	56	18	1.7	1.6	2.04	0.77	1.64	2.59	67.0	7.3	181.9	79.4	1.3	2.0	0.1	0.0	0.0	0.0	0.3
45	CML445-IR(BC0)-B-B-60-B/TESTERB	90	57	12	1.7	1.5	1.88	1.00	1.12	3.20	68.7	5.8	183.9	73.9	1.0	2.1	0.1	0.0	0.0	0.0	0.2
20	CML312-IR(BC0)-B-B-B-92/TESTERA	89	57	14	1.7	1.7	1.48	0.87	1.59	2.83	69.0	4.1	183.9	84.5	1.2	2.6	0.0	0.0	0.0	0.1	0.1
56	CML384-IR(BC0)-B-B-B-126/TESTERB	84	63	16	1.6	2.1	1.20	0.76	1.35	2.68	70.7	4.2	180.2	76.0	1.2	2.6	0.0	0.0	0.0	0.0	0.1
94	Local Check1	84	62	17	1.6	1.8	1.93	0.51	1.48	2.45	60.4	5.7	180.2	73.4	1.8	2.9	4.9	2.0	3.7	7.8	9.0
31	CML78-IR(BC0)-B-B-B-130/TESTERA	84	60	21	1.7	1.8	2.24	0.83	0.64	2.71	68.3	9.4	176.1	79.3	1.4	2.4	-0.0	0.0	0.0	-0.1	-0.1
9	CML373-IR(BC0)-B-B-93-B/TESTERA	84	65	22	1.6	1.5	1.70	0.51	1.76	2.68	68.9	6.1	170.5	80.6	1.6	2.5	0.1	0.0	0.0	0.0	0.6
10	CML373-IR(BC0)-B-B-180-B/TESTERA	83	60	15	1.7	1.9	1.36	0.85	0.84	3.55	68.9	5.3	177.6	75.7	1.6	2.1	-0.0	0.0	0.0	0.0	0.0
25	CML384-IR(BC0)-B-B-B-126/TESTERA	81	64	9	1.6	1.5	1.89	0.75	0.93	2.95	67.7	5.3	181.7	74.2	1.3	2.1	-0.0	0.0	0.0	0.0	-0.1
16	CML312-IR(BC0)-B-B-B-60/TESTERA	79	63	21	1.6	1.1	1.33	0.83	1.05	3.94	69.6	7.3	177.0	74.1	1.2	2.6	0.1	0.0	0.0	0.0	0.2
38	CML373-IR(BC0)-B-B-55-B/TESTERB	79	64	9	1.6	1.8	1.65	0.62	0.82	3.32	70.2	5.1	189.2	84.5	1.5	2.3	0.1	0.0	0.0	0.1	0.3

95	Local Check2	79	66	30	1.5	1.0	2.59	0.75	1.06	1.93	63.4	6.7	175.5	74.9	1.2	3.0	6.3	2.1	6.7	9.2	11.6
8	CML373-IR(BC0)-B-B-70-B/TESTERA	77	64	28	1.4	1.5	2.37	0.97	0.68	1.36	69.0	6.3	170.2	71.9	1.4	2.1	0.0	0.0	0.0	0.0	0.1
57	CML78-IR(BC0)-B-B-B-7/TESTERB	77	67	15	1.6	1.6	1.15	0.77	0.89	3.41	65.0	5.3	158.8	69.4	1.0	2.2	0.1	0.0	0.0	0.0	0.3
66	CML444-IR(BC0)-B-B-154-B/TESTERC	76	68	7	1.5	1.7	1.41	0.56	1.16	2.85	66.7	5.1	185.3	74.4	1.7	2.3	0.1	0.0	0.0	0.0	0.3
39	CML373-IR(BC0)-B-B-70-B/TESTERB	74	71	19	1.4	1.7	1.23	0.45	1.54	2.33	70.6	4.6	174.0	74.7	1.2	1.6	0.0	0.0	0.0	0.0	0.1
55	CML247-IR(BC0)-B-B-B-110/TESTERB	74	68	27	1.6	1.1	1.13	0.49	1.16	4.13	71.5	5.8	165.8	70.9	1.4	2.1	0.0	0.1	0.0	0.0	0.1
51	CML312-IR(BC0)-B-B-B-92/TESTERB	73	67	23	1.6	1.1	1.37	0.61	0.82	4.12	72.5	3.1	182.5	79.7	1.3	2.1	0.0	0.0	0.0	0.0	0.0
7	CML373-IR(BC0)-B-B-55-B/TESTERA	71	72	12	1.5	1.0	1.39	0.65	1.04	3.14	70.2	6.1	179.3	75.7	1.3	2.1	0.0	0.0	0.0	0.0	0.1
50	CML312-IR(BC0)-B-B-B-79/TESTERB	71	73	10	1.4	1.6	1.65	0.57	1.00	2.01	72.3	5.9	182.9	86.1	1.2	2.5	0.1	0.0	0.0	0.1	0.3
62	CML78-IR(BC0)-B-B-B-130/TESTERB	71	73	20	1.3	0.8	1.77	0.61	1.44	1.98	70.8	8.5	165.9	76.0	1.2	2.6	0.3	0.0	0.0	0.4	0.6
33	CML390-IR(BC0)-B-B-6-B/TESTERB	69	71	25	1.3	2.3	0.75	0.74	0.77	2.02	71.0	6.0	199.7	88.1	1.0	1.9	0.0	0.0	0.0	0.0	0.2
35	CML444-IR(BC0)-B-B-154-B/TESTERB	69	72	16	1.3	1.9	1.54	0.65	0.57	2.05	70.9	4.2	177.9	78.1	1.4	2.3	0.1	0.0	0.0	0.0	0.2
49	CML312-IR(BC0)-B-B-B-67/TESTERB	68	77	9	1.3	1.6	1.16	0.53	1.08	2.33	72.1	3.6	181.1	79.0	1.3	2.3	0.0	0.0	0.0	0.0	0.1
60	CML78-IR(BC0)-B-B-B-123/TESTERB	67	75	12	1.4	1.4	1.17	0.66	0.61	3.14	69.7	5.5	187.7	77.4	1.5	2.0	0.1	0.0	0.0	0.0	0.3
36	CML444-IR(BC0)-B-B-158-B/TESTERB	67	76	7	1.3	1.5	1.56	0.61	0.66	2.36	70.8	6.2	197.5	92.2	1.4	2.5	-0.0	0.0	0.0	0.0	-0.1
81	CML312-IR(BC0)-B-B-B-79/TESTERC	66	75	12	1.3	1.6	1.65	0.61	0.67	1.81	67.1	5.9	194.1	85.7	1.4	2.3	-0.0	0.0	0.0	0.0	-0.2
71	CML373-IR(BC0)-B-B-93-B/TESTERC	64	76	19	1.3	1.1	0.91	0.85	0.58	3.05	67.0	3.9	186.4	75.0	1.9	2.3	0.1	0.0	0.0	0.1	0.4
34	CML444-IR(BC0)-B-B-131-B/TESTERB	62	79	9	1.3	1.5	1.36	0.34	0.67	2.84	70.7	4.4	184.6	80.0	1.3	2.1	0.0	0.0	0.0	0.0	0.1
54	CML247-IR(BC0)-B-B-B-108/TESTERB	55	84	1	1.1	1.1	1.19	0.48	0.67	2.11	69.9	6.0	177.5	68.5	1.3	2.2	0.0	0.0	0.0	0.0	0.1
48	CML312-IR(BC0)-B-B-B-65/TESTERB	54	84	14	1.2	1.4	0.84	0.23	0.58	3.12	67.1	4.3	158.4	66.9	1.3	2.3	0.1	0.0	0.0	0.2	0.2
41	CML373-IR(BC0)-B-B-180-B/TESTERB	53	86	7	1.0	1.0	1.21	0.57	0.55	1.79	71.7	5.0	163.8	73.1	1.2	2.1	-0.0	0.0	0.0	0.0	0.1
47	CML312-IR(BC0)-B-B-B-60/TESTERB	52	85	11	1.2	1.0	1.38	0.40	0.22	2.78	73.3	6.2	166.0	68.6	1.4	2.1	0.0	0.0	0.0	0.0	0.1
40	CML373-IR(BC0)-B-B-93-B/TESTERB	50	86	8	1.1	1.2	0.48	0.42	0.59	2.77	72.7	3.5	177.0	73.0	1.3	2.0	0.0	0.0	0.0	0.0	0.2
37	CML373-IR(BC0)-B-B-38-B/TESTERB	45	86	16	1.1	0.9	0.85	0.17	0.41	3.16	65.3	3.2	189.7	64.5	1.4	2.1	0.1	0.0	0.0	0.0	0.2
6	CML373-IR(BC0)-B-B-38-B/TESTERA	45	89	6	0.9	0.9	1.19	0.51	0.31	1.49	66.9	6.8	184.7	71.0	1.2	2.2	0.1	0.0	0.0	0.2	0.4
59	CML78-IR(BC0)-B-B-B-62/TESTERB	43	88	6	0.9	1.1	0.84	0.13	0.69	2.03	69.2	6.2	160.4	62.3	1.2	2.1	-0.0	0.0	0.0	0.0	0.0

32	CML395-IR(BC0)-B-B-41-B/TESTERB	42	87	16	0.8	0.9	1.74	0.31	0.33	0.80	66.7	4.4	179.2	76.7	1.0	1.7	0.0	0.0	0.0	0.0	0.1
	Mean	**100**	**49**	**16**	**1.95**	**1.97**	**1.95**	**0.95**	**1.42**	**3.44**	**67.5**	**5.7**	**186.0**	**79.1**	**1.3**	**2.4**	**0.2**	**0.1**	**0.1**	**0.3**	**0.4**
	LSD(0.05)	**31**	**23**	**7**	**0.50**	**1.03**	**1.10**	**0.78**	**1.01**	**1.52**	**3.0**	**2.1**	**13.0**	**7.8**	**0.3**	**0.4**	**0.5**	**2.0**	**0.6**	**0.8**	**0.9**
	Mse				**0.48**	**0.40**	**0.46**	**0.24**	**0.39**	**0.89**	**17.6**	**5.3**	**298.8**	**117.1**	**0.2**	**0.1**	**0.5**	**0.0**	**0.5**	**1.2**	**1.2**
	P	**	**	**	**	**	**	**	**	**	**	**	**	**	**	*	**	ns	**	**	**
	Min	**42**	**6**	**1**	**0.81**	**0.83**	**0.48**	**0.13**	**0.22**	**0.80**	**60.4**	**3.1**	**158.4**	**62.3**	**1.0**	**1.6**	**-0.1**	**0.0**	**0.0**	**-0.1**	**-0.2**
	Max	**170**	**89**	**32**	**3.13**	**3.57**	**3.56**	**2.44**	**2.92**	**5.47**	**73.3**	**9.4**	**222.4**	**99.9**	**1.9**	**3.0**	**6.3**	**2.1**	**6.7**	**9.2**	**11.6**
	No. of Signif.sites	5	5	5	5	1	1	1	1	1	5	3	4	5	4	2	5		4	5	4

Color coding: Very good; Good; Average; Poor; Very poor

** (P < 0.01); * (P < 0.05); ns = not significant.

RelGY: Relative Grain yield; GY: Grain yield; Acr: Across sites; Anth date: Anthesis date; ASI: Anthesis silking interval; Plt hgt: Plant height; Ear hgt: Ear height; P. sorg: *Puccinia sorghi*; E. turc: *Exserohilum turcicum*; Striga avg: Striga average; Striga 6,8,10,12 wks: Striga count at 6,8,10 and 12 weeks
UK. S.A: Ukiriguru Sengerema A; UK. S.B: Ukiriguru Sengerema B; UK. N.A: Ukiriguru Nyashimba A; UK. N.B: Ukiriguru Nyashimba B; KBS: Kibos Agriculture Research Station

Appendix 2. Analysis of Variance for Grain yield (GY) for Ukiriguru-Sengerema A

SOURCE OF VARIATION	DF	MS	F
Replication	2	8.84	**
Block	33	1.18	**
Line	30	1.23	**
Tester	2	11.91	**
Line x Tester	60	0.55	ns
Error	151	0.40	
Total	278		
σ^2_{gca}		0.34	
σ^2_{sca}		0.08	

** (P< 0.01); * (P< 0.05); ns: not significant; DF: Degrees of Freedom; MS: Mean squares; F: F-value

Appendix 3. Analysis of Variance for grain yield (GY) for Ukiriguru-Sengerema B

SOURCE OF VARIATION	DF	MS	F
Replication	2	6.38	**
Block	33	1.44	**
Line	30	1.02	ns
Tester	2	9.84	**
Line x Tester	60	0.88	**
Error	151	0.46	
Total	278		
σ^2_{gca}		0.07	
σ^2_{sca}		0.21	

** (P< 0.01); * (P< 0.05); ns: not significant; DF: Degrees of Freedom; MS: Mean squares; F: F-value

Appendix 4. Analysis of Variance for grain yield (GY) for Ukiriguru-Nyashimba A

SOURCE OF VARIATION	DF	MS	F
Replication	2	12.38	**
Block	33	0.79	**
Line	30	0.68	**
Tester	2	5.88	**
Line x Tester	60	0.27	ns
Error	151	0.24	
Total	278		
σ^2_{gca}		0.21	
σ^2_{sca}		0.02	

** (P< 0.01); ns: not significant; DF: Degrees of Freedom; MS: Mean squares; F: F-value

Appendix 5. Analysis of Variance for Grain yield (GY) for Ukiriguru-Nyashimba B

SOURCE OF VARIATION	DF	MS	F
Replication	2	4.03	**
Block	33	0.88	**
Line	30	1.05	ns
Tester	2	13.80	**
Line x Tester	60	0.72	**
Error	151	0.37	
Total	278		
σ^2_{gca}		0.17	
σ^2_{sca}		0.18	

** (P< 0.01); ns: not significant; DF: Degrees of Freedom; MS: Mean squares; F: F-value

Appendix 6. Analysis of Variance for Grain yield (GY) for Kibos

SOURCE OF VARIATION	DF	MS	F
Replication	2	16.70	**
Block	33	2.27	**
Line	30	3.20	*
Tester	2	20.33	**
Line x Tester	60	1.62	**
Error	151	0.88	
Total	278		
σ^2_{gca}		0.79	
σ^2_{sca}		0.37	

** (P< 0.01); * (P< 0.05); ns: not significant; DF: Degrees of Freedom; MS: Mean squares; F: F-value