GENETIC ANALYSIS OF DROUGHT TOLERANT EARLY MATURING WHITE MAIZE (*Zea mays* L.) INBREDS WITH *STRIGA* RESISTANCE GENES FROM *Zea diploperennis*

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DECLARATION

I hereby declare that except for references to work of other researchers, which have been duly cited, this work is my original research and that neither part nor whole has been presented elsewhere for the award of a degree.

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ABSTRACT

Recurrent drought and parasitism by *Striga hermonthica* Del. Benth constitute the two most important stresses limiting maize (*Zea mays* L.) production and productivity in sub-Saharan Africa (SSA). Yield losses can reach up to 85% when the two stresses occur simultaneously in the field. The use of resistant varieties is more sustainable, economical, and efficient for African farmers. Several early (90-95 days to maturity) *Striga* resistant maize hybrids have been commercialized in the sub-region. However, the levels of resistance are not as high as desired as they still support *Striga* emergence thus increasing the *Striga* seed bank in the soil each season. The International Institute of Tropical Agriculture (IITA) has developed new early maturing maize inbreds containing novel *Striga* resistance genes from *Zea diploperennis.* Knowledge and understanding of the mode of gene action conferring *Striga* resistance and drought tolerance in these new early maturing maize inbreds would be invaluable in developing hybrids adapted to both stresses in the sub-region. The objectives of this study were to: (i) determine the genetic diversity and reaction of these early maturing maize inbred lines under *Striga* infestation and drought environments, (ii) determine the mode of inheritance of *Striga* resistance in an early maturing inbred line containing resistance genes from *Zea diploperennis*, (iii) determine the combining abilities for grain yield and other agronomic traits and heterotic groups of 30 drought tolerant, early maturing inbreds with the *Striga* resistance genes, (iv) identify high yielding and stable hybrids under *Striga*-infested, drought and optimal growing conditions (v) examine the inter-trait relationship of early maturing maize hybrids under the *Striga* infestation and drought. Genetic diversity among 36 early maturing inbred lines was assessed using 8145 SNP markers. The cluster analysis and population structure analysis separated the inbred lines into four distinct groups based on their genetic distance indicating high level of genetic variability among the lines. Using the base indices for selection, 22% of the inbred lines combined resistance to *Striga* and tolerance to drought. Generation mean analysis was used to study the inheritance of resistance to *Striga* in the early maturing maize inbred line, TZdEI 352, containing genes from *Zea diploperennis* to facilitate its effective use in resistance breeding programmes in SSA. Only models that incorporated epistasis in addition to additive and dominance gene effects were adequate in explaining variation in the six generations studied. Epistasis played an important role in *Striga* resistance genes from *Zea diploperennis* in tropical maize. One hundred and fifty hybrids derived from crosses involving the 30 inbreds utilizing North Carolina Design II plus six hybrid checks were evaluated under artificial *Striga* infestation at Mokwa and Abuja, drought at Ikenne, Bagauda, Minjibir and optimal environments at Ikenne, Mokwa and Abuja, in 2013 and 2015. Significant GCA and SCA effects for grain yield and most measured traits were detected under the three research conditions. The higher values of GCA over SCA obtained for grain yield, flowering traits, plant and ear heights, husk cover, *Striga* damage and number of emerged *Striga* plants at 8 and 10 weeks after planting under *Striga* infested and optimal environments, indicated that they were controlled by additive gene action. The non-additive gene action was more important than the additive gene action for days to silking, anthesis-silking interval, ear height, stalk and root lodging, ears per plants, ear and plant aspects while additive gene action was more important for grain yield, plant height, husk cover, and stay green characteristics under drought environments. There were no maternal effects in the expression of the traits either under *Striga* infestation, drought or optimal growing environments. Inbreds TZdEI 268, TZdEI 352 and TZdEI 173 had superior positive GCA-male and GCA-female effects for grain yield and negative GCA-male and GCA-female effects for *Striga* damage and number of emerged *Striga* plants under *Striga* infestation indicating that they contributed to higher grain yield in their hybrids and could be used to improve tropical germplasm for *Striga* resistance. The lines TZdEI 492 and TZdEI 378 with outstanding positive GCA effects for grain yield under drought environments could be used to improve tropical germplasm for drought tolerance. The inbred lines were classified into four heterotic groups across the research environments using GCA effects of multiple traits. The inbred lines classified into each heterotic group may be recombined to form populations that could be improved through recurrent selection. Grain yield ranged from 1134 kg ha^{-1} for TZEI 26 x TZEI 5 to 5362 kg ha^{-1} for TZdEI 173 x TZdEI 280 under *Striga* infestation, 579 kg ha^{-1} for TZdEI 314 x TZdEI 378 to 3601 kg ha^{-1} for TZdEI 479 x TZdEI 260 under drought and 2376 kg ha^{-1} for TZdEI 82 x TZdEI 71 to 7769 kg ha^{-1} for TZdEI 260 x TZdEI 396 under optimal conditions. The additive main effects and multiplicative interaction analysis identified TZdEI 173 x TZdEI 280, TZdEI 173 x TZdEI 492, TZdEI 441 x TZdEI 260, TZdEI 82 x TZdEI 260, TZdEI 71 x TZdEI 396, TZdEI 396 x TZdEI 131, TZdEI 396 x TZdEI 264, TZdEI 98 x TZdEI 352, TZdEI 157 x TZdEI 352, TZEI 18 x TZdEI 357, TZdEI 268 x TZdEI 378, TZdEI 157 x TZdEI 280, TZdEI 492 x TZdEI 441 and TZEI 60 x TZEI 5 as the highest yielding and stable hybrids with combined *Striga* resistance and drought tolerance genes. Also, they had reduced *Striga* emergence and host plant damage. These hybrids should be tested in multi-location and on-farm trials to confirm the consistency in performance and promoted for release and commercialization in the *Striga* endemic areas with short duration of rainfall in West and Central Africa to contribute to increased maize productivity, poverty alleviation and reduced *Striga* seed bank in the soil. *Striga* resistant and drought tolerant hybrids with outstanding performance across stress environments could be obtained through accumulation of favorable alleles for stress tolerance in parental lines. Ear aspect was identified as the most reliable secondary trait for indirect selection for grain yield under both *Striga*-infested and drought.

DEDICATION

This work is dedicated to God Almighty for the strength and vision in carrying out this project and to my parents, Mr. and Mrs. G.O. Akaogu and daughter; Kamsiyochukwu Pearl for their love and support throughout the research.

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ABA: Abscisic Acid
AFLP: Amplified Fragment Length Polymorphism
ALS: Acetolactate Synthase
AMMI: Additive Main Effects and Multiplicative Interaction
ANOVA: Analysis of Variance
CIMMYT: International Maize and Wheat Improvement Center
CTAB: Cetyl Trimethyl Ammonium Bromide
DNA: Deoxyribonucleic acid
FAO: Food and Agriculture Organization
GCA: General Combining Ability
GD: Genetic Distance
GGE: Genotypes plus Genotypes by environments interactions
GEI: Genotype by environment interaction
GMA: Generation Mean Analysis
HGCAMT: Heterotic grouping based on GCA of Multiple Traits
HSGCA: Heterotic groups' based on Specific and General Combining Ability
IITA: International Institute of Tropical Agriculture
IPCA: Interaction Principal Component Axes
NC II: North Carolina Design II
NCRPIS: North Central Regional Plant Introduction Station
PIC : Polymorphic Information Content
QTL : Quantitative Trait Loci
RAPD : Randomly Amplified Polymorphic DNA
RFLP : Restriction Fragment Length Polymorphism
SAS : Statistical Analytical Software
SCA: Specific Combining Ability
SNP: Single Nucleotide Polymorphisms
SNP-GD: Single Nucleotide Polymorphism based Genetic Distance
SSA: Sub-Saharan Africa
SSR: Simple Sequence Repeats
USA: United States of America
WAP: Weeks after Planting
WCA: West and Central Africa

CHAPTER ONE

1.0 GENERAL INTRODUCTION

Maize (*Zea mays* L.) is a food security crop for millions of populace in sub-Saharan Africa (SSA). It is commonly grown at subsistence levels by African farmers in the rural areas of the sub-region (Shiferaw *et al*., 2011). It is ranked the third principal cereal after *Oryza sativa* L. and *Triticum aestivum* L. in terms of its harvest area, nutritional value and consumption. All parts of the crop can be used for food and non-food products (IITA, 2009). In developed nations such as the United States of America (USA), the highest producer in the world with grain yield of about 7 tons per hectare, 37% of the maize produced is used largely for biofuel and 33% for livestock feed. In contrast, Nigeria is the largest producing country in Africa with an average grain yield of less than 2 ton/ha (FA0, 2012) and 80% of maize production is for human consumption.

The significance of maize in the savannas of SSA has been rapidly growing in the last twenty years replacing traditional cereals such as millet (*Pennisetum glaucum* (L.) R.Br.) and sorghum (*Sorghum bicolor* (L.) Moench) in regions of the savannas with good access to markets and agricultural inputs such as fertilizers (Badu-Apraku and Fakorede, 2003). In addition to its high yield potential and responsiveness to fertilizer, it has the tendency for alleviating the food insecurity and malnutrition problems caused by the high levels of urbanization in West and Central Africa (WCA) countries (Byerlee and Eicher, 1997). The increase of maize production in the sub-region is largely due to the fact that the savannas, which are the maize belts of WCA, are characterized by high incidence of in-coming radiation, low night temperatures and low humidity as well as low pest and disease pressure. Despite the implementation of the Agricultural Structural Adjustment Programmes and the huge potential of maize as an industrial and food crop in the sub-region, its production and productivity have not met the increasing demands of human population due to lack of improved seeds, unavailability/high cost of inorganic fertilizers and herbicides, and poor crop management practices as well as increasing levels of biotic and abiotic stresses (Heerink, 2005). The abiotic stresses include recurrent drought and poor soil fertility while the biotic stresses include insects such as stem borers, army worms and parasitic weeds such as *Striga spp* and foliar diseases. Of these stress factors, infestation by *Striga hermonthica* (Del.) Benth and drought are the two important stresses limiting maize (*Zea mays* L.) production in WCA. Under field conditions, the two stresses can occur simultaneously resulting in 85% yield reduction (Adetimirin *et al*., 2000). Therefore, there is a need to breed for stress-resilient maize for the sub-region.

Three species namely *Striga hermonthica*, *Striga asiatica* and *Striga aspera* attack maize but only the first two are of major economic importance in the savannas of WCA (Berner *et al*., 1996). About 100% yield losses due to *Striga hermonthica* could be obtained depending on the soil fertility, the type of genotype grown, severity of infestation and the prevailing environmental conditions (Lagoke *et al*., 1991; Berner *et al*., 1996). Farmers have been forced to abandon their fields heavily infested by *Striga* (Ejeta, 2007a). Several measures have been proposed for reducing the effects of *Striga* including the use of resistant varieties, catch crops, crop rotation, intercropping and high amount of nitrogen fertilizer. However, genetic resistance is the most efficient and ecosystem friendly and sustainable approach for African farmers (Rich and Ejeta, 2008; Akaogu *et al*., 2012).

During the last two decades changes in the climatic conditions, movement of maize to marginal areas by high value crops, low soil organic matter, water retention and soil infertility has increased the occurrence of drought (Banziger *et al*., 2000). Effects of drought include delayed silk emergence which gives rise to extended anthesis-silking interval, reduction in the quantity of pollen shed, tassel blasting and ear barreness resulting in total crop failure (Banziger *et al*., 2000). According to Edmeades *et al*. (1995) average annual maize yield reduction of 15% occurs in the savanna of WCA as a result of drought stress. About 40 to 90% reduction in grain yield was recorded when moisture stress occurred from a few days before anthesis to the start of grain filling (Menkir and Akintunde, 2001; Badu-Apraku *et al*., 2011a). Several chemical and cultural methods have been used for *Striga* control but have proved ineffective and unsustainable for the famers in the sub-region. The use of host plant resistance which is more sustainable (Rich and Ejeta, 2008) has not been completely effective due to the limited knowledge on the genetic factors controlling the life span of the parasite, the polygenic nature of *Striga* resistance and complex genotype x environment interactions (Scholes and Press, 2008). Most resistance to *Striga spp.* appears to be polygenic and quantitatively inherited. The International Institute of Tropical Agriculture (IITA) maize programme has used resistance genes from diverse germplasm sources including temperate and tropical materials identified following numerous years of wide testing in the savannas of WCA. However, the *Striga* resistance genes have not been as effective as desirable in the control of *Striga* because they allow the flowering and seed production of the *Striga* plants thereby increasing the *Striga* seed bank in the soil. Consequently, there has been an exploration for novel genes for resistance to *Striga hermonthica* in the wild relative of maize, *Zea diploperennis* (Lane *et al*., 1997; Amegbor *et al*., 2017). Several early maturing inbreds have been developed containing the novel *Striga* resistance genes from *Z. diploperennis* in IITA. However, the combining ability and heterotic groups of the inbreds have not yet been determined.

Hybrid development, promotion and adoption are promising strategies for significantly increasing maize production and productivity and for revolutionalizing agriculture in WCA (Akaogu *et al*., 2012). A number of seed companies have emerged in the sub-region during the last decade giving way to commercial hybrid production. However, there are limited early maturing hybrids with combined tolerance/resistance to *Striga* and drought commercialized for the areas of the savanna agro-ecologies with a short growing period. For successful hybrid production and commercialization, information on the combining abilities and the heterotic groupings of the inbreds are of primary importance to plant breeders. Identification of inbred lines which show heterosis under drought and *Striga* infestation is an important step towards addressing the challenges posed by these constraints. Information on heterotic patterns of the lines can be obtained from crosses using different mating designs including the diallel, line x tester and North Carolina (NC) II designs. However, each of these mating designs has its limitations. When more than 20 inbred lines are involved for crossing, it is impracticable to use diallel analysis to elucidate information on the heterotic patterns (Melchinger, 1999). However, line x tester and NC II designs are suitable. When there are no testers of known heterotic classification available, it is difficult to use the line x tester design analysis. However NC II design can be used to sample a large number of inbred lines by dividing them into smaller groups or sets. Studies have shown that classification of inbred lines using the specific combining ability (SCA) of grain yield alone has not been a reliable method because the heterotic groups of inbred lines is affected by the evaluation environments (Menkir *et al*., 2003). For example, Fan *et al*. (2009) reported that the SCA effects of grain yield were often greatly influenced by the environments, which often at times lead to assigning the same inbred line into different heterotic groups under different studies. Therefore several other heterotic grouping methods such as molecular markers (Reif *et al.,* 2003; Flint-Garcia *et al*., 2009) and based on general combining ability of multiple traits (HGCAMT) have been proposed (Badu-Apraku *et al*., 2013a).

Most tropical maize lines share some common parentage and *Striga* resistance gene sources, their exclusive use in hybrid development due to their novel *Striga* resistance gene could heighten the risk of narrow genetic base in maize production field. Therefore, systemic exploitation of these maize lines that will guarantee future gain from selection and minimize narrow genetic base, requires thorough assessment of genetic relatedness in these maize lines before their utilization in breeding programs. Liu *et al*. (2003) suggested that, utilization of desirable genes from diverse sources of maize inbreds requires a total understanding of the genetic and pedigree relationships, and also the genetic variation among them. Knowledge of the genetic relatedness among inbred lines using molecular markers would help select inbreds that have adequate genetic diversity, and optimized the discovery of single nucleotide polymorphisms (Liu *et al*., 2003). There is lack of consistency between the hybrid performance and the genetic distance (GD) derived from the molecular markers (Romay *et al.,* 2013).

The objectives of the study were to:

(i) assess the genetic diversity and reaction of early maturing maize inbred lines under *Striga* infestation and drought environments

(ii) determine the mode of inheritance of *Striga hermonthica* resistance in early maturing maize containing *Striga* resistance genes from *Zea diploperennis*,

(iii) determine the combining abilities for yield and other agronomic traits and heterotic groups of early maturing white *Striga* resistant and drought tolerant maize inbreds,

(iv) identify high yielding and stable hybrids under *Striga*-infested, drought and optimal growing conditions and

(v) assess the inter-trait relationship of early maturing maize hybrids under *Striga*-infestation and drought.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Maize production

Maize (*Zea mays* L.), known as corn in the USA, is a cross pollinated crop in the family Poaceae. It originated from Mexico and Central America and has several wild species including teosinte (*Z. perennis, Z. nicaraguensis, Z. luxurians* and *Z. diploperennis*) in the genus *Zea* (Doebely, 1990). Maize is ranked the third most consumed grain cereal after *Triticum aestivum* L. and *Oryza sativa* L. in the world (FAO, 2011). During the past twenty years in WCA, maize has become a major food and cash crop and has witnessed rapid increases in production (Fakorede *et al*., 2003). In Nigeria, maize is the second most consumed cereal after rice. Its high energy content makes it essential in both human and animal diets; hence it is rapidly replacing traditionally grown cereals such as *Pennisetum glaucum* (L.) R.Br and *Sorghum bicolor* (L.) Moench in areas of the savannas with good fertilizer inputs and markets (Badu-Apraku and Fakorede, 2003).

The total annual world production of maize is estimated to be about 883 million tons with the USA as the leading producer (Fig. 2.1). In West Africa, Nigeria produces 9.2 million tons out of the overall production of 16 million tons. However, the average grain yield of maize in Nigeria is less than 2 tons per hectare (FAO, 2012) in comparison to USA which produces about 7 tons per hectare.

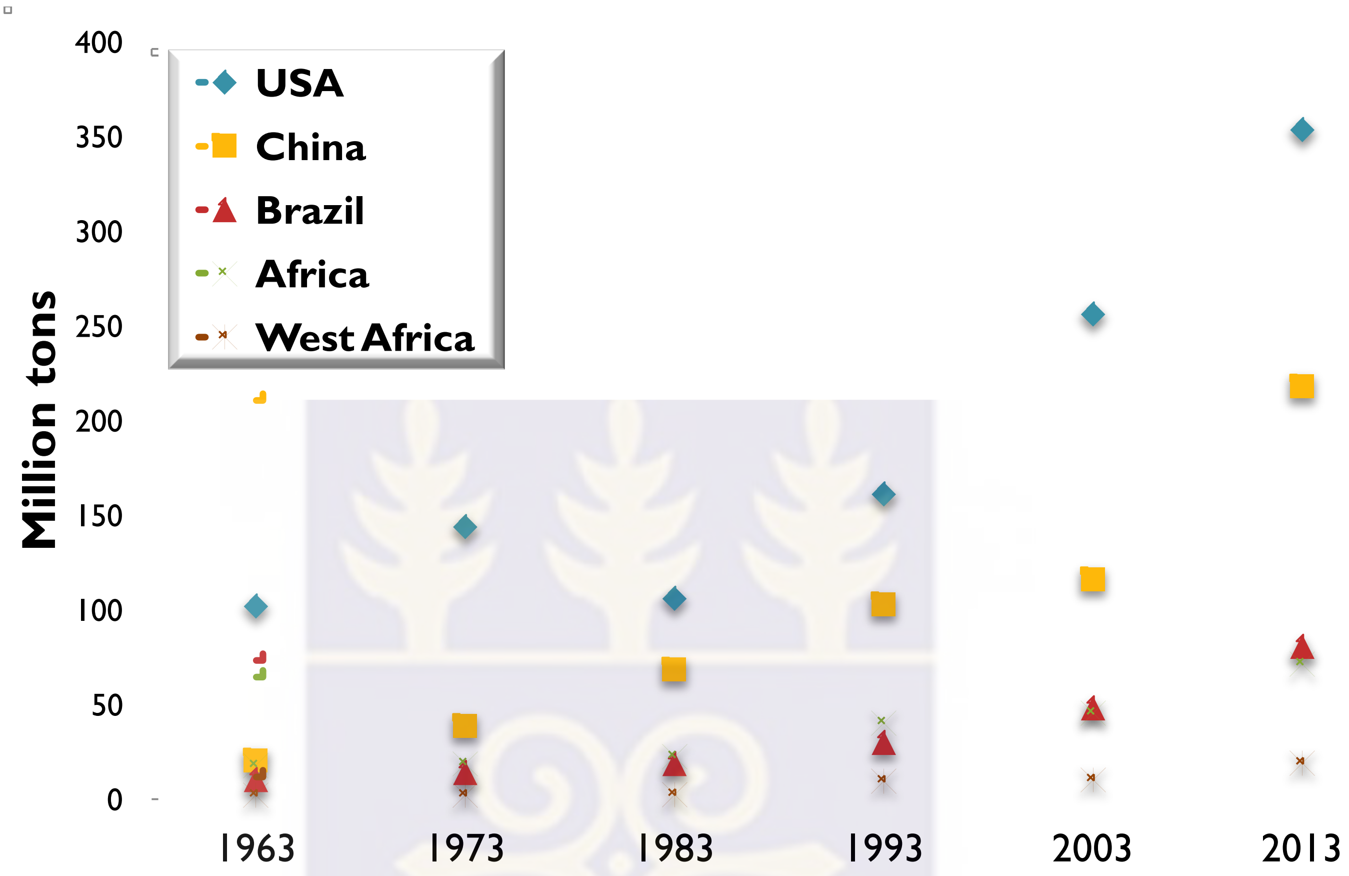


Figure 2.1: Changes in maize production in different continents of the world from 1963 to 2013 (FAOSTAT, 2012)

2.2 Constraints to maize production and productivity

The savannas of WCA, which is the maize belt of the region beacause of favourable climatic conditions such as high incoming radiation, low prevalence of pests and diseases, and low night temperatures is greatly constrained by several biotic and abiotic stresses, including infestation by *Striga hermonthica*, recurrent drought, low soil fertility, heat stress, foliar diseases, army worms and stem borers (Badu-Apraku *et al*., 2017). Among these stresses, infestation by *Striga hermonthica* and recurrent drought are the most prominent living and non-living factors limiting maize production and productivity in the savannas of WCA. Under field conditions, *Striga* parasitism and drought occur simultaneously with severe consequences (Badu-Apraku *et al*., 2010). Adetimirin *et al*. (2000) reported that drought has geometrically increased the yield losses caused by *Striga*; while drought and *Striga* reduced average yield of four maize hybrids by 27% and 53.7%, respectively, the combined effect of the two stresses reduced maize yield in the hybrids by 85.5%. Therefore, for high and sustainable production and productivity of maize in WCA, researchers need to address simultaneously the problems posed by the two important stresses viz: *Striga* and drought.

2.2.1. Parasitic weed *Striga* (witchweed)

The genus *Striga*, known as witchweed, is an obligate parasite in the family Scrophulariaceae. It depends completely on its host for its nutrients and water without contributing anything beneficial in return. The genus *Striga* has about 28 species which parasitize both monocot and dicot plants (Estep *et al.,* 2011). The crops infested by *Striga* species in Africa are *Sorghum bicolor*, *Zea mays, Pennisetum glaucum, Eleusine coracana, Oryza glaberrima, Oryza sativa, Vigna unguiculata* and *Saccharum officinarum* (Rodenburg *et al*., 2006; Scholes and Press, 2008). The most common of these species which infest cereals are *S. hermonthica* (Del.)

Benth., *S. forbesii* Benth, *S. aspera* (Willd.) Benth, *S. asiatica* (L.) Kuntze while *S. gesneriodes* (Willd.) Vatke infests cowpea and tobacco (Estep *et al.,* 2011). Across environments, there can be different biotypes of *S. hermonthica,* an outcrossing species (Kim, 1994) which produces more than 200,000 seeds per plant (Parker and Riches, 1993). The *Striga* seed banks are built up by continuous growing of the host plants (Kunisch *et al.*, 1991) and the seed can remain dormant for more than 10 years in the soil (Gbèhounou, *et al.*, 2003; Hearne, 2009) and cause total crop failure resulting in yield losses depending on the prevailing climatic conditions and the host plant (Parker and Riches, 1993). The growth of *Striga* plants on the host are conditioned by chemical stimulants known as Strigolactones which are produced by the maize plants under stress conditions (Bouwmeester *et al.*, 2003). The *Striga* plants germinate from the soil in response to the chemical exudates (Strigolactones) produced in the roots of the maize plants (Matusova *et al*., 2005). Following germination, the *Striga* plants cannot survive except by attachment to the host using haustoria to derive its water and nutrients for growth and development. The *Striga* plants flower and set seeds about six weeks after emergence and remain attached to the host, thereby increasing its seed bank. Prevailing climatic factors determine the success of the parasitism between *Striga* and its host which are controlled by several genetic and physiological processes (Ejeta, 2007b). The yield reduction in the host plant is caused by phytotoxic effects which favour the source-sink partitioning of the assimilates into the roots rather than the shoot, thus reducing grain yield (Ransom *et al.*, 1996).

2.2.1.1 Effects of *Striga* on maize

S. hermonthica (Del.) Benth, *S. aspera* (Willd.) Benth, and *S. asiatica* (L.) Kuntze*,* are the common species in WCA. *S. hermonthica* is the most prevalent and devastating of the three affecting food grain with maize as the chief host (Berner *et al.*, 1995; Yoshida, *et al.*, 2010). In

Africa, more than 24% of the total land cultivated with maize are heavily infested by *Striga* (de Groote *et al.*, 2008). In West Africa, about 64% of the cereal production areas are *Striga* infested (Gressel *et al.*, 2004) while 70% of Nigeria's arable land is lost to *Striga hermonthica* parasitism (Hartman and Tanimonure, 1991). Other cereals infested by *S. hermonthica* are pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*), sorghum (*Sorghum bicolor*), and upland rice (*Oryza sativa*). Average yield reduction in cereals caused by *Striga* infestation are estimated to be about 20 - 80% (Atera *et al*., 2011). *Striga* species totally depend upon their hosts for food and water during growth below the soil surface. When they appear above the soil surface, they produce chlorophyll and become semi-parasitic, manufacturing some of their own food but continuing to depend largely upon the host (Stewart *et al*., 1991). *Striga* causes reduction in host growth with effects being more severe under limited soil moisture and nutrients. Other damage to host crops, especially maize, includes chlorotic blotches, leaf scorching (firing) particularly around the margins of the leaves, leaf drying resembling the situation under moisture stress (wilting), stunted growth, poor pollen production and barreness. The severity and nature of damage depend on time of host infestation. Early infestation causes reduction in plant height and yield, while late infection reduces yield components such as cob length, cob diameter, ear and seed weight (Kim, 1991).

Striga reduces host plant growth via two processes. The first is competition for carbon by direct transfer of the host plant carbon to the parasite. The second is impairment of photosynthesis through a less efficient use of light in the fixation of carbon dioxide (Stewart *et al*., 1991). Apart from the translocation of photosynthate carbon, there is movement of other non-photosynthate compounds especially organic nitrogen. Synthesis of organic nitrogen compounds occurs in the host roots and depends on a supply of sucrose from the host shoot and inorganic nitrogen from the soil. In sorghum and maize, decline in photosynthesis occurs before the emergence of *Striga* and accounts for 80% of yield loss (Stewart *et al*., 1991). Similar observations of reduction in crop growth prior to parasite emergence have been made in cowpea (Emechebe *et al*., 1991). In WCA, farmers have abandoned their heavily *Striga* infested fields (Ejeta, 2007a) which is a major biotic constraint limiting cereal production of resource poor farmers. This *Striga* menace is aggravated by inherent soil infertility, recurrent drought, lack of crop rotation, short fallow periods, and continuous cultivation of marginal lands with little fertilizer input (Menkir *et al*., 2001). *Striga* parasitism is less severe in the presence of good growing conditions such as high soil nitrogen and sufficient rainfall which is not obtainable in Africa (Rich and Ejeta, 2008).

2.2.1.2 *Striga hermonthica* control methods

The effect of *Striga* parasitism on maize is determined by several factors such as ability to withstand the parasite, inoculum density of *Striga* seed in the soil, the level of soil fertility and amount of soil moisture (Kim and Adetimirin, 1997a; Kim and Adetimirin, 1997b). Several control measures are available such as hand picking, crop rotations, use of trap crops, high nitrogen fertilizer application to increase soil fertility (Oswald, 2005; Van Ast *et al.*, 2005; Joel *et al*., 2007) and the use of tolerant/resistant varieties (Badu-Apraku *et al*., 2004a; Menkir *et al*., 2012, Badu-Apraku *et al*., 2013a). Also, intercropping with forage legume *Desmodium uncinatum* (Khan *et al.*, 2007) and use of herbicide coating on maize seeds (imidazolinone) are used as control measures (Kanampiu *et al.*, 2003). Despite all the numerous control strategies aforementioned, none can completely eradicate the *Striga* infestation on maize fields (Oswald, 2005). Control strategies such as crop rotation, intercropping, and prolonged fallow help to build the soil structure and fertility which combats the *Striga* menace (Kureh *et al.*, 2000).

However, the rapid increase in human population has given rise to rigorous land use with reduced fallow periods (Webb *et al.*, 1993), and in some regions, endless cereal cropping with slight or zero application of both organic and inorganic fertilizer (Van Ast *et al.*, 2005). This has resulted in the decline of soil fertility and therefore reduced the success of the control methods (Berner *et al.*, 1996). The use of catch crop such as cotton which produces germination stimulants that can cause spontaneous germination of *Striga* seeds in fields previously infested, thereby decreasing its seed bank in the soil. Effective hand picking of the mature *Striga* plants before they flower and produce seed can decrease the quantity of *Striga* seeds in the soil, without appreciably increasing the crop yield (Verkleij and Kuiper, 2000) because serious damage to the maize crop would have been done before the *Striga* plant emerges from the soil (Parker and Riches, 1993). Furthermore, hand weeding is painstaking, time consuming and impossible to use for *Striga* control on a large scale. In Kenya, the use of herbicide coating imazapyr (imidazolinone) and pyrithiobac on the maize seeds increased grain yield by 17% when grown in *Striga*-infested soils (Abayo *et al.*, 1998). Dicamba (3, 6-dichloro-methoxybenzoic acid), when applied at the time of *Striga* attachment, suppresses emergence of the *Striga* plants and provides some yield protection (Odhiambo and Ransom, 1993). However, dicamba does not give the consistent control essential to make it cost operative (Abayo *et al.*, 1998). Although, the use of herbicides that can block acetolactate synthase (ALS) pathway is an effective control method of parasitic plants, there is the risk of mutation of traits conferring resistance to ALS-inhibiting herbicide. The use of ethylene gas in *Striga*-infested soil to cause spontaneous germination of the *Striga* seeds in the absence of the host before planting of crops is another effective *Striga* control method but very costly and the African resource poor farmers can not afford it (Parker and Riches, 1993).

Host-plant resistance, exemplified by a reduced level of *Striga* attachment to the host, or tolerance, which is the potential of the host plant to produce a reasonably high yield despite infestation, is the most economical, efficient and most environmentally-sustainable method in Africa for decreasing the severe damage caused by *Striga* (DeVries, 2000; Badu-Apraku *et al.*, 2004a). Several maize populations, hybrids, open-pollinated varieties, and inbred lines with *Striga* resistance or tolerance have been commericalized in WCA (Badu-Apraku *et al.*, 2004a; Badu-Apraku *et al.*, 2005; 2007a; Menkir *et al.*, 2012). Novel *Striga* resistance genes were found in the wild maize relative, *Z. diploperennis,* and the resistance genes have been introgressed into cultivated maize of tropical adaptation (Menkir, 2006; Amusan *et al.*, 2008). The maize plants have expressed resistance to *Striga hermonthica* through different mechanisms including low or no stimulation of chemical exudates; production of strigolactones which facilitates *Striga* seed germination (Kiruki *et al.*, 2006); prevention of the attachment of the parasites to its roots or death of the attached parasites resulting in fewer *Striga* plants and production of yield higher than those of the susceptible genotypes (Badu-Apraku and Akinwale, 2011). *Striga* tolerant genotypes support as many *Striga* plants as the intolerant genotypes but produce more yield and show reduced damage syndrome than the susceptible genotypes (Kim, 1994; Badu-Apraku *et al.*, 2010). The use of *Striga*-resistant cultivars reduces parasite seed reproduction and this depletes the *Striga* seed bank (Haussmann *et al.*, 2004; Badu-Apraku and Lum, 2007).

It has been documented that *Striga* control is most effective when a number of individual technologies are combined in an integrated *Striga* control programme. This provides sustainable approach over widespread of physical environments (Ellis-Jones *et al.*, 2004). In the USA, *Striga* damage has been brought under control with the aid of herbicides, ethylene injection, fumigation and application of very high amounts of ammonium nitrate fertilizer (Doggett, 1984). A 46% decrease in *Striga* seed bank in the soil and 88% improvement in crop productivity were observed with the integrated *Striga* control approach (Franke *et al.*, 2006). Adequate N fertilizer and herbicide applications are effective at reducing crop damage by *Striga* as well as reducing *Striga* emergence (Kim, 1991; Mumera and Below, 1993). *Striga* resistant maize grown after planting of soybean increased the benefit in two cropping seasons by 100% when compared with continuous maize (Ellis-Jones *et al.*, 2004). With all the control methods available, the *Striga* problem still persists. The use of maize varieties that are *Striga* and drought resistant/tolerant in an integrated *Striga* control approach will be the most economically viable and practical approach for the farmers in WCA.

2.2.1.3 Novel *Striga* resistance from *Zea diploperennis*

Zea diploperennis is a wild relative of maize mostly found in the Sierra de Manantlán Biosphere Reserve of Mexico and has a large economic potential for the improvement of cultivated maize (Sánchez-Velásquez, 2002). Parker and Riches (1993) reported that resistance genes may not exist in domesticated maize to combat the biotic stresses limiting maize production. Consequently, there has been a search for novel genes for *Striga* resistance in the wild relative of maize, *Zea diploperennis* (Lane *et al.*, 1997; Amegbor *et al.*, 2017). Novel sources of *Striga* resistance were found in the wild maize, *Zea diploperennis* (teosinte) and *Trypsacum dactyloides* as well as in land races and have been introgressed into maize (Kling *et al.*, 2000; Hearne, 2009). This has resulted in the development and registration of a *Striga* resistant inbred line, TZSTR1108 (Menkir *et al.*, 2006).

2.2.1.4 Genetics and mechanism of *Striga* tolerance/resistance in maize

Improvement and utilization of *Striga* resistant varieties in WCA has been gradual because of unavailable durable sources of resistance, and insufficient knowledge of the mechanism and genetics of *Striga* resistance and/or tolerance. Information on genetic basis of resistance to *Striga* is essential for breeders in their selection processes among segregating populations.

Striga tolerance refers to the capability of the host plant to survive and produce appreciable yield in the presence of the attached *Striga* plants while *Striga* resistance is the ability of the host plant to suppress the germination of the parasites, leading to reduced *Striga* emergence (Kim, 1994). The complexity of the host parasite and environment interactions is the main limiting factor in the development and deployment of *Striga* resistant varieties (Ejeta, 2007b). The limited progress made so far in the improvement and commericalization of *Striga*-resistant cultivars is mostly attributable to the scarce sources of resistance, the complexity of inheritance of resistance, and scant knowledge about specific mechanisms associated with expression of resistance in maize to the parasite (Amusan *et al*., 2008). Selection for host plant damage symptoms and reduced *Striga* emergence has been effective in developing inbred lines, hybrids and open-pollinated varieties with tolerance/resistance to *S. hermonthica* (Menkir *et al*., 2012, Badu-Apraku *et al*., 2013a). *Striga* damage is used as the index of tolerance while the number of emerged *Striga* plants is used as the index of resistance. According to DeVries (2000), *Striga* tolerance is measured by the host damage on a scale of 1–9, where 1 = most tolerant and 9 = highly sensitive.

Several authors have reported that resistance to *Striga hermonthica* is polygenic and the secondary traits for indirect selection for high grain yield under *Striga* infestation and breeding for *Striga* tolerance and resistance are *Striga* damage and number of emerged *Striga* plants

(Kim, 1994; Ejeta *et al*., 1997; Badu-Apraku *et al*., 1999). Contradictory results have been reported on the gene action regulating grain yield, number of emerged *Striga* plants, and *Striga* damage. Under *Striga* infestation, additive gene action played a more vital role than non-additive gene action in controlling *Striga* damage and yield (Berner *et al*., 1995; Badu-Apraku *et al*., 2007a). However, in other studies, dominance gene action was more important than the additive in regulating the host plant damage while additive gene action played a vital role in the control of the number of emerged *Striga* plants (Gethi and Smith, 2004; Badu-Apraku *et al*., 2007b; Yallou *et al*., 2009). Knowledge and understanding of gene actions including additive, dominance gene effects (a and d) and the three types of digenic interactions, that is, additive x additive (aa), additive x dominance (ad) and dominance x dominance (dd) are very vital in planning effective and efficient gene deployment schemes in a resistance development programme.

Inbred lines of maize (TZi 3 and TZi 12) with resistance to *Striga* were first identified at IITA in 1983 (Kim, 1991). These maize inbreds express tolerance to infection. This is characterized by a reduced damage in the field despite a high *Striga* infection at the early stages of maize growth (Buiel and Parlevliet, 1996). Various breeding methods have been employed to increase *Striga* resistance in maize. At IITA, recurrent selection and inbred-hybrid methods have been used to transfer favourable genes for *Striga* resistance in maize. However, farmers in the *Striga* endemic zones of WCA are currently asking for varieties that possess resistance to multiple stresses and are reluctant to accept maize varieties that do not meet this requirement (Badu-Apraku *et al.*, 2010). Therefore, there is a crucial need for introgressing drought and low N tolerance genes into maize cultivars for increased productivity under *Striga* infestation since the three stresses occur simultaneously in the field with adverse effect on yield

2.2.2. Effects of drought on maize

Drought is rainfall deficit, leading to a protracted departure from normal water availability. The effect of drought is very high in the savannas of WCA because of the unreliable and erratic distribution of rainfall (Eckebil, 1991). Drought is caused by less than normal precipitation over a period of time, usually a season or more to the extent that the amount of water available in the soil for crop growth and development is not within reach. Drought is the second main abiotic factor limiting the production and productivity of maize in WCA after poor soil fertility (Badu-Apraku *et al*., 2010). On the average, It occurs two to three times each decade in sub-Saharan Africa (DNRP-GAPCC, 2000) and is usually accompanied by climatic conditions such as high temperatures, high wind, and low relative humidity, excess water loss through evaporation and transpiration in many regions. The demand for food production in marginal and semi-arid regions which are drought-prone will increase as a result of population growth as well as global warming and ozone depletion (Curry *et al*., 1995) which have changed climatic conditions leading to irregular, unreliable quantities and distribution of rainfall resulting in several billions of USA dollars lost annually to drought (Badu-Apraku *et al*., 2011a). Drought may occur at any time during maize growth and development, however some stages are more sensitive than others. Its occurrence at flowering and grain-filling periods may cause losses in yield of about 40 - 90% (NeSmith and Ritche, 1992; Menkir and Akintude, 2001). About 45 – 60% grain yield loss was obtained when drought occurred during silking (Campos *et al*., 2006). Losses in maize yield caused by drought stress alone has been estimated at 12-15% in WCA (Edmeades *et al*., 1995; Waddington *et al*., 1995). The most symptoms of adverse effects of drought when it occurs during flowering in maize include: flowering asynchrony, delayed silking resulting in extended anthesis-silking interval, tassel blasting, decrease in pollen potency and viability, reduced pistil receptivity and embryo abortion which can result in ear barrenness and total yield loss (Banziger *et al*., 2000). When drought occurs after plant stand establishment, there is undesirable expression of morphological characters such as reduced leaf area and plant height as well as acceleration of leaf senescence from the leaves below the ear. The stomata closure by plant in an attempt to reduce water loss through evapotranspiration simultaneously reduce photosynthetic capacity. Therefore, assimilate partitioning to growing sink is affected. In addition when drought occurs during linear grain growth, remobilization of stem reserves can occur leading to lodging (Winkel *et al.,* 2001).

2.2.2.1 Genetics and mechanism of drought tolerance in maize

Drought stress affects almost all plant functions, including developmental events, the ability of leaves to assimilate carbon dioxide and nutrient uptake of roots (Schulze, 1991; Sari - Gorla *et al*. 1999). Crops use physio-morphological characters such as stay-green of leaves, leaf area and leaf chlorophyll concentration to overcome drought stress. For example, in *Sorghum bicolor* L. Moench the stay-green of leaves is a post flowering adaptive trait that makes the plant resistant to premature senescence and root lodging during grain production period (Crasta *et al*., 1999). In maize, the stay-green trait contributes to improved overall plant health resulting in tolerance to drought and resistance to stalk lodging (Duvick, 1992; Guei and Wassom, 1992).

Physiological or biochemical mechanisms of drought tolerance related to the levels of proline and abscisic acid (ABA) in plant leaves are well documented (Landip *et al*., 1995; Desai and Singh, 2001). Landip *et al*. (1995) found that maize hybrids with higher leaf ABA concentration had delayed pollen shed, reduced plant height and grain yield compared to those with lower leaf ABA concentration. The ABA hormone acts as a catalyst to plant survival during moisture stress but does not contribute to grain yield production. During moisture stresss, cell expansion such as leaf area, plant height, anthesis and silk emergence is delayed (Banziger *et al*., 2000). Generally, plants produce an osmotically active substance which allows them to take up more water from the soil in order to maintain the turgor and allow cellular activities for a longer period of time during drought (Bolanos and Edmeades, 1991).

Studies on the mode of gene action controlling inheritance of grain yield of tropical maize under moisture stress are limited and the few that are available are contradictory. According to Guei and Wassom (1992) additive genetic effects played more important role than non-additive genetic effects in the control of flowering traits while dominance effects were more important than additive effects for ears per plant (EPP) and grain yield in two maize populations. In contrast, Badu-Apraku *et al*. (2004b) reported additive genetic variance was more important than non-additive effects for grain yield and other agronomic traits examined in a maize population, Pool 16 DT, improved for grain yield under drought stress following eight cycles of recurrent selection. Also, they indicated that non-additive gene action was large and should be taken into considered during subsequent selection. Meseka *et al*. (2007) also found significant effects of both additive and dominance variance in 24 late maturing tropical maize inbreds used in line x tester design and screened under induced drought stress and well-watered conditions. Under well-watered conditions, additive variance explained more than half of the variation observed for all traits, excluding EPP.

2.3 Contribution of secondary traits to yield improvement under *Striga infestation* and drought

Under stress conditions, the heritability of grain yield is very low (Badu-Apraku *et al*., 2004b) and selection for yield alone is ineffective. Therefore, plant breeders have focused attention on reliable secondary traits alongside with yield to improve selection efficiency. A base index that incorporates grain yield along with other secondary traits that are highly heritable, easy to measure and highly correlated with yield could be used to improve selection efficiency (Banziger and Lafitte, 1997; Banziger *et al*., 2000). For example, a selection index which incorporated superior grain yield under *Striga* infestation with EPP, host plant damage and *Striga* emergence count at 8 and 10 weeks after planting (WAP), number of emerged *Striga* plants at 8 and 10 WAP are reliable secondary traits that have been used to improve yield and *Striga* resistance and tolerance in maize (Badu-Apraku *et al*., 2009). Under drought, grain yield with low value for plant and ear aspects, stay green characteristic, short anthesis-silking interval (ASI), increased EPP and superior grain yield under optimal growing conditions have been used to improve selection efficiency for higher levels of tolerance to drought and low soil nitrogen in maize (Bolanos and Edmeades, 1996; Banziger and Lafitte, 1997; Badu-Apraku *et al*., 2004b; Oyekunle and Badu-Apraku, 2013; Akaogu *et al*., 2017). Research in Pioneer Hi-Bred and the International Maize and Wheat Improvement Centre (CIMMYT) indicates that under drought the most important secondary traits used for selecting higher grain yield are ears per plants, shortened ASI, and stay green (Banziger *et al*., 2000). Badu-Apraku *et al*. (2017) selected top performing genotypes under multiple stresses (*Striga* infestation, recurrent drought and low soil nitrogen) using multiple trait index that incorporated grain yield, anthesis-silking interval, ears per plant, plant and ear aspects, stay-green characteristic, *Striga* damage and number of emerged *Striga* plants at 8 and 10 weeks after planting under multiple stress and superior grain yield under optimal growing conditions.

Furthermore, plant breeders have used path analysis to examine the relationships among traits during recurrent selection to ensure that selection in the desired direction has not resulted in undesirable changes in the traits of interest. For example, Badu-Apraku *et al*. (2012a) investigated the relative changes in genetic correlations during four cycles of recurrent selection for increased yield and resistance to *Striga hermonthica* in maize population. The authors observed that the increased grain yield was correlated with increased EPP, heights of the plant and ears, shortened anthesis-silking intervals, ear aspect and *Striga* damage syndrome. Based on these results, the base index was re-examined, since the index used for carrying out selection under *Striga* infestation was designed to increase grain yield, ears per plant, improved ear aspect and reduce number of emerged *Striga* plants while the other traits particularly plant and ear heights were expected to remain constant. Information on the mode of expression of the secondary traits in parental lines, their hybrid combinations and relationships with grain yield could improve the efficiency in the improvement of hybrid performance under *Striga* infestation and drought conditions.

2.4 Application of DNA markers in maize research with emphasis on resistance/tolerance to *Striga* and drought

Maize has become a model biological system for testing the potential application of deoxyribonucleic acid (DNA) markers in crop improvement (Menkir, 1999). Recent progress in the use of DNA markers on maize genome include characterization and quantification of genomic variation among inbred lines within and between heterotic groups, broadening and diversification of genetic base of adapted germplasm through introgression of unique alleles from various donors, and identification and incorporation of marker-linked Quantitative Trait Loci (QTL) into breeding populations (Menkir, 1999).

In assessing the genetic diversity, the use of DNA markers has been used to speed up the process and offered a better alternative to the expensive and time consuming conventional breeding procedure. Descriptions based on morphology do not involve the use of complex laboratory procedures and are indeed essential for determining the agronomic potential of the genetic materials. Genotypic differentiation of crops such as maize based on the physical appearance could be defective and inconsistent due to the complexity of the genotype × environment interactions (Smith and Smith, 1988; Mohammadi *et al*., 2002). However, the DNA markers used in assessing genetic diversity may be accompanied by some constraints such as relatively low levels of polymorphism, insufficient genomic coverage and developmental regulation as well as pleiotropic effects (Smith *et al*., 1997). In examining the relationship between restriction fragment length polymorphism (RFLP) based distance of parents and the yield potential of their hybrids, the results showed that the combination of lines from different heterotic groups had a greater mean genetic distance estimate than the combination of lines from the same heterotic group (Melchinger, *et al.,* 1990). The study however concluded that RFLP data were not useful for predicting performance of hybrids generated by crossing lines from genetically divergent heterotic groups.

In recent years, polymerase chain reaction (PCR) based markers such as amplified fragment length polymorphism (AFLP) and simple sequence repeats (SSR) have become powerful tools for studying genetic diversity (Prassana *et al*., 2002). Microsatellites, otherwise known as SSR, are tandem repeats of sequence units generally less than 5 bp in length (Bruford and Wayne, 1993). They are co-dominant and their reproducibility makes them ideal for genome mapping and population genetics studies (Dayanandan *et al*., 1998). Being genetically co-dominant, they can distinguish between homozygous and heterozygous genotypes. Microsatellites have been used in discriminating USA and European maize germplasm (Smith *et al.,* 1997). Several efforts have been devoted to characterizing tropical maize germplasm using SSR markers (Reif *et al.,* 2003; Menkir *et al*., 2005; Aguiar *et al*., 2008; Akaogu *et al*., 2012; Badu-Apraku *et al*., 2013 a, b; Oyekunle *et al*., 2015). Reif *et al*. (2003) utilized 83 SSR markers to investigate heterotic patterns among some early and intermediate subtropical germplasm and they identified two heterotic groups comprising of a flint and dent mixture. They observed that the pedigree information of the populations were in agreement with genetic distances obtained by SSR markers. A similar finding was reported by Ifie (2013) who studied genetic diversity between nine CIMMYT and 87 IITA early maturing inbreds using 31 SSR and 261 single nucleotide polymorphisms (SNP) markers. They concluded that SSR markers were invaluable complementation to conventional plant breeding for heterotic classification and could be used to introgress elite germplasm. Different studies in maize have implored the use of SNP markers including genetic diversity assessment, linkage map construction, linkage mapping, marker assisted selection, genome wide association studies (GWAS), and genomic selection (Lu *et al.*, 2009; Yang *et al*., 2011). Several authors have studied the genetic diversity of tropical maize lines. For example, Menkir *et al*. (2005) assessed 41 late and intermediate tropical inbred lines derived from four different genetic background using 21 AFLP and 31 SSR markers. Akaogu *et al*. (2012) studied the genetic variation of 22 extra-early tropical *Striga* resistant lines using 23 pairs of SSR markers. Furthermore, Badu-Apraku *et al*. (2013b) studied the genetic diversity of 17 extra-early inbreds, with combined resistance or tolerance to drought and *Striga*. Correlation between genetic distance estimates of parental lines and the means of their F_1 hybrid were insignificant for grain yield and most other traits. Also, these maize inbreds have been phenotyped for reactions to *Striga* infestation and drought and it should be possible to compare the pattern of observed *Striga* resistance and drought tolerance reactions in these maize lines to the pattern of variability at different SNP loci to determine the relationship between the phenotypic and genotypic expression of these inbred lines. SNP markers are biallelic in nature and have lower information content when compared to SSRs. SNPs occur at higher density in the genome with lower genotyping error rates and are amenable to high-throughput technology (Rafalski, 2002; Kennedy *et al*., 2003). In addition, SNP genotyping can provide improved marker data quality and quantity when compared with SSRs (Jones *et al*., 2007; Hamblin *et al*., 2007).

Several hybrid groups generated by diallel or line × tester crosses have been studied under stress and non-stress conditions during the last ten years. Badu-Apraku *et al*. (2016) studied heterotic grouping of selected IITA and CIMMYT early maturing yellow maize inbreds using three different methods namely: heterotic grouping based on specific and general combining ability (HSGCA), genetic distance based on single nucleotide polymorphism markers (SNP-GD) and general combining ability effects of multiple traits (HGCAMT) methods. They concluded that HGCAMT is an effective method for heterotic classification of the inbred lines studied. Furthermore, the authors concluded that DNA markers could be used in heterotic classification of inbreds that are yet to be screened in the field. Also, the efficacy of any of the three heterotic classification approaches depends on the nature of genetic materials studied (Annor and Badu-Apraku, 2016; BaduApraku *et al*., 2015, 2016).

During the last decade, several grouping methods such as the HSGCA, HGCAMT and DNA markers; SNP and SSR have been useful in classifying the tropical inbred lines developed in SSA into distinct heterotic classes (Badu-Apraku *et al*., 2015, 2016). In addition, DNA markers have been widely used to investigate genetic variation and predict F_1 hybrid performance or heterosis in maize based on molecular markers' genetic distance (Melchinger *et al.,* 1990; Smith *et al.,* 1991; Melchinger, 1999). Several authors have studied the potential of DNA markers in estimating the yield performance of maize hybrid (Melchinger *et al*., 1990; Charcosset *et al*., 1998; Bernardo, 1992) but the available results cannot be considered conclusive. The consistency of DNA markers in computing the distances between genes depends on the number of markers, genomic coverage, type of gene action and the independent information provided by each individual marker (Hahn *et al*., 1995). Dudley *et al*. (1991) found that the correlation between genetic distance and hybrid yield was not significant. In several studies, low but significant positive correlations were observed between RFLP marker and yield performance of hybrid (Lee *et al*., 1989; Messmer *et al*., 1993). Mohammadi *et al*. (2008) reported low and insignificant correlation between SSR markers' genetic distance estimates and SCA, on one hand, and significant correlation between genetic distance estimate and total yield on the other. Munhoz *et al*. (2009) attributed the low correlation obtained between randomly amplified polymorphic DNA (RAPD) based genetic distance and heterosis to the random distribution of the markers, inadequate coverage of the maize genome. The AFLP markers were better than RFLP markers in predicting the value of parental variation in maize (Ajmone-Marsan *et al*., 1998). In contrast, multidimensional scanning of 2,815 maize inbred lines revealed genetic association between the maize inbred lines preserved at the North Central Regional Plant Introduction Station (NCRPIS) germplasm bank determined using principal coordinate analysis of the genetic distances matrix. The results showed that stiff stalk and non-stiff stalk inbreds which showed the highest levels of heterosis were grouped very closely together. Essentially the lines from the two groups overlapped while tropical lines that did not combine as well with the US lines were well separated from the US lines (Romay *et al*., 2013). The study also identified two MO17 related lines that shared 97% of DNA markers with B73 with which they showed high heterosis. Most studies that examine a large number of inbreds have concluded that markers do not identify heterosis potential.

Chapter Three

3.0 GENETIC DIVERSITY OF EARLY MATURING MAIZE INBREDS CONTAINING *Striga* RESISTANCE GENES FROM *Zea diploperennis*

3.1 Introduction

The successful introgression of novel genes for *Striga* resistance from the wild relative of maize, *Zea diploperennis,* to diverse maize inbred lines (Kling *et al*., 2000; Menkir, 2006; Menkir *et al.,* 2006; Amegbor *et al*., 2017) makes them fundamental resources for genetic and physiological studies, and their potential in breeding successful hybrids is encouraging. Since these maize lines share some common parentage and *Striga* resistance gene sources, their exclusive use in hybrid development, due to their novel *Striga* resistance gene, could widen the genetic base in maize production fields. Therefore, systemic exploitation of these maize lines that will allow gains from selection and minimize the narrow genetic base requires thorough genetic diversity assessment in the maize lines. Knowledge and understanding of the genetic diversity and genetic relatedness within a germplasm collection could be an invaluable aid in deciding on breeding strategies (Semagn *et al*., 2012). DNA markers are invaluable in determining the level of genetic diversity present within genetic materials (Senior *et al*., 1998). Genetic diversity in maize has been assessed using several types of DNA markers. Application of Restriction Fragment Length Polymorphism (RFLP), Randomly Amplified Polymorphism DNA (RAPD), Simple Sequence Repeat (SSR) and Single Nucleotide Polymorphism (SNP) markers have provided effective genotyping and are not affected by the different processes of plant physiology or the environment. The genetic distance (GD) estimates may be useful for placing inbred lines into distinct heterotic groups if used along with pedigree information so that crosses between closely related lines are avoided (Lu *et al*., 2009). The use of SNP as "marker of choice" is due to emergence of next generation sequencing technologies (Prasanna, 2012).

The objectives of this study were to:

(i) determine the extent of genetic diversity within and between *Striga* resistant and drought tolerant maize lines from different source populations,

(ii) classify the lines into distinct groups based on their genetic distances,

(iii) assess the yield performance of early maturing maize inbreds under drought and *Striga*-infested environments

(iv) examine the correlation between *Striga* resistance, drought tolerance reactions and SNP genotypic distance matrices and inter-trait relationship among the inbred lines under drought and *Striga* infestation using sequential path analysis.

3.2 Materials and methods

3.2.1 Genetic materials

An extra-early drought tolerant and *Striga* resistant maize population, TZEE-W Pop STR C4 was crossed to four IITA intermediate maturing white inbreds, TZSTRI 104, TZSTRI 105, TZSTRI 107, and TZSTRI 108 containing genes for *Striga* resistance from *Zea diploperennis* in an effort to transfer *Striga* resistance genes into the population. The F_1s were backcrossed for two generations to the extra-early population to recover extra-earliness. The backcrosses were selfed for six generations under *Striga* and drought conditions to develop several early maturing white inbreds with resistance to *Striga hermonthica*, tolerance to low soil nitrogen and drought. A total of thirty-six early maturing inbreds derived from diverse germplasm sources were selected for the present study (Table 3.1).

Table 3.1: Pedigree of the 36 white early maturing maize Inbred lines used in the diversity study

Inbreds	Pedigree	Reaction to stress	
		Striga hermonthica	drought
TZdEI 71	TZEE-W POP STR 104 S6 98/208-2/2-2/2-1/2-1/2	Susceptible	Tolerant
TZdEI 124	TZEE-W POP STR 104 S6 83/208-1/1-2/2-3/4-1/3	Resistant	Susceptible
TZdEI 202	TZE-W POP STR 108 S6 195/198-1/2-1/2-2/2-2/4	Susceptible	Tolerant
TZdEI 315	TZEE-W POP STR 107 S6 53/254-2/2-3/3-1/3-2/3	Susceptible	Susceptible
TZdEI 399	TZE-W POP STR 107 S6 118/254-2/2-1/1-2/2-1/3	Susceptible	Tolerant
TZdEI 260	TZEE-W POP STR 108 S6 93/198-1/1-3/3-1/2-1/5	Tolerant	Susceptible
TZdEI 479	TZEE-W POP STR 105 S5 126/253-1/2-1/2-2/3-1/4	Tolerant	Susceptible
TZdEI 82	TZE-W POP STR 104 S6 98/208-2/2-2/2-1/2-2/3	Susceptible	Susceptible
TZdEI 485	TZEE-W POP STR 105 S5 197/253-2/2-1/2-1/2-1/3	Susceptible	Tolerant
TZdEI 352	TZE-W POP STR 107 S6 24/254-1/2-1/1-1/1-2/2	Resistant	Tolerant
TZdEI 441	TZE-W POP STR 107 S6 232/254-1/1-1/4-2/3-1/2	Tolerant	Susceptible
TZdEI 84	TZEE-W POP STR 104 S6 98/208-2/2-1/2-1/3-3/5	Susceptible	Susceptible
TZdEI 280	TZE-W POP STR 108 S6 65/198-1/1-2/2-1/2-4/5	Susceptible	Susceptible
TZdEI 357	TZE-W POP STR 107 S6 37/254-2/2-2/2-1/3-2/2	Resistant	Susceptible
TZdEI 492	TZE-W POP STR 105 S6 2/253-1/1-2/2-1/2-1/2	Susceptible	Tolerant
TZdEI 98	TZE-W POP STR 104 S6 83/208-1/1-2/2-2/4-5/5	Tolerant	Tolerant
TZdEI 157	TZE-W POP STR 104 S6 22/160-1/3	Tolerant	Tolerant
TZdEI 173	TZE-W POP STR 104 S6 41/160-1/2	Susceptible	Tolerant
TZdEI 283	TZE-W POP STR 108 S6 34/198-1/2-1/3-1/2-2/3	Resistant	Tolerant
TZdEI 105	TZE-W POP STR 104 S6 83/208-1/1-2/2-1/4-1/4	Tolerant	Tolerant
TZdEI 120	TZEE-W POP STR 104 S6 18/208-2/2-3/4-1/2-2/2	Susceptible	Susceptible
TZdEI 131	TZE-W POP STR 104 S6 83/208-1/1-2/2-3/4-3/4	Tolerant	Susceptible
TZdEI 264	TZEE-W POP STR 108 S6 54/198-1/1-1/4-3/3-4/9	Susceptible	Tolerant
TZdEI 378	TZE-W POP STR 107 S6 53/254-2/2-3/3-3/3-1/2	Susceptible	Susceptible
TZdEI 268	TZEE-W POP STR 108 S6 1/198-1/1-2/2-2/2-1/4	Tolerant	Susceptible
TZdEI 314	TZEE-W POP STR 107 S6 53/254-2/2-3/3-2/3-1/3	Susceptible	Susceptible
TZdEI 396	TZE-W POP STR 107 S6 85/254-1/1-2/3-3/3-1/1	Susceptible	Tolerant
TZEI 7	WEC STR S7 Inbred 12	Tolerant	Tolerant
TZEI 18	TZE-W Pop STR Co S6 Inbred 136-3-3	Susceptible	Tolerant
TZEI 31	TZE-W Pop x LD S6 Inbred 4	Susceptible	Tolerant
TZdEI 425	TZE-W POP STR 107 S5 223/254-1/2-2/2-2/3-1/2	Susceptible	Susceptible
TZdEI 551	TZE-W POP STR 105 S5 112/253-1/1-3/4-2/4-1/3	Susceptible	Susceptible
Check 1-TZEI 2	TZE-W Pop X 1368 STR S7 Inbred 2	Tolerant	Susceptible
Check 2- TZEI 3B	TZE-W Pop X 1368 STR S7 Inbred 4	Tolerant	Susceptible
Check 3- TZEI 26	WEC STR S8 Inbred 4	Susceptible	Susceptible
Check 4- TZEI 65	TZE-W Pop STR Co S6 Inbred 141-1-2	Resistant	Tolerant

Twenty-nine out of the thirty-six inbreds shared common *Striga* resistance genes from the wild relative of maize, *Zea diploperennis*, and are designated as TZdEI lines while the remaining seven lines, without the genes, are designated as TZEI.

3.2.2 Experimental locations and field layout

The experiment was conducted under *Striga*-infested conditions in Abuja (9^{o}15’N and 7^{o} 20’E, 300 m altitude, 1,700 mm annual rainfall) in 2015 and Mokwa (9^{o}18’N and 5^{o}4’E, 457 m altitude, 1,100 mm annual rainfall) in 2014 and 2015, and terminal drought in Bagauda (12°00′ N, 8°22′ E, 580 m altitude, 800 mm annual rainfall) in 2015 and induced drought at Ikenne (6^{o} 87’N, and 3^{o} 7’E, 60 m altitude, 1500 mm annual rainfall) in 2014 and 2015. The trial was laid out as 6 x 6 lattice square design and replicated two times. A 4 m single row plots spaced 0.75 m apart with 0.4 m between plants in each row were used. One week before planting at Mokwa and Abuja, ethylene gas was plunged into the soil at a depth of 12 cm and repeated at intervals of 1 m to induce sponateous germination of *Striga* seeds present in the soil in order to ensure uniform infestation. The artificial *Striga* infestation procedure as recommended by the IITA Maize Improvement Programme was used (Kim, 1991; Kim and Winslow, 1991). Seeds of the *Striga* plants were collected from *Sorghum bicolor* (L.) Moench fields at end of the growing season and stored for at least six months. The *Striga* seeds were mixed thoroughly with sand in the proportion of 1:99 by weight.

The *Striga* seed–sand mixture was applied using calibrated scoops, which supplied about 5000 germinable seeds in each planting hole. Three maize seeds were sown into each infested hole.

For the dry season evaluations at Ikenne, drought was induced by stopping water supply from 28 days after planting till harvesting so that the maize plants depend on the available soil moisture for physiological processes. The volume of the water level in the soil was assessed on weekly basis using a device called Diviner 2000. The soil at Ikenne is eutric nitrosol and is characterized by high water-holding capacity and the plots are flat and fairly uniform. For all evaluations, number of plants were thinned to two plants per stand ten days after planting giving a total of 66,667 plants ha^{-1}.

For the drought experiment at Ikenne and Bagauda, 60 kg ha^{-1} each of N, P, and K was applied as 15-15-15 NPK at planting. Additional 30 kg ha^{-1} N as urea was applied at 4 weeks after planting (WAP). In the *Striga* experiment, 20 kg ha^{-1} each of N, P, and K was applied as 15-15-15 NPK at two weeks after planting. At 5 weeks after planting, 10 kg ha^{-1} N as urea was added. The delayed and reduced fertilizer rate was to stimulate the production of Strigolactone and enhance *Striga* emergence because high levels of nitrogen fertilizer suppresses growth of *Striga* plants (Kim, 1991). At all locations except in the *Striga* experiments, weeds were controlled through the combination of Primextra^{R} and Grammoxone^{R} (Paraquat) applied at 2 days after planting (DAP). In the *Striga* experiments, weeds excluding *Striga* were controlled by hand picking.

3.2.3 Data collection

In all experiments, data for measured traits were recorded on individual plot basis. Data on when half of the plants in a plot had started to shed pollen and produced silks were recorded as number of days to 50% anthesis (DA) and 50% silking (DS). The interval between anthesis-silking (ASI) was then calculated as the difference between DA and DS. The distance from the plant base to the length of the first tassel branch was measured on ten plants per plot as the height of the plant while the ear height was measured as the distance from the plant base to the node carrying the upper ear. Ears per plant (EPP) were calculated as the total number of harvested ears per plot divided by the number of plants harvested. Plant aspect which is the overall artchitecture of the plants in a plot was estimated on a scale of 1 to 9 where 1 = excellent, uniform with no foliar diseases and 9 = very poor with several diseased plants. Husk cover was scored on a scale of 1 to 9, where 1 = very tightly arranged husks and extended beyond the ear tip and 9 = ear tips loose with kernels exposed. Ear aspect which is the general appearance of the ears/cobs was recorded on a scale of 1 to 9, where 1 = clean ears with no insect and disease symptom, large, uniform and tightly filled ears and 9 = ears with about 90% - 100% diseased and insect damaged.

Leaf senescence data were recorded for the moisture stressed plots at 10 weeks after planting on a scale of 1 to 9, where 1 = all leaves are green and 9 = almost all leaves are dead. The data taken on the *Striga*-infested plots were similar to those of the drought stress except that no data were taken on the leaf senescence (stay green characteristic).

Adiditional data, including number of emerged *Striga* plants and *Striga* damage at 8 and 10 weeks after planting (WAP) were recorded on the *Striga*–infested plots. *Striga* damage was rated on individual plots on a scale of 1 to 9, where 1 = highly resistant plant with no *Striga* damage, and 9 = highly susceptible plants with no ears (DeVries, 2000; Badu-Apraku and Akinwale, 2011). Number of emerged *Striga* plants were subjected to logarithm transformation using log (y +1) before analysis of variance to avoid multiplicative effects. At physiological maturity, stalk lodging (number of plants broken below the highest ear node) and root lodging (number of plants that fell from the root) were counted and converted into percentages before square root transformation. Also, field weight of the ears were taken. Grain moisture was determined using moisture metre on a sample of ten ears randomly picked per plot. Grain yield was computed based on 80% shelling percentage and adjusted to 15% moisture. The formula used for calculating grain yield is shown below:

$$\text{Grain yield (kg/ha)} = \text{field weight (kg/plot)} \times \frac{(100 - \text{moisture})}{85} \times \frac{10000}{0.4 \times 0.75} \times \frac{80}{100}$$

For the drought experiment at Ikenne and Bagauda, all the harvested ears from each plot were shelled to determine percent moisture which was used to obtain grain weight. The grain yield was adjusted to 15% moisture and computed from the grain weight as follows:

$$\text{Grain yield (kg/ha)} = \text{grain weight (kg/plot)} \times \frac{(100 - \text{moisture})}{85} \times \frac{10000}{0.4 \times 0.75}$$

3.2.4 Data analyses

Analysis of variance (ANOVA) was done separately on plot means for grain yield and other measured traits under *Striga*-infested and drought conditions with PROC general linear model in SAS using a RANDOM statement with the TEST option (SAS Institute, 2011). Similarly, ANOVA was conducted for all traits across research conditions. In the ANOVA, the location–year combinations was the environment, replicates, and blocks were considered as random factors while inbred lines (genotypes) were considered as fixed effects and the adjusted means and standard errors were estimated. The base indices were computed and used in ranking the inbred lines based on their reactions under both research conditions. Under *Striga* infestation, the base index values were calculated as shown below:

$$BI = [(2 \times YLD) + EPP - (SRD8 + SRD10) - 0.5\,(NESP8 + NESP10)],$$

Where YLD is the grain yield under *Striga* infestation, EPP is number of ears per plant, SRD8 and SRD10 are host plant damage at 8 and 10 WAP, and NESP8 and NESP10 are number of emerged *Striga* plants at 8 and 10 WAP.

Under induced drought stress, the base index values were computed using the equation

BI = [(2 x GY) + EPP – ASI – PASP – EASP - LD],

where GY is grain yield under drought, EASP is ear aspect, EPP is number of ears per plant, PASP is plant aspect, and LD is stay green characteristic (leaf death scores) and ASI is anthesis-silking interval.

Broad-sense heritability (H) of grain yield and other traits were estimated for each environment as

$$H = \sigma_g^2 / (\sigma_g^2 + \sigma_{gxe}^2 / e + \sigma_e^2 / re)$$

where σ_g^2 is variance for genotype, σ^2_{gxe} is variance for genotype x environment and σ_e^2 is error variance, *e* is number of environments, and *r* is number of replications per environment.

Sequential path co-efficient analyses were performed to explain the relationships among traits under each and across research conditions using the method described by Mohammadi *et al*. (2003). The stepwise regression was used to place the predictor traits into first, second and third order based on their individual contributions to the total differences in grain yield with minimized multicolinearity (Badu-Apraku *et al*., 2012b; 2014). At first, all other traits were regressed on grain yield and those with significant contributions to grain yield at $P < 0.05$ were identified as first order traits. Subsequently, traits that were not identified as first-order traits were regressed on each of the first order traits to identify those with significant contributions to grain yield through the first-order traits and they were categorized as second-order traits. The procedure was repeated to identify traits in subsequent orders. The path coefficients were the standardized b-values from the result of the regression analysis (Mohammadi *et al*., 2003; Badu-Apraku *et al*., 2012b, 2014; Talabi *et al*., 2016). The stepwise multiple regression analysis tested the significance of the path coefficients using t-test at 0.05 level of probability and retained only traits with significant values and indicated the percentage of the variation they contributed in the dependent variable.

3.2.5 Molecular analysis

3.2.5.1 DNA extraction and genotyping using diversity arrays technology (DArT) platform

The 36 inbred lines, screened for their reactions to *Striga hermonthica* and drought (Table 3.1), were planted in the IITA green house in Ibadan for genetic diversity assessment. At two weeks after planting, young leaves were collected from 15 - 20 seedlings of each inbreds and stored at -80 °C. The leaf samples were lyophilized in console dry system from Labconco (Labconco Inc., Missouri, USA) that dries at -50°C, 1-22 pascals pressure for 48 hours. DNA was extracted from the lyophilized leaves of the 36 inbreds using modified CTAB (Cetyl Trimethyl Ammonium Bromide) protocol (Doyle and Doyle, 1987). The quantity and quality of the DNA was tested on 1% agarose gel using λ-DNA standard and were sent to the CIMMYT, Mexico, for genotyping using Diversity Arrays Technology (DArT) sequence platform (www.diversityarrays.com/dart-application-dartseq). Two inbred lines had low quality genomic DNA and were removed from the molecular study. A total of 51,009 single nucleotide polymorphism (SNP) markers were obtained. SNP markers that had 10% missing data points were filtered using TASSEL Software version 5.34 (Bradbury *et al*., 2007) leaving a total of 8145 polymorphic markers for analysis.

3.2.5.2 Genetic diversity analysis

The PowerMarker software version 3.25 was used to compute the major allele frequency, number of genes, heterozygosity, polymorphic information content (PIC) and allele diversity value for all markers (Liu and Muse, 2005). The PIC was determined by the allele sizes of the SNP markers at each locus using Nei's (1972) genetic diversity formula as reported by Smith *et al*. (1997):

$$PIC = 1 - \Sigma\, pi$$

Where *pi* is the frequency of the *i*th allele.

Cluster analysis was performed based on the genetic distance (GD) matrix using neighbor joining trees for the SNP marker data and were viewed employing Dendroscope version 3.2.2 (Huson *et al*., 2007).

Using PROC CORR in SAS version 9.3, correlation analysis was perfomed using the data from the GD matrix of the inbred lines and the means of the corresponding F_1 hybrids for traits recorded under *Striga*-infested and drought environments (SAS Institute, 2011).

3.2.5.3 Population structure analysis of inbred lines

For the SNP analysis, a model-based clustering method using the software package STRUCTURE version 2.3.4 (Pritchard *et al*., 2000; Falush *et al*., 2003) was used to establish the population structure among 34 early maturing maize inbred lines. The model assumed the number of clusters to be K. K ranged from 2 to 9 and each structure simulation was repeated 3 times using the admixture model with a burn-in period of 100,000 iterations and a Markov Chain Monte Carlo (MCMC) set at 100,000. The optimal sub-population model was investigated by plotting the log probability L(K) and Δk of the data over runs, as implemented in STRUCTURE HARVESTER (Earl and vonHoldt, 2012) and the most likely value of K was determined. The K with the highest probability was used to assign individual genotypes into groups. Individuals with membership probability greater than or equal to 0.70 were placed in the same group while lines with membership probability less than 0.70 were placed in a mixed group (Lu *et al*., 2009; Yang *et al*., 2011).

3.3 Results

3.3.1 Performance and reaction of early maturing inbreds under *Striga* infested and drought environments

The two main effects, inbreds (G), environment (E) and their interactions (GEI), were significant for all traits except environment for ear aspect, GEI for grain yield, days to anthesis, *Striga* emergence count at 8 WAP and ears per plant (Table 3.2). In contrast, the two main effects and their interactions showed significant mean squares for all traits except GEI for grain yield and plant height under induced drought stress. Across the research conditions, mean squares for the inbreds, environment and GEI were significant for grain yield and other measured traits.

Table 3.2: Mean squares from analysis of variance for grain yield and other traits of 36 early maturing white maize inbred lines screened under artificial *Striga* infestation at Mokwa and Abuja, drought stress at Bagauda and Ikenne and across research conditions during 2014 and 2015 growing seasons.

Source	**DF**	**Grain yield (kg ha^{-1})**	**Days to anthesis**	**Days to silking**	**Antheis-silking interval**	**Plant height (cm)**	**Ear aspect (scale 1-9)**	**Ears per plant**	***Striga* damage rating (scale 1-9)**		**Number of emerged *Striga* plants**	
***Striga* infestation**									8 WAP	10 WAP	8 WAP	10 WAP
Environment (E)	2	6641695**	753.39**	750.56**	5.08**	9341.52**	0.31ns	0.14**	3.49**	5.91**	9.03**	12.10**
Genotype (G)	35	998643**	17.92**	20.85**	1.76*	246.79**	1.24**	0.07**	1.22**	2.18**	1.43**	1.80**
BLOCK (E*REP)	30	290682ns	4.53ns	5.25ns	1.30ns	132.77*	0.37ns	0.03ns	0.40ns	0.35ns	0.45ns	0.42ns
Replication/(E)	3	360056ns	8.50*	15.48**	7.17**	414.09**	1.99**	0.11**	0.22ns	0.70ns	1.17ns	0.46ns
G* E	70	310475ns	3.60ns	5.62*	1.81*	197.58**	0.77**	0.04ns	0.66**	0.84**	0.63ns	0.62*
Error	69	221604	2.92	3.43	1.13	82.49	0.32	0.03	0.33	0.32	0.50	0.39
Heritability		0.70	0.81	0.74	0	0.25	0.39	0.48	0.47	0.63	0.33	0.51
Drought									**SGC**	**Plant aspect (1-9)**		
Environment (E)	2	15171868.14**	908.73**	728.58**	8.90**	20974.78**	23.13**	5.60**	19.13**	55.01**		
Genotype (G)	35	306114.39**	12.93**	9.12**	3.00**	412.16**	1.79**	0.04*	2.58**	2.54**		
BLOCK (E*REP)	30	83507.3ns	4.76**	4.39**	1.00ns	203.90ns	1.22*	0.03ns	0.81ns	0.74ns		
Replication/(E)	3	103602.33ns	9.71**	7.90**	1.14ns	1134.84**	3.21**	0.07*	0.89ns	2.97**		
G * E	70	138456.25ns	6.93**	7.36**	1.56**	247.54ns	1.16**	0.04*	1.29**	1.36**		
Error	69	92911.2	2.47	2.20	0.82	195.64	0.67	0.02	0.59	0.65		
Heritability		0.59	0.49	0.26	0.42	0.46	0.46	0.22	0.51	0.57		
Across												
Environment (E)	5	18781046.35**	690.76**	645.91**	9.60**	20398.19**	12.92**	2.78**				
Genotype (G)	35	939085**	22.52**	21.87**	2.63**	461.02**	2.05**	0.05**				
BLOCK (E*REP)	60	188850ns	4.64**	4.82**	1.15ns	168.33ns	0.79**	0.03ns				
Replication/(E)	6	231829ns	9.10**	11.69**	4.15**	774.47**	2.60**	0.09**				
G * E	175	241428*	5.82**	6.86**	1.78**	223.33**	0.94**	0.04*				
Error	96	175642	2.72	2.88	0.99	134.00	0.47	0.03				
Heritability		0.78	0.76	0.71	0.23	0.02	0.58	0.39				

SGC, stay green characteristic; WAP, weeks after planting, *, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

The heritability values ranged from 25% for plant height to 81% for days to anthesis on plot-mean basis under *Striga* infestation. Similarly, the heritability estimates under drought ranged from 22% for ears per plant to 59% for grain yield. Across the research conditions, the heritability estimates ranged from 2% for plant height to 78% for grain yield (Table 3.2).

Under *Striga* infestation, mean yield of the inbred lines varied from 909 kg ha^{-1} for TZdEI 84 to 2879 kg ha^{-1} for TZdEI 283 with a mean of 1547 kg ha $^{-1}$. *Striga* damage at 8 WAP ranged from 3.0 to 5.17 with a mean of 4.09; while at 10 WAP it ranged from 3.50 to 6.33 with a mean of 4.83. The number of emerged *Striga* plants ranged from 0.14 to 2.75 at 8 WAP and from 1.0 to 3.1 at 10 WAP (Table 3.3). Only 18 inbreds, out of the 36 evaluated, had positive base indices under *Striga* infestation. The base index is an indication of response of the inbred lines to *Striga.* A positive base index meant resistance/tolerance to *Striga* while a negative base index meant susceptibility to *Striga*. In contrast, grain yield varied from 176 kg ha^{-1} for TZdEI 173 to 1637 kg ha^{-1} for TZdEI 283 with a grand mean of 754 kg ha^{-1} under drought. Stay green characteristic ranged from 3.17 to 5.80 with a mean of 4.27. Out of the 36 inbred lines evaluated, only 15 showed positive base indices under drought indicating that they were tolerant to the stress with 10 of them producing more than the mean grain yield (Table 3.4). Eight inbred lines had positive base indices across the two stress conditions: TZdEI 283, TZdEI 352, TZdEI 98, TZEI 7, TZEI 65, TZdEI 157, TZdEI 378, and TZdEI 396.

Table 3.3: Grain yield and other traits of the 36 early maturing white *Zea diploperennis* inbreds screened under *Striga* infestation at Mokwa in 2014, Abuja and Mokwa in 2015.

Inbreds	**Grain yield (kg ha^{-1})**	**Days to anthesis**	**Days to silking**	**Anthesis -silking interval**	**Plant height (cm)**	***Striga* damage rating (WAP)**		**Number of emerged *Striga* (WAP)**		**Stalk lodging**	**Ear aspect**	**Ears per plant**	**Base Index**
						8	10	8	10				
TZdEI 283	2879	59	60	1.50	128.33	3.33	3.67	1.60	2.56	1.00	3.50	0.98	9.78
TZdEI 352	1628	61	64	2.50	124.17	3.00	3.50	1.33	1.94	2.07	4.50	1.15	7.49
TZdEI 124	1971	58	58	0.67	133.50	3.33	4.00	1.27	1.60	3.64	4.67	0.94	5.93
Check 4 - TZEI 65	1789	55	56	1.00	110.33	3.50	3.67	0.68	1.48	2.49	4.83	0.93	5.86
TZdEI 98	2414	58	59	0.50	123.83	3.83	4.17	1.30	1.96	2.42	4.00	0.86	5.51
TZdEI 357	1962	62	63	1.67	122.17	3.67	3.83	1.43	2.31	1.68	4.50	0.95	4.81
Check 1- TZEI 2	2291	59	61	1.33	125.17	4.17	4.50	1.12	1.93	1.71	4.17	0.93	4.61
TZdEI 131	1921	58	59	1.50	129.83	3.50	4.67	1.53	2.38	2.93	4.50	0.93	3.38
TZdEI 441	1319	62	64	2.00	119.00	3.50	4.17	1.19	1.80	2.16	4.83	0.98	2.73
TZdEI 260	1406	58	59	0.83	116.33	4.17	4.83	0.46	1.12	2.12	4.83	0.95	1.61
TZdEI 479	1607	57	58	1.33	120.33	4.00	4.67	1.24	2.04	2.40	4.67	0.95	1.60
TZdEI 173	1273	58	59	1.67	120.17	4.00	4.33	1.17	1.92	1.96	4.67	1.03	1.50
TZEI 7	1875	59	61	1.17	128.00	3.67	4.50	0.96	2.38	2.01	4.83	0.70	1.41
TZdEI 396	1791	60	61	0.83	128.50	4.17	5.00	1.81	2.61	2.17	4.67	0.99	0.92
TZdEI 82	1362	61	61	0.60	129.60	4.40	5.00	0.14	0.55	2.56	5.00	0.83	0.31
TZdEI 378	1593	59	60	1.17	118.50	4.33	4.83	1.75	2.41	3.02	4.50	0.99	0.19
TZdEI 157	1446	60	60	0.67	119.17	4.00	4.67	1.54	2.23	3.34	4.33	0.92	0.18
TZdEI 280	1815	58	60	1.83	99.00	4.17	5.00	1.79	2.12	1.94	4.83	0.85	0.16
Check 2 - TZEI 3B	1567	56	57	1.17	117.17	4.50	5.17	1.09	1.68	2.89	4.67	0.92	-0.19
TZdEI 399	1541	60	62	2.00	113.67	3.67	4.67	2.17	2.74	2.53	4.67	0.86	-0.26
TZdEI 105	1425	57	59	1.83	123.33	4.17	4.50	1.42	1.90	3.04	4.83	0.85	-0.26
TZdEI 268	1329	59	59	0.33	127.83	4.00	4.83	1.49	2.15	1.45	5.17	0.94	-0.27
TZdEI 485	1028	61	62	1.17	120.00	3.83	5.00	0.97	1.01	1.98	5.00	0.84	-1.07
TZdEI 492	1706	60	61	1.17	117.50	4.33	5.17	2.10	2.69	2.65	4.50	0.84	-1.76
TZdEI 71	2009	58	60	1.67	122.17	4.67	5.83	1.24	1.81	4.11	5.67	0.64	-2.43
TZEI 18	1778	58	61	2.33	113.33	4.33	4.83	2.42	3.10	3.74	4.17	0.74	-2.48
TZdEI 315	1181	58	59	1.00	111.67	4.50	5.33	1.28	2.01	3.04	4.83	0.90	-2.84
TZdEI 120	1332	57	58	0.83	128.33	4.67	5.17	1.04	1.60	2.82	4.50	0.75	-3.07
TZdEI 264	1255	59	61	1.67	108.33	4.00	5.67	2.04	2.75	1.00	5.17	0.91	-3.21
TZdEI 202	1085	56	57	1.67	123.00	4.50	5.00	1.01	1.65	3.34	4.67	0.75	-3.62
TZdEI 425	1011	63	65	1.50	107.00	4.25	5.50	1.60	2.40	2.09	5.50	0.92	-3.81
TZdEI 314	1239	57	58	1.00	119.67	4.33	5.33	2.24	2.92	2.40	4.83	0.84	-4.41
TZdEI 84	909	59	61	1.83	133.83	5.00	5.50	0.41	1.20	4.00	5.67	0.75	-5.33
TZEI 31	1009	59	61	1.33	111.33	4.50	5.67	1.87	2.77	3.35	5.17	0.81	-6.15
TZdEI 551	945	59	62	2.50	123.33	4.33	5.50	1.66	2.26	1.43	5.83	0.69	-6.32
Check 3- TZEI 26	948	56	57	1.17	120.83	5.17	6.33	2.75	2.99	3.92	5.33	0.73	-10.52
Mean	1548	59	60	1.36	120.59	4.09	4.83	1.42	2.09	2.54	4.77	0.88	
Standard error	217	0.79	0.85	0.49	4.19	0.26	0.26	0.33	0.29	0.64	0.26	0.08	

Table 3.4: Grain yield and other traits of the 36 early maturing white *Zea diploperennis* inbred lines evaluated under drought stress at Ikenne in 2014, Bagauda and Ikenne in 2015.

Inbreds	**Grain yield (kg ha^{-1})**	**Days to anthesis**	**Days to silking**	**Anthesis-silking interval**	**Plant height (cm)**	**Stalk lodging**	**Plant aspect (scale 1-9)**	**Ear aspect (scale 1-9)**	**Ears per plant**	**Stay green characteristic (scale 1-9)**	**Base Index**
TZdEI 283	1637	60	61	1.33	111.15	2.55	3.50	3.83	0.77	3.17	12.22
TZEI 7	1385	58	60	1.80	97.82	1.61	4.17	4.40	0.82	3.17	9.10
TZdEI 399	1195	60	61	1.00	107.76	2.80	3.80	4.40	0.77	3.60	8.56
Check 4 - TZEI 65	1319	61	62	1.00	90.23	1.83	4.67	4.75	0.86	3.60	8.37
TZdEI 98	1186	61	61	0.50	109.40	1.78	4.17	4.83	0.80	3.50	8.34
TZdEI 71	1051	58	59	1.00	121.62	2.42	4.40	4.60	0.80	3.60	6.98
TZdEI 425	1565	61	63	2.00	95.00	3.42	4.50	5.50	0.72	3.50	5.97
TZdEI 352	714	62	64	1.67	118.58	2.10	3.50	4.67	0.74	3.17	5.47
TZEI 18	1251	59	61	2.00	90.93	2.27	4.33	4.83	0.62	4.00	4.00
TZEI 31	1036	60	61	1.00	106.98	2.86	5.00	5.40	0.68	4.60	2.20
TZdEI 157	685	62	64	1.75	98.00	3.49	5.75	5.25	0.80	4.00	0.80
TZdEI 378	812	60	62	1.67	88.82	3.26	4.83	5.33	0.66	4.50	0.51
TZdEI 396	469	61	62	1.67	101.05	2.48	4.00	5.50	0.61	3.50	0.46
TZdEI 314	436	60	60	0.33	91.92	2.33	5.50	4.83	0.67	4.67	0.21
TZdEI 315	445	62	63	1.00	90.00	2.55	4.83	5.50	0.79	4.83	0.13
TZdEI 479	707	62	63	1.17	104.52	1.76	5.50	5.60	0.61	4.00	-0.53
TZdEI 264	639	61	63	2.20	91.63	3.26	5.50	5.83	0.76	3.67	-0.62
TZdEI 84	599	60	62	1.60	107.20	4.05	5.00	5.25	0.69	4.80	-0.69
TZdEI 492	699	61	63	1.40	110.28	3.65	4.60	5.60	0.61	4.80	-0.79
TZdEI 485	704	61	61	1.50	106.40	2.80	5.60	4.75	0.66	5.40	-1.11
TZdEI 280	415	61	63	2.00	88.55	2.56	4.33	5.50	0.54	3.67	-1.64
TZdEI 441	194	61	63	2.20	92.30	3.90	3.80	6.00	0.64	3.40	-1.76
TZdEI 105	446	59	61	1.20	99.63	3.09	5.67	5.33	0.61	4.17	-1.84
Check 1- TZEI 2	1162	59	62	3.20	83.48	2.99	5.40	5.20	0.65	5.80	-2.13
TZdEI 202	775	56	60	3.40	112.08	2.81	5.17	5.00	0.63	4.50	-2.14
TZdEI 82	520	61	62	1.17	97.60	2.03	5.83	5.00	0.58	4.83	-2.30
TZdEI 131	303	61	63	1.83	100.78	3.19	5.17	5.83	0.64	4.00	-3.05
TZdEI 357	511	64	65	1.33	104.43	1.99	5.33	6.33	0.50	3.83	-3.52
TZdEI 120	841	57	60	2.17	105.22	3.53	5.33	5.83	0.50	5.33	-4.23
TZdEI 260	521	57	60	2.83	81.63	2.99	6.17	5.80	0.74	5.00	-4.82
Check 2 - TZEI 3B	222	60	63	2.33	87.50	2.77	5.50	5.50	0.60	5.00	-5.72
TZdEI 173	176	62	64	2.00	98.90	2.58	6.20	5.75	0.64	5.00	-6.48
TZdEI 268	379	60	63	2.60	97.52	3.71	6.00	6.40	0.59	4.40	-6.75
TZdEI 124	496	59	61	2.33	108.50	3.16	5.83	6.33	0.50	4.67	-6.77
TZdEI 551	213	59	62	3.17	107.67	4.46	5.50	6.33	0.55	4.33	-7.83
Check 3- TZEI 26	437	57	60	3.33	100.22	3.00	5.67	6.00	0.53	5.67	-8.60
Means	755	60	62	1.79	100.01	2.81	5.00	5.37	0.66	4.27	
Standard error	180.14	0.76	0.72	0.44	6.67	0.64	0.38	0.38	0.07	0.36	

3.3.2 Genetic diversity assessment of the inbred lines

The neighbor-joining tree plotted on the basis of Nei's genetic distance matrix using the SNP data divided the inbred lines into four groups. TZdEI 485, TZdEI 479, TZdEI 399, TZdEI 396, TZdEI 357, TZdEI 441, TZdEI 84, TZdEI 315, TZdEI 378, TZdEI 314, TZdEI 202 and TZdEI 120 constituted the first group. TZdEI 551, TZdEI 492, TZEEI 66, TZEI 31, TZEI 2, TZEI 3B, TZEI 18, TZEI 7 and TZEI 65 formed the second group. TZdEI352, TZdEI 283, TZdEI 173, TZdEI 105, TZdEI 425, TZdEI 264, TZdEI 280 and TZdEI 260 made up the third group while TZdEI 98, TZdEI 157, TZdEI 131, TZdEI 124, TZdEI 82 and TZdEI 71 formed the fourth group (Fig. 3.1). Similarly, the population structure analysis classified the inbred lines into four distinct groups as presented with the different colours red (group 1), green (group 2), blue (group 3) and yellow (group 4). The number of lines assigned to each group differed with group 1 having the largest number of 22 inbreds, with 5 in group 2, 4 in group 3 and 3 in group 4 (Fig. 3.2).

There were no significant correlation values between GD estimates of the inbred lines and hybrid means for grain yields ($r = 0{\cdot}06$), *Striga* damage at 8 WAP ($r = -0{\cdot}03$) and 10 WAP ($r = -0{\cdot}01$), number of emerged *Striga* plants at 8WAP ($r = 0{\cdot}01$) and 10 WAP ($r = 0{\cdot}04$), and EPP ($r = 0.01$) under *Striga* infestation (Table 3.5). In contrast, highly significant correlations were observed between GD estimates of the inbred lines and hybrid means for grain yield ($r = 0{\cdot}39$), plant aspect ($r = -0{\cdot}25$), ear aspect ($r = -0{\cdot}31$) and ears per plant ($r = 0{\cdot}19$), stay green characteristic ($r = -0.30$) but was not significant for ASI ($r = 0{\cdot}02$) under drought environments (Table 3.6).

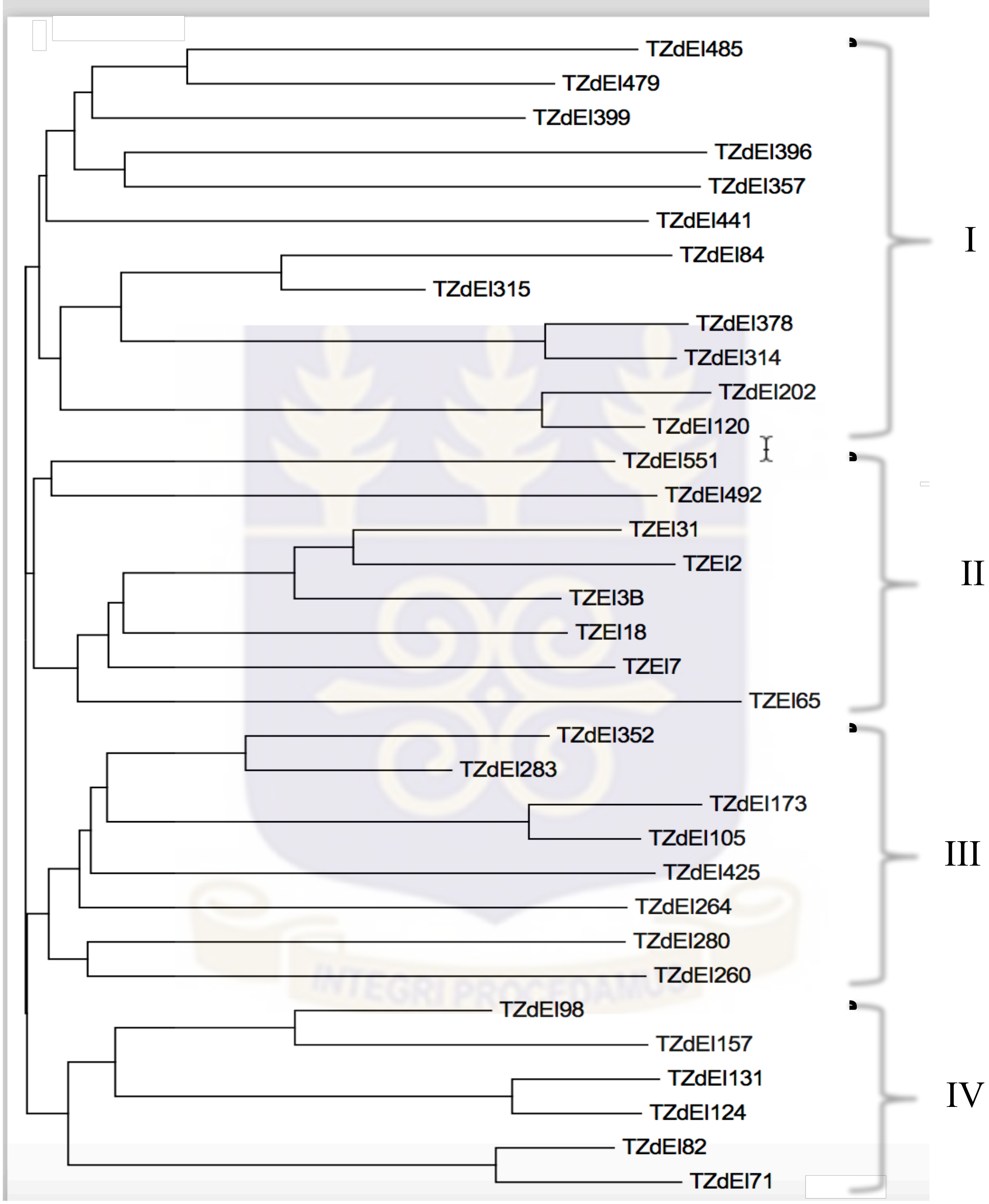


Figure 3.1: Dendrogram of the 34 inbred lines based on Nei's genetic distance estimated from 8145 SNP markers.

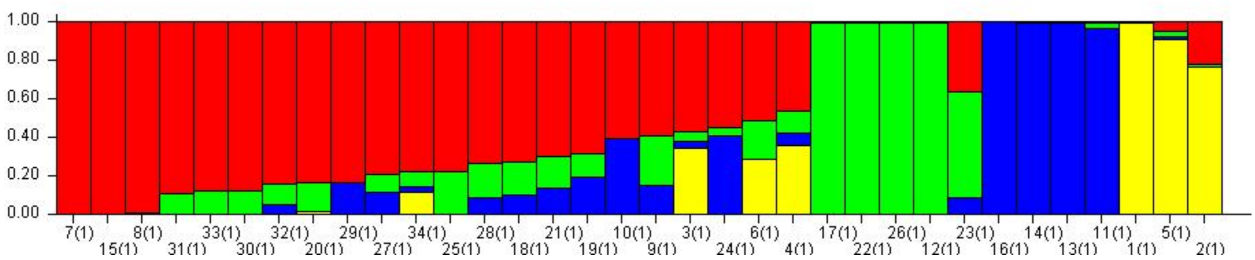


Figure 3.2: Population structure of 34 early maturing maize inbred lines based on 8145 SNP markers for k=3.

Each individual is represented by a single vertical line that is partitioned k=3 segments in the x-axis, with lengths proportional to the estimated probability membership (y-axis)

Table 3.5: Correlation coefficients between genetic distance (GD) and traits used as indices for *Striga* resistance in early maturing maize inbred lines.

	Grain Yield	Ears per plant	***Striga* damage rating**		**Number of emerged *Striga* plants**	
			8 WAP	10 WAP	8 WAP	10 WAP
Genetic Distance	0.06ns	0.01ns	-0.03ns	-0.01ns	0.01ns	0.04ns
Grain yield		0.39**	-0.74**	-0.79**	0.09ns	0.07ns
Ears per plant			-0.34**	-0.33**	-0.15ns	-0.17*
***Striga* damage at 8 WAP**				0.89**	0.02ns	0.02ns
***Striga* damage at 10 WAP**					-0.03ns	0.02ns
Number of emerged *Striga* plants at 8 WAP						0.94**

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

Table 3.6: Correlation coefficients between genetic distance (GD) and traits used as indices for drought tolerance in early maturing maize inbred lines.

	Grain Yield	Anthesis silking interval	Ear aspect	Plant aspect	Ears per plant	Stay green character
Genetic Distance	0.39**	0.02ns	-0.31**	-0.25**	0.19*	-0.30**
Grain yield		-0.35**	-0.80**	-0.57**	0.49**	-0.46**
Anthesis-silking interval			0.36**	0.11ns	-0.28**	0.26**
Ear aspect				0.52**	-0.45**	0.56**
Plant aspect					-0.35**	0.52**
Ears per plant						-0.36**

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

3.3.3 Inter-trait relationship of the inbred lines under drought and *Striga* infestation

The stepwise multiple regression result identified ear aspect (EASP) as the most important trait with significant direct contribution to grain yield explaining 46% of the variation in grain yield under drought conditions (Fig. 3.3). Four traits (EPP, SL, HUSK, DYSK) were identified in the second order having indirect effects on grain yield through EASP. Three of the four traits had positive indirect effects while only EPP had the highest and negative indirect effect (-0.649) through EASP. There were five traits in the third order: STGR, RL, ASI, PASP and DA. Only two traits, EHT and PHT, were classified as the fourth-order traits with significant indirect effects on grain yield while EHT had indirect effects through three of the third-order traits: STGR (-0.358), ASI (-0.330) and PASP (-0.402).

In the *Striga* environments, ear aspect (EASP) was also identified by step-wise multiple regression analysis as the only first-order trait of direct contribution to grain yield accounting for 51% of the total variation (Fig. 3.4). Four traits (RAT 2, CO_1, ASI, RAT 1) were identified in the second order having indirect contributions to yield. *Striga* damage at 10 WAP (0.657) and ASI (0.278) had positive indirect contributions to grain yield whereas number of emerged *Striga* plants at 8 WAP (-0.302) and *Striga* damage at 8 WAP (-0.494) had negative indirect effects on the variation obtained in grain yield. Seven traits (HUSK, CO_2, RL, EHT, DYSK, DA and SL) were identified in the third-order but only husk cover made contribution through two of the second-order traits (RAT 2 and RAT 1). Five of the seven third-order traits had positive values ranging from 0.156 to 0.919. Only EHT (-0.130) and DA (-3.434) had negative indirect effects through the second-order traits. Ears per plant (EPP) and plant height (PLHT) consistuted the fouth-order traits.

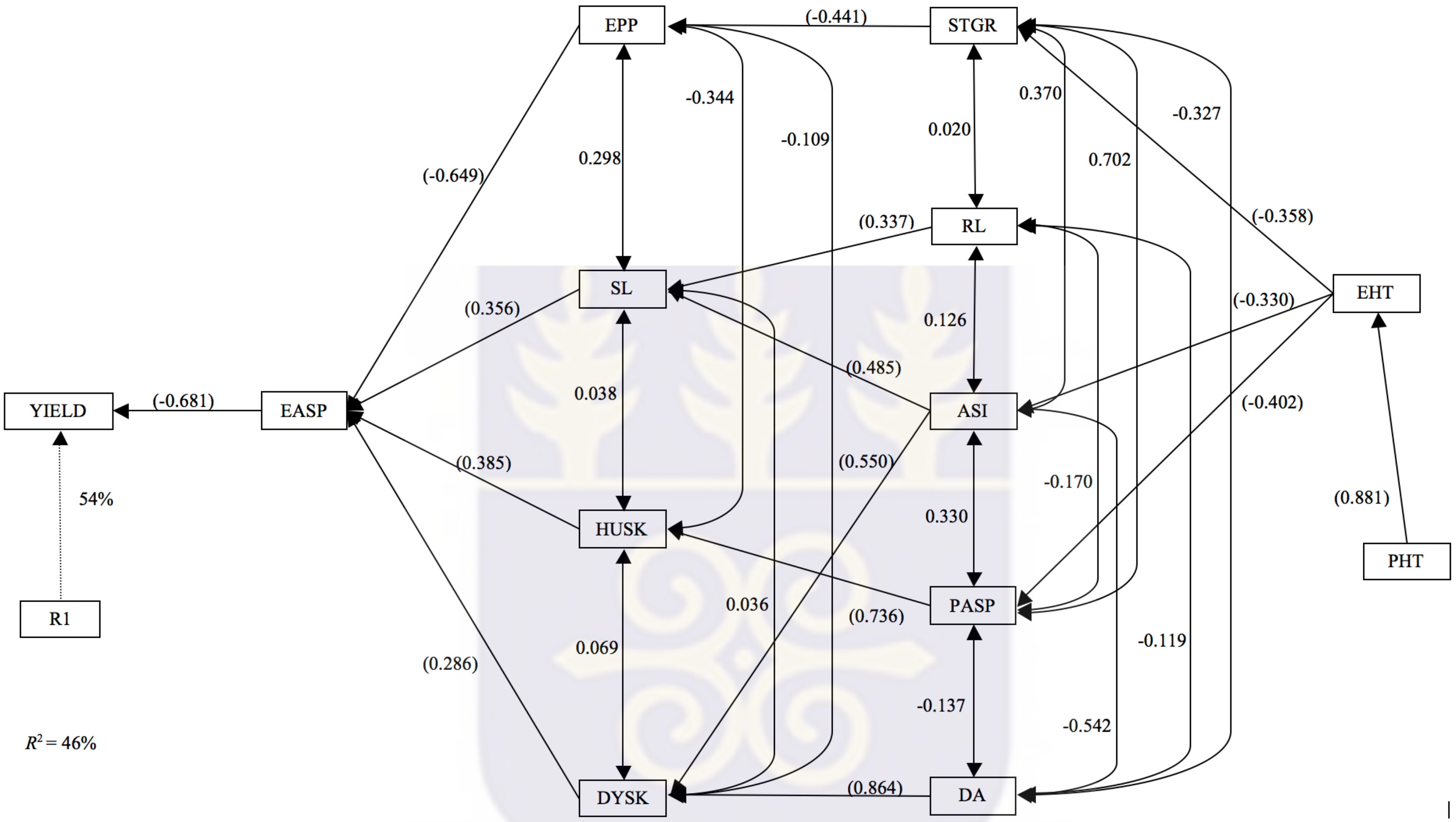


Figure 3-3: Path analysis diagram displaying the relationship between traits of the inbreds screened under drought conditions at Ikenne and Bagauda, 2014 – 2015

Values written in bold are the error effects; direct path coefficients are the values in parenthesis while other values are correlation coeeficients. R1 is error effects; DA, days to 50% anthesis; DYS, days to 50% silking,; ASI, anthesis-silking interval; EASP, ear aspect; HUS, husk cover; EPP, ears per plant; PASP, plant aspect; PHT, plant height; EHT, ear height, STGR, stay green characteristics; RL, root lodging; SL, stalk lodging and YIELD, grain yield.

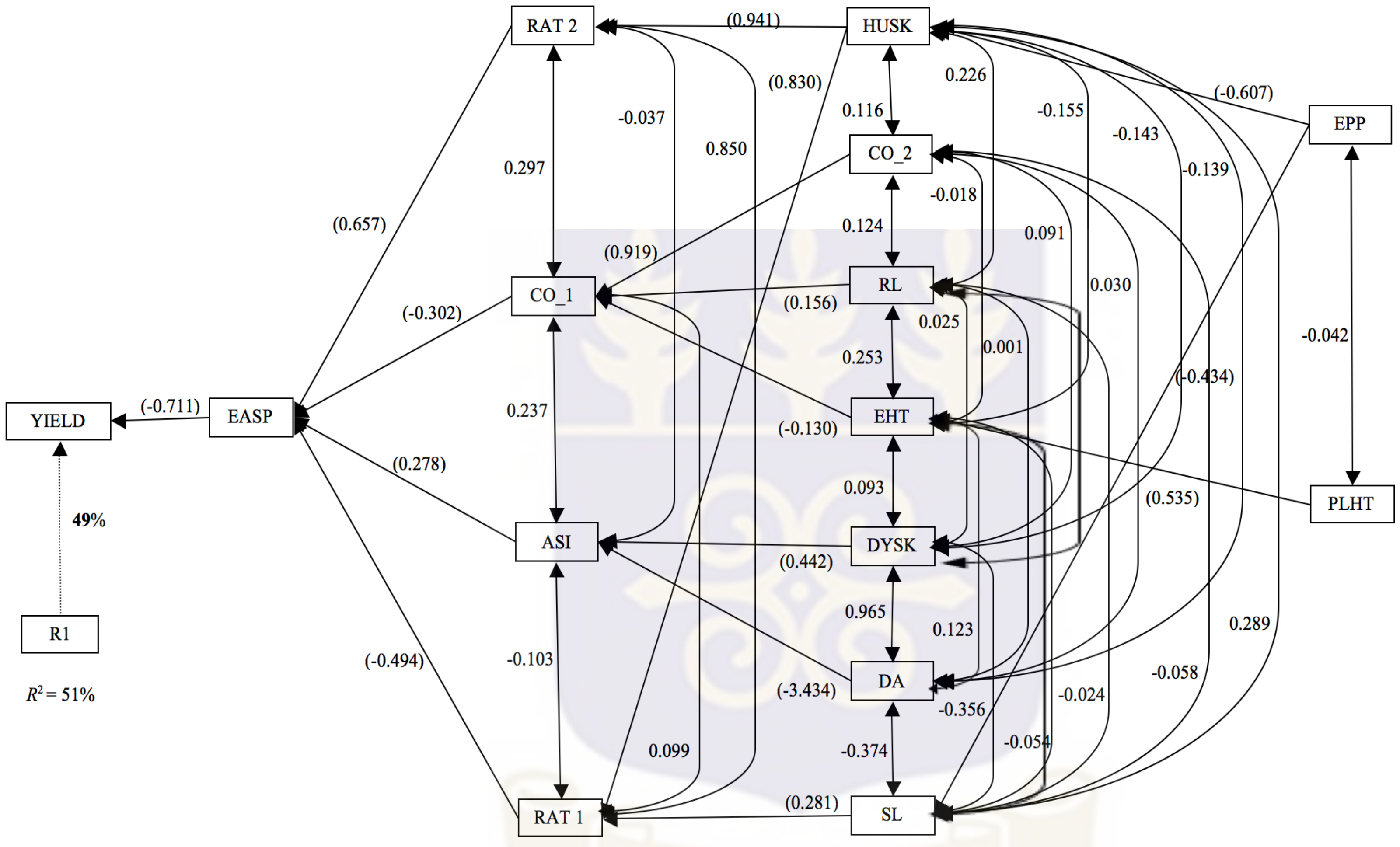


Figure 3-4: Path analysis diagram displaying the relationship of traits of the inbreds screened under artificial *Striga* infestation at Abuja and Mokwa 2014 – 2015

Values written in bold are the error effects; the direct path coefficients are values in parenthesis and other values are correlation coeeficients. R1 is error effects; YIELD, grain yield; DA, days to 50% anthesis; DYSK, days to 50% silking,; ASI, anthesis-silking interval; PHT, plant height; EASP, ear aspect; EPP, ears per plant; HUSK, husk cover; PASP, plant aspect; EHT, ear height, RAT 1 and RAT 2, Striga damage score at 8 and 10 WAP; CO_1 and CO_2, number of emerged Striga plants at 8 and 10 WAP; RL, root lodging; SL, stalk lodging..

3.4 Discussion

The genotypic mean squares were highly significant for most traits under *Striga* infestation, drought stress and across research conditions indicating that there was large genetic variation among the inbreds which should enable selection for drought tolerance, *Striga* resistance and increased grain yield under the two conditions. The significant environment mean squares observed for most measured traits under *Striga* infestation and drought stress indicated that the test locations were unique in discriminating among the inbreds and that testing the inbred lines in a wide array of locations over years is required to identify the most stable lines for hybrid production (Badu-Apraku *et al.*, 2007a; 2011a). The significant environment x genotype interaction mean squares for grain yield, *Striga* damage at 8 and 10 WAP and *Striga* emergence count at 10 WAP indicated that the inbred lines varied in their response to infestation at the different locations and that there could be different biotypes of *Striga hermonthic*a at the experimental locations. This finding corroborates with the results of Badu-Apraku *et al.* (2008) and Badu-Apraku and Lum (2010).

The 36 inbred lines were characterized as *Striga* resistant/tolerant using the base index which combined grain yield, ears per plant, *Striga* damage, and number of emerged *Striga* plants. Fifty percent (50%) of the inbred lines had positive base indices and therefore, had some level of resistance/tolerance to *Striga*. Also, the inbred lines were categorized as drought tolerant using the selection index which combined grain yield, ears per plant, anthesis-silking interval, plant and ear aspects, and stay green characteristics. Forty-two percent (42%) of the inbreds had positive values of the base index indicating some level of tolerance to drought.

The lack of significant phenotypic correlation between grain yield and number of emerged *Striga* plants indicated that the number of emerged *Striga* plants was not a consistent trait for selecting for *Striga* resistance. Similar findings were recorded by Kim and Adetimirin (1995) and Badu-Apraku *et al*. (2007a). Similarly, the strong phenotypic correlations between number of emerged *Striga* plants at 8 and 10 WAP and *Striga* damage at 8 and 10 WAP suggested that either of the parameters would be adequate for selecting for *Striga* resistance corroborating the findings of Badu-Apraku *et al*. (2007a). This result raised the question as to whether collection of data for both *Striga* damage and number of emerged *Striga* plants at 8 WAP and 10 WAP was needed considering the labour and time involved in measuring these traits. The data for the two traits could be recorded at 8 WAP or 10 WAP without much sacrifice in precision. The significant phenotypic correlation between grain yield and stay green characteristic under drought stress indicated that the stay green characteristic was one of the consistent traits for selecting grain yield under drought stress. This is in disparity with the results of Badu-Apraku *et al*. (2012b) who reported that the most consistent traits for selecting for yield under drought stress in extra-early maturing maize were ear aspect, anthesis-silking interval, plant aspect and number of ears per plant. The discrepancy in the findings of the two studies could be due to the differences in the maturity groups of the inbreds used.

Furthermore, the causal relationships among traits under *Striga* infestation and drought were examined using sequential path co-efficient analyses. EASP was selected as the most important trait contributing to the variation in grain yield obtained under both *Striga* infestation and drought environments. In addition, EPP, stalk lodging, husk cover and days to silking were identified as the second order traits contributing to the change in grain yield under drought condition while *Striga* damage at 8 and 10 WAP, number of emerged *Striga* plants at 8 WAP and ASI were identified as the second order traits under *Striga* infestation.

Under drought, stay green characteristic, root lodging, ASI, PASP and days to anthesis were identified as third-order traits while ear and plant heights were identified as the fourth-order traits. However, ear height had indirect effect through three of the five third-order traits (STGR, RL, ASI, PASP and DS) indicating its potential value for selecting drought tolerant lines. Similar studies have been conducted in WCA. Talabi *et al*. (2016) identified EASP, EPP, PASP, STGR and ASI as the most consistent secondary traits in selecting drought tolerant genotypes in a study involving 250 early maturing full-sib progenies. Similarily, Badu-Apraku *et al*. (2012b) identified EPP, PASP, EASP, DS, ASI, PHT and EHT as the most reliable traits in selecting extra-early maize drought-tolerant inbred lines. Also, Banziger and Lafitte (1997) identified EPP, ASI and STGR as the most reliable indirect traits for selecting drought and low-N tolerant genotypes.

Obviously, reliable secondary traits in selecting outstanding drought tolerant and *Striga* resistant/tolerant genotypes may vary depending on the nature of the genetic material used, prevailing climatic condition and location of the experiment, but some traits appear to be consistent under different research conditions. In this study, EASP was the most consistent secondary trait in selecting drought tolerant and *Striga* resistant genotypes. Badu-Apraku *et al*. (2012b) and Talabi *et al*. (2016) reported similar findings for extra-early maturing maize inbreds and early maturing full-sib progenies under drought environments.

The low to moderately high genetic distances among the inbreds indicated that the lines are distinct. The neighbour-joining tree and the model based clustering approach of the population structure both classified the inbred lines into four groups indicating high correspondence between the two methods in grouping the lines into divergent genetic types for hybrid production.

3.5 Conclusions

Significant genotypic variation existed among the inbreds for grain yield and other agronomic traits under *Striga* infested and drought environments indicating that progress could be made in selecting for *Striga* resistance and drought tolerance.

The level of drought tolerance and *Striga* resistance in the 36 early maturing maize inbred lines were determined using the base index. About 42% and 50% of the inbreds were identified as drought tolerant and *Striga* resistant/tolerant respectively.

The inbred lines were categorised into four divergent groups using the cluster analysis and population structure analysis.

Ear aspect was identified as a reliable secondary trait for selection for high grain yield under both research conditions.

Chapter Four

4.0 INHERITANCE OF RESISTANCE TO *Striga hermonthica* IN AN EARLY MATURING MAIZE (*Zea mays* L.) INBRED LINES CONTAINING RESISTANCE GENES FROM *Zea diploperennis*

4.1 Introduction

In maize research, *Striga* resistance is the ability of the host plant to suppress the germination and attachment of the *Striga* plants resulting in reduced number of emerged *Striga* plants while *Striga* tolerance is the ability of the host plant to survive and produce reasonable yield in the presence of the attached *Striga* plants (Kim, 1994). Several reports indicating that several genes control resistance to *Striga* have been documented (Kim, 1994; Ejeta *et al*., 1997). The maize plants have expressed resistance to *Striga hermonthica* through different mechanisms including low stimulation of strigolactones which stimulate *Striga* germination (Kiruki *et al*., 2006), suppression of growth of the parasites (Amusan *et a*l., 2008), low induction of haustorial (Gurney *et al*., 2003), inability to support *Striga* emergence (Lane *et al*., 1997; Gurney *et al*., 2003; Amusan *et al*., 2008) and escape through root architecture (Amusan *et al*., 2008). The use of recurrent selection in introgressing favourable alleles for *Striga* resistance in maize has been documented (Menkir and Kling, 2007; Badu-Apraku *et al*., 2006, 2008). Equal contribution of the favorable alleles for improvement are obtained when the trait is governed by additive gene action (Badu-Apraku *et al*., 2009). Information on the mode of gene action governing the inheritance of resistance would facilitate the introgression of resistance genes and deployment of resistant varieties (Akanvou and Doku, 1998).

Generation mean analysis is very useful in determining gene effects for polygenic traits (Mather and Jinks, 1982). It has the ability to compute the digenic genetic effects such as additive × additive [i], additive × dominance [j] and dominance × dominance [l] interactions (Singh and Singh, 1992). The preponderance of additive gene action over dominance gene action for grain yield and *Striga* traits has been documented in maize (Badu-Apraku *et al*., 2015, 2016; Akaogu *et al*., 2012). Partitioning of the genetic effects into its components: additive, dominance gene effects (d and h) and the three types of digenic interactions, that is, additive x additive (i), additive x dominance (j) and dominance x dominance (l) effects will provide very vital information for planning an effective gene deployment schemes in the *Striga* resistance improvement programs of SSA.

The objective of this study was to examine the mode of inheritance of an early maturing maize inbred line, TZdEI 352 containing *Striga* resistance genes from *Zea diploperennis* and a *Striga* susceptible inbred line TZdEI 425.

4.2 Materials and methods

The *Striga* resistant maize inbred, TZdEI 352 was crossed to the *Striga* susceptible inbred, TZdEI 425. The F_1 progeny were selfed and backcrossed to the resistant and susceptible parents to obtain F_2, BC_1P_1 and BC_1P_2 generations. Field evaluations of the parents, F_1, F_2, and backcrosses were carried out in 2015 at the IITA research stations at Mokwa and Abuja. Both locations are in the southern Guinea savanna agro-ecology of Nigeria, where *Striga* is endemic. The experimental design was randomized complete block design and the trial was replicated four times under artificial infestation with *Striga* seeds. The plots were 4 m long with 0.75 m apart and 0.4 m between plants in a row. The experimental units were three row plots for the parental inbreds and F_1 generations, six-row plots for the BC_1P_1 and BC_1P_2 generations, and a twelve-row plots for the F_2 progeny generation. One week before planting, ethylene gas was applied at both locations to cause suicidal germination of the seed of the parasite present in the soil. The ethylene gas was injected into the soil at a depth of 12 cm. This was repeated at intervals of 1 m. At planting, 8.5 g sand/*Striga* mixture (5,000 germinable *Striga* seeds) was placed in each planting hole with three maize seeds which were later thinned to two plants per hill at ten days after emergence giving a final population density of 66,667 plants per hectare. About 20 kg ha^{-1} each of N, P, and K was applied as 15-15-15 NPK two weeks after planting and additional 10 kg ha^{-1}N in form of urea was applied at five weeks after planting. Weeds other than *Striga* were removed by hand.

At each location, 30 plants from the homozygous generations (P_1, P_2 and F_1), 60 plants from backcross generations (BC_1P_1) and (BC_1P_2) and 120 plants from the F_2 generations were assessed for *Striga* damage and number of emerged *Striga* plants at 8 and 10 weeks after planting (WAP) in each replicate. *Striga* damage was recorded on a scale of 1 to 9 (1 = normal plant growth, no visible damage; 9 = severe damage or death) as proposed by Kim (1991; 1994).

The generation means were utilized in the analyses of variance for all tests. The data were first analyzed using the F-test to detect differences in mean performance of the generations studied. Generation mean analysis (GMA) was conducted on *Striga* damage and number of emerged *Striga* plants at each location. Homogeneity of variances was tested using Bartlett's test (Bartlett, 1937) to determine if the data from the two locations could be pooled for combined analysis and the test was significant, hence data from individual environments were analysed separately. Data were subjected to generation mean analyses using the sequential model fitting procedure to determine the simplest and yet adequate model to describe the data. Since the additive-dominance model was found to be inadequate to explain the observed variations, estimates of additive, dominance and digenic gene interaction were computed as described by Mather and Jinks (1982). The mean effect m, pooled additive effect [d], pooled dominance effect [h], pooled additive x additive interaction effect [i], pooled additive x dominance interaction effect [j] and pooled dominance x dominance interaction effect [l] are related to the generation means according to the following equations:

$$m = (P_1)/2 + (P_2)/2 + 4F_2 - BC_1P_1 - BC_1P_2$$

$$[d] = (P_1)/2 - (P_2)/2$$

$$[h] = -(3P_1)/2 - (3P_2)/2 - F_1 - F_2 + 6BC_1P_1 + 6BC_1P_2$$

$$[i] = -4F_2 + 2BC_1P_1 + 2BC_1P_2$$

$$[j] = -P_1 + P_2 + 2BC_1P_1 - 2BC_1P_2$$

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

The genetic parameters were estimated by unweighted regression analyses. The adequacy of each model was based on statistical significance of the genetic parameters and included the coefficient of determination, R^2, the residual mean squares, F-test and the chi-square test of agreement between the observed and predicted mean of each generation estimated from the fitted mode. Significance of the estimates was tested by the standard error of each of the parameters.

Significant parameters were re-estimated by the weighted least-square method using matrix procedure (Mather and Jinks, 1982). Weights were computed as reciprocals of the variances of generation means. Expected generation means were estimated only from significant gene effects by the following equations:

$P_1 = m + [d] + [i]$

$P_2 = m - [d] + [i]$

$F_1 = m + [h] + [l]$

$F_2 = m + \frac{1}{2}[h] + \frac{1}{4}[l]$

$BC_1P_1 = m + \frac{1}{2}[d] + \frac{1}{2}[h] + \frac{1}{4}[i] + \frac{1}{4}[j] + \frac{1}{4}[l]$

$BC_1P_2 = m - \frac{1}{2}[d] + \frac{1}{2}[h] + \frac{1}{4}[i] - \frac{1}{4}[j] + \frac{1}{4}[l]$

4.3 Results

The means of the six generations for *Striga* damage and number of emerged *Striga* plants evaluated in Mokwa and Abuja are presented in Table 4.1. Although parental lines were fixed inbreds (S_8), there were genetic variation in levels of *Striga* damage and number of emerged *Striga* plants among the lines studied. The generation mean analysis of *Striga* damage and number of emerged *Striga* plants predicted from additive and dominance gene effects alone deviated significantly from the observed means. Therefore, the simple additive-dominance model was inadequate to explain the differences in *Striga* damage and number of emerged *Striga* plants of the generations. Hence, the digenic interactions was included in the simple addidtive-dominance model (Table 4.2). The genetic effects were higher in Mokwa than Abuja for the traits studied. Among the main effects, additive (d) was higher than the dominance (h) component for *Striga* damage at 8 and 10 WAP in Mokwa while dominance (h) was greater than the additive (d) component for *Striga* damage at 10 WAP in Abuja, and number of emerged *Striga* plants at both location.

Table 4.1: Means of *Striga* damage and number of emerged *Striga* plants of the six generations (P_1, P_2, F_1, F_2, BC_1P_1, and BC_1P_2) evaluated at Mokwa and Abuja in 2015

	Abuja				Mokwa			
Generation	*Striga* damage		Number of emerged *Striga* plants		*Striga* damage		Number of emerged *Striga* plants	
	8 WAP	10 WAP	8 WAP	10 WAP	8 WAP	10 WAP	8 WAP	10 WAP
P_1	3.00±0.0	3.33±0.33	3.00±0.57	5.33±0.88	2.50±0.50	3.75±0.75	14.25±2.36	15.75±2.06
P_2	5.00±0.0	6.33±0.33	21.67±7.22	28.33±7.54	4.25±0.25	6.25±0.25	35.25±14.96	36.00±16.04
F_1	2.00±0.0	2.67±0.33	10.33±7.13	12.33±8.25	3.50±0.5	4.25±0.63	25.00±8.38	26.75±8.66
F_2	2.70±0.05	3.17±0.06	0.31±0.11	0.35±0.11	3.59±0.05	5.12±0.06	1.48±0.27	1.85±0.28
BC_1P_1	2.30±0.04	2.48±0.05	0.31±0.13	0.36±0.13	2.44±0.07	3.84±0.06	1.96±0.41	2.36±0.42
BC_1P_2	3.00±0.08	3.44±0.10	0.56±0.19	0.62±0.19	3.86±0.06	5.19±0.22	1.86±0.46	2.14±0.44
Mean	2.70	3.08	0.51	0.58	3.37	4.81	1.98	2.34
SE ±	0.03	0.04	0.10	0.11	0.04	0.04	0.23	0.23
Mid-parent	4.00	4.83	12.34	16.83	3.38	5.00	24.75	25.88

Table 4.2: Estimates of genetic components of means for *Striga* damage and number of emerged *Striga* plants at Mokwa and Abuja in 2015 obtained by the weighted least square (Mather and Jinks, 1982)

Parameter	Abuja			Mokwa			
	Striga damage	Number of emerged *Striga*		*Striga* damage		Number of emerged *Striga*	
	10 WAP	8 WAP	10 WAP	8 WAP	10 WAP	8 WAP	10 WAP
m	2.91±0.19	0.42±0.27	0.46±0.31	3.45±0.11	4.70±0.15	1.82±0.73	2.24±0.86
[d]	1.24±0.44	-0.24±0.70	-0.18±0.86	1.25±0.30	1.48±0.35	-1.07±2.12	-1.57±2.40
[h]	-2.59±0.91	-5.81±2.30	-10.39±3.35	0.46±1.45	-0.24±1.89	-20.39±12.09	-23.21±11.09
[i]	0.14±0.94	0.62±1.65	0.68±1.67	-1.51±0.52	-2.18±0.43	2.94±5.56	2.89±5.80
[j]	-0.72±1.46	-9.35±12.94	-8.82±14.41	0.90±2.34	0.62±3.64	18.38±34.93	22.94±36.15
[l]	2.68±1.53	25.95±26.21	34.63±28.40	-0.28±4.66	-0.95±6.63	72.73±20.54	72.21±19.30

*WAP, weeks after planting; m, mean effect; d, pooled additive effect; h, pooled dominance effect; i, pooled additive x additive interaction effect; j, pooled additive x dominance interaction effect; l, pooled dominance x dominance interaction effect.

Among the interactions, additive x additive interactions (i) were larger than additive x dominance (j) and dominance x dominance (l) for *Striga* damage while dominance x dominance interactions (l) were larger than (i) and (j) for number of emerged *Striga* plants.

Estimates of additive gene effects showed variation in magnitude and sign for number of emerged *Striga* plants at both locations while the dominance effects were similar. In both locations, the (d) and (dd) were in opposite directions for *Striga* damage and number of emerged *Striga* plants except for *Striga* damage at 10 WAP in Mokwa indicating that the nature of epistasis is duplicate. The models that incorporated digenic gene interaction were adequate to explain the variation in *Striga* damage and *Striga* emergence at Abuja and Mokwa (Table 4.3).

Table 4.3: Significant gene effects by weighted least square (Mather and Jinks, 1982) for *Striga* traits and adequacy of associated models

Location	Trait	Parameter Number	Gene type	df	X^2 value
Abuja	*Striga* damage at 10 WAP	5	m,d,h,i,l	1	5.76
	Number of emerged *Striga* plants at 8 WAP	5	m,d,h,j,l	1	0.59
	Number of emerged *Striga* plants at 10 WAP	5	m,d,h,j,l	1	0.75
Mokwa	*Striga* damage at 8 WAP	5	m,d,h,i,l	1	4.42
	Striga damage at 10 WAP	5	m,d,h,i,l	1	0.09
	Number of emerged *Striga* plants at 8 WAP	5	m,d,h,j,l	1	1.08
	Number of emerged *Striga* plants at10 WAP	5	m,d,h,j,l	1	0.93

WAP, weeks after planting; m, mean effect; d, pooled additive effect; h, pooled dominance effect; I, pooled additive x additive interaction effect; j, pooled additive x dominance interaction effect; l, pooled dominance x dominance interaction effect

4.4 Discussion

The resistant parent had lower means for number of emerged *Striga* plants and *Striga* damage than the susceptible parent indicating that *Striga* resistance was expressed by low value for *Striga* damage and fewer number of emerged *Striga* plants.. Similar results have been reported in *Zea mays* (Kim *et al*., 1999; Mbogo *et al*., 2015) and *Sorghum bicolor* (Oliver *et al*, 1991; Arnaud *et al*., 1999). The BC_1P_1 means for number of emerged *Striga* plants at 8 and 10 WAP and *Striga* damage at 10 WAP skewed towards the resistant parent P_1. This indicated that *Striga* resistance/tolerance is quantitatively inherited and controlled by several genes. Also, the distribution of the population when backcrossed to the susceptible parent (BC_1P_2) was skewed towards TZdEI 425, the susceptible parent P_2. In general, backcrossing to the susceptibile parent increased allele frequency for susceptibility while alleles frequency for resistance increased when backcrossing to the resistant parent therefore there was a shift towards the resistance direction.

The significant dominant genetic effects (d) for number of emerged *Striga* plants and *Striga* damage at Abuja and the high mean values of dominance over additive mean values implied that dominance effects controls the inheritance of *Striga* resistance and tolerance. This finding corroborated that of Akanvou *et al*. (1997), who found out that dominance genetic effects were more important than additive genetic effects in regulating inheritance of number of emerged *Striga* plants. In contrast, Gethi and Smith (2004), reported that additive gene effects played more important role than dominance gene effects in regulating all the measured resistance traits.

At Mokwa, additive genetic effects were significant for *Striga* damage while dominance genetic effects were significant for number of emerged *Striga* plants at 10 WAP only. The effects of the additive gene action were higher than dominance effects for *Striga* damage while dominance effects were higher than additive effects for number of emerged *Striga* plants. This implied that additive gene actions controlled *Striga* damage while dominance gene actions controlled number of emerged *Striga* plants. Similar results have been reported by Akanvou *et al*. (1997). The differences in expression of the *Striga* damage at Abuja and Mokwa suggested the presence of genotype and environment interactions and that probably different biotypes of *Striga hermonthica* existed at Mokwa and Abuja test locations. Similar results were reported by Badu-Apraku *et al.* (2015). The models that included the digenic gene interactions in addition to additive and dominance effects were adequate in explaining the variation for *Striga* damage and number of emerged *Striga* plants among the generations studied, there was no need for fitting a higher order model incorporating trigenic interactions. This suggested the involvement of epistasis in inheritance of *Striga* resistance from *Zea diploperennis* background in tropical maize germplasm. This is in agreement with the results of Adetimirin *et al*. (2001) who concluded that epistasis was involved in maize host resistance to *Striga.*

According to Mather and Jinks, (1982), genetic interaction is said to be duplicating when the (d) and (dd) estimates have the opposite signs and are complementary when they are similar. Gene interactions for *Striga* damage and number of emerged *Striga* plants were of duplicate type since the (d) and (dd) estimates had opposite signs. The presence of duplicate type of gene interaction confirmed the iinvolvement of epistatic effects.

4.5 Conclusion

The model that incorporated digenic interactions was adequate in explaining the variation observed in inheritance to *Striga* resistance among the generations studied. *Striga* resistance genes from *Zea diploperennis* showed duplicate epistatic interactions which is similar to those found in tropical maize germplasm. Improvement of traits using recurrent selection will not be the most appropriate since dominance effects were more important than additive effects. It is of pratical application in hybrid breeding.

Chapter Five

5.0 COMBINING ABILITY AND HETEROTIC GROUPING OF *Striga* RESISTANT AND DROUGHT TOLERANT EARLY MATURING MAIZE INBRED LINES AND THEIR PERFORMANCE IN HYBRID COMBINATIONS

5.1 Introduction

The availability of early maturing varieties (90–95 days to maturity) and extra-early maturing varieties (80–85 days to maturity) has allowed maize to expand into the dry savannas of WCA, replacing millet (*Pennisetum glaucum* (L.) R. Br.,) and sorghum (*Sorghum bicolor* (L.) Moench), the traditional cereals thus reducing food scarcity in the middle of the year, when food reserves are almost empty after the long dry season. However, *Striga hermonthica* (Del.) Benth parasitism and recurrent drought are the two major constraints to maize production in the sub-region. Consequently, breeding for early and extra-early maize cultivars with improved tolerance to drought stress and tolerance to *Striga* that fit into areas with a short duration of the growing season is essential to improve productivity and ensure stable production of the crop.

Development of hybrid varieties, their promotion and adoption, are promising strategies for an appreciable increase in maize production and to revolutionize agriculture in WCA. A number of seed companies have sprung up in the sub-region in the last decade, setting the stage for commercial hybrid seed production. However, there are no commercial early maturing hybrids with resistance/tolerance to *Striga* and drought available to these companies to produce for the farmers in the savanna where there are short growth periods and *Striga* hotspots. Fortunately, the IITA maize programme has developed a large number of early and extra-early inbred lines with improved tolerance to *Striga* and drought at the flowering and grain filling stages (Badu-Apraku and Oyekunle, 2012). Information on the general and specific combining abilities of inbred lines is very vital in identifying productive hybrids for commercial hybrid production without making all possible crosses among the parental inbreds. The major challenge facing IITA's maize breeders presently is to test these inbreds in hybrid combinations to identify and promote commercialization of productive hybrids with tolerance to *Striga* and drought in WCA.

The objectives of the present study were to:

(i) determine the combining abilities and heterotic grouping of the early maturing maize inbreds under *Striga* infested and drought environments.

(ii) identify high yielding and stable hybrids across *Striga*-infested, drought, optimal growing environments and across the three research environments for commercialization in the sub-region.

(iii) determine the inter-trait relationship of early maturing maize hybrids under the *Striga*-infested and drought conditions.

5.2 Materials and methods

5.2.1 Genetic materials

The genetic materials used for this study were 30 inbred lines (Table 5.1) selected from the 36 lines screened for *Striga* resistance and drought tolerance in chapter three of this thesis. The lines were selected based on their performance under *Striga* infestation and drought. The 30 inbreds were divided into six sets, with each set comprising five inbred lines. The five inbred lines in each set were used as females and crossed with five inbred lines in another set used as males as proposed in the NC II mating design (Comstock and Robison, 1948). Each inbred line was used as a female parent in one set and as a male parent in another set. A total of 150 crosses (6 sets x 25 hybrids) were made.

Table 5.1: Pedigree of the selected 30 white early maturing maize inbred lines used in North Carolina Design II study

Inbreds	Pedigree	Reaction to stress	
		Striga hermonthica	Drought
TZdEI 71	TZEE-W POP STR 104 S6 98/208-2/2-2/2-1/2-1/2	Susceptible	Tolerant
TZdEI 124	TZEE-W POP STR 104 S6 83/208-1/1-2/2-3/4-1/3	Resistant	Susceptible
TZdEI 202	TZE-W POP STR 108 S6 195/198-1/2-1/2-2/2-2/4	Susceptible	Tolerant
TZdEI 315	TZEE-W POP STR 107 S6 53/254-2/2-3/3-1/3-2/3	Susceptible	Susceptible
TZdEI 399	TZE-W POP STR 107 S6 118/254-2/2-1/1-2/2-1/3	Susceptible	Tolerant
TZdEI 260	TZEE-W POP STR 108 S6 93/198-1/1-3/3-1/2-1/5	Tolerant	Susceptible
TZdEI 479	TZEE-W POP STR 105 S5 126/253-1/2-1/2-2/3-1/4	Tolerant	Susceptible
TZdEI 82	TZE-W POP STR 104 S6 98/208-2/2-2/2-1/2-2/3	Susceptible	Susceptible
TZdEI 485	TZEE-W POP STR 105 S5 197/253-2/2-1/2-1/2-1/3	Susceptible	Tolerant
TZdEI 352	TZE-W POP STR 107 S6 24/254-1/2-1/1-1/1-2/2	Resistant	Tolerant
TZdEI 441	TZE-W POP STR 107 S6 232/254-1/1-1/4-2/3-1/2	Tolerant	Susceptible
TZdEI 84	TZEE-W POP STR 104 S6 98/208-2/2-1/2-1/3-3/5	Susceptible	Susceptible
TZdEI 280	TZE-W POP STR 108 S6 65/198-1/1-2/2-1/2-4/5	Susceptible	Susceptible
TZdEI 357	TZE-W POP STR 107 S6 37/254-2/2-2/2-1/3-2/2	Resistant	Susceptible
TZdEI 492	TZE-W POP STR 105 S6 2/253-1/1-2/2-1/2-1/2	Susceptible	Tolerant
TZdEI 98	TZE-W POP STR 104 S6 83/208-1/1-2/2-2/4-5/5	Tolerant	Tolerant
TZdEI 157	TZE-W POP STR 104 S6 22/160-1/3	Tolerant	Tolerant
TZdEI 173	TZE-W POP STR 104 S6 41/160-1/2	Susceptible	Tolerant
TZdEI 283	TZE-W POP STR 108 S6 34/198-1/2-1/3-1/2-2/3	Resistant	Tolerant
TZdEI 105	TZE-W POP STR 104 S6 83/208-1/1-2/2-1/4-1/4	Tolerant	Tolerant
TZdEI 120	TZEE-W POP STR 104 S6 18/208-2/2-3/4-1/2-2/2	Susceptible	Susceptible
TZdEI 131	TZE-W POP STR 104 S6 83/208-1/1-2/2-3/4-3/4	Tolerant	Susceptible
TZdEI 264	TZEE-W POP STR 108 S6 54/198-1/1-1/4-3/3-4/9	Susceptible	Tolerant
TZdEI 378	TZE-W POP STR 107 S6 53/254-2/2-3/3-3/3-1/2	Susceptible	Susceptible
TZdEI 268	TZEE-W POP STR 108 S6 1/198-1/1-2/2-2/2-1/4	Tolerant	Susceptible
TZdEI 314	TZEE-W POP STR 107 S6 53/254-2/2-3/3-2/3-1/3	Susceptible	Susceptible
TZdEI 396	TZE-W POP STR 107 S6 85/254-1/1-2/3-3/3-1/1	Susceptible	Tolerant
TZEI 7	WEC STR S7 Inbred 12	Tolerant	Tolerant
TZEI 18	TZE-W Pop STR Co S6 Inbred 136-3-3	Susceptible	Tolerant
TZEI 31	TZE-W Pop x LD S6 Inbred 4	Susceptible	Tolerant

5.2.2 Field evaluation

One hundred and fifty single cross maize hybrids plus six hybrid checks were assessed under end of season drought at Bagauda during the 2013 and 2015 growing seasons and Minjibir in 2015, managed drought stress at Ikenne during the 2013/2014 and 2015/2016 dry seasons.

The hybrids were also screened under artificial *Striga* infestation at Mokwa and Abuja and optimal conditions (rain-fed, no drought and no artificial *Striga* infestation) at Mokwa, and Ikenne during the 2013 and 2015, and at Abuja in 2015 growing seasons in Nigeria. The trials were laid out as 12 x 13 randomized incomplete block design with two replications. Single rows of 4 m long spaced 0.75 m apart and 0.4 m between plants in a row were used. At two weeks after planting, number of plants were reduced to two plants/hill resulting in a population density of 66,667 plants ha^{-1} at all sites. The hybrids were screened under artificial *Striga* infestation at Mokwa and Abuja using the IITA *Striga* infestation method (Kim, 1991) that ensures uniform infestation of each hill with about 5000 *Striga* seeds. The managed drought stress at Ikenne was achieved by stopping irrigation water from 28 days after planting till harvesting, so that the maize plants depend on available water in the soil for physiological processes. Standard agronomic practices as described in Chapter three of this thesis were applied to the hybrid trials at all sites.

5.2.3 Data collection

Data recorded for the optimum experiment are days to 50% silking (DS) and 50% anthesis (DA), anthesis-silking interval (ASI), plant and ear heights, number of ears/plot (EPP), husk cover, root and stalk lodging, ear aspect and plant aspect. Grain yield was calculated in kg/ha and estimated based on 80% shelling percentage and adjusted to 15% moisture. Observations made on the *Striga*-infested and drought environments are as described in Chapter three of this thesis.

5.2.4 Data analyses

Data on the number of emerged *Striga* plants was transformed using [log (counts+1)] to reduce the heterogeneity of variances for *Striga* counts while data for stalk and root lodging in percentages were transformed using arcsine. Analysis of variance (ANOVA) was performed separately on plot means for grain yield and other measured traits under *Striga*-infested, drought and rain-fed conditions in SAS with PROC general linear model using a RANDOM statement with the TEST option (SAS Institute, 2011). Similarly, ANOVA was done for all traits across research conditions. In the ANOVA, the location–year combinations (environment), blocks and replicates were considered as random factors while hybrids (genotypes) were considered as fixed effects and the adjusted means and standard errors estimated. The ANOVA of NC II crosses for each location-year combination was performed on the entries without the checks using PROC general linear model in SAS using a RANDOM statement with the TEST option (SAS Institute, 2011).

The general linear model for NC II mating design is:

$$X_{ijklm} = \mu + S_l + g_i(S_l) + g_j(S_l) + h_{ij}(S_l) + E_m + r_k(SE)_{lm} + (SE)_{lm} + (E_g)_{im}(S_l) + (E_g)_{jm}(S_l) + (E_h)_{ijm}(S_l) + e_{ijklm}$$

Where,

Xijklm = the observed value of the progeny of the ith female, jth male in the kth replication within set l and in the mth environment

μ = population mean;

S_i = average effect of the l^{th} set;

$g_i(S_l)$ = GCA effect common to all hybrids of the i^{th} female nested within lth set

$g_j(S_l)$ = GCA effect common to all hybrids of the j^{th} male nested within lth set;

$h_{ij}(S_l)$ = SCA effect of hybrid from the i^{th} female and j^{th} male nested within lth set;

E_m = average effect of the mth environment;

$r_k(SE)_{lm}$ = effect of the kth replication nested within the lth set and mth environment;

$(SE)_{lm}$ =Interaction between the set effect and the environment;

$(E_g)_{jm}(S_l)$ and $(E_g)_{jm}(S_l)$ = Interaction between environment and GCA nested within sets;

$(E_h)_{ijm}(S_l)$ = Interaction between environment and SCA nested within sets

e_{ijklm} = the experimental error

The genotype (hybrid) component of variance was partitioned into variance due to female parent, male parent and their interactions (female x male). The effects of the female sets and male sets is the GCA effect while the female x male sets interaction represents SCA effects (Hallauer and Miranda, 1988). The F-test for GCA-female, GCA-male and SCA mean squares was calculated using the mean squares values for their interaction with the environment. The mean squares for environment x SCA were tested using the pooled error mean squares.

The proportionate contribution for each trait was calculated as percentage of the sum of squares for the genotype attributed to GCA and SCA as follows:

Contribution of GCA_{male} = [ssm / (ssm + ssf + ssmf) x 100]

Contribution of GCA_{female} = [ssf / (ssm + ssf + ssmf) x 100]

Contribution of SCA (%) = [ssmf / (ssm + ssf + ssmf) x 100]

Where:

ssm = sum of squares due to males within sets,

ssf = sum of squares due to females within sets,

ssmf = sum of squares due to male x female within sets interaction

The relative GCA_{males}, $GCA_{females}$ and SCA effects for grain yield were computed from the adjusted means using the line x tester approach (Singh and Chaudhary, 1985)

$GCA_{males} = X_j - Y$

$GCA\ females = X_i - Y$

$SCA = X_{ij} - X_i - X_j + Y$

Where:

X_j = the mean of hybrids with a given male averaged over replicates, environments and females,

X_i = the mean of hybrids with a given female averaged over replicates, environments and males,

X_{ij} = the mean of a given hybrid averaged over replicates, environments and females,

Y = the experimental mean.

Standard errors for GCA effects were computed as described by Cox and Frey (1984):

$SE_{GCA} = (MS_{fe}[f-1)/mfer]^{1/2}$ or $(MS_{me}[m-1)/mfer]^{1/2}$

$SE_{SCA} = ([MS_{fme}(m-1)(f-1) / mfer])^{1/2}$

Where, MS_{fe}, MS_{me} and MS_{fme} are the respective female x environment, male x environment and female x male x environment interaction mean squares and were multiplied by the appropriate proportion of total number of observations (female x male x replicate x environment). The test for the significance of the general and specific combining ability effects was done using t–tests, with t = GCA / SE_{GCA} or SCA / SE_{SCA}, respectively.

The mid-parent (MPH) and better parent (BPH) heterosis for grain yield, days to 50% anthesis and silking, ear aspect, plant aspect, ears per plant, *Striga* damage at 8 and 10 WAP, number of emerged *Striga* plants at 8 and 10 WAP and the stay-green characteristic for a cross was computed as follows:

Heterosis values for mid-parent (MPH) and better-parent (BPH) was calculated as:

$$MPH = \frac{(F_1 - MP)}{MP} x\, 100$$

$$BPH = \frac{(F_1 - BP)}{BP} x\, 100$$

where, F_1 is the mean of the hybrid and MP = (P1 + P2)/2 in which P1 and P2 are the respective means of the inbred parents, BP = the mean of the better parent.

Broad-sense heritability (H) of grain yield and other traits were estimated for each environment as

$$H = \sigma_g^2 / (\sigma_g^2 + \sigma_{g\times e}^2 / e + \sigma_e^2 / re)$$

where σ_g^2 is variance for genotype, σ^2_{gxe} is variance for genotype x environment and σ_e^2 is error variance, *e* is number of environments, and *r* is number of replications per environment.

Repeatability of the traits (Falconer and Mackay, 1996) under drought, *Striga* infested, optimal and across environments were computed on genotype-mean basis using the following formula: environments

$$R = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_{ge}^2}{e} + \frac{\sigma^2}{re}}$$

where r is the number of replicates per environment; e is the number of environments; σ_g^2 is variance due to genotypes; σ^2_{ge} is variance due to genotype × environment interactions; σ^2 represents the estimate of experimental error variance. The restricted maximum likelihood (REML) method in SAS MIXED procedure was used to estimate variances. One out of the 14 environments with heritability of grain yield less than 0.30 were removed from all analyses (Table 5.2).

The base indices as described in chapter three for *Striga* resistance and drought tolerance were used in identifying *Striga* resistant and drought tolerant single-cross hybrids for commercial production.

The grain yield of the selected 35 early hybrids were subjected to the additive main effects and multiplicative interaction (AMMI) analysis to examine the relationships among hybrids (G), environments (E) and G × E interaction and to select stable and high yielding hybrids for commericalization in WCA. The AMMI model was described by Zobel *et al*. (1988), Gauch and Zobel (1988), and Crossa (1990). This analysis uses principal component analysis to break down (G × E) effects into a number of interaction principal component axes (IPCAs). The genotype main effect plus G × E interaction (GGE) biplot software Windows application that fully automates biplot analysis (Yan, 2001) was used for the AMMI analysis. The AMMI model equation of Sadeghi *et al*. (2011) was used.

Table 5.2: Environments, locations, research conditions and years of evaluation of early maturing maize hybrids under *Striga*-infested, drought and optimal environments in Nigeria.

Environment	Location	Research condition	Year	Grain yield (kg ha^{-1})	Repeatability
1	Mokwa	*Striga*-infested	2013	3765	0.72
2	Mokwa	*Striga*-infested	2015	3091	0.27
3	Abuja	*Striga*-infested	2013	2807	0.68
4	Abuja	*Striga*-infested	2015	3767	0.61
5	Ikenne	Managed Drought	2013/2014	2367	0.77
6	Ikenne	Managed Drought	2015/2016	698	0.51
7	Minjibir	Managed Drought	2015	547	0.34
8	Bagauda	Terminal Drought	2013	3966	0.63
9	Bagauda	Terminal Drought	2015	4159	0.58
10	Mokwa	Rainfed	2013	5539	0.69
11	Mokwa	Rainfed	2015	7203	0.68
12	Ikenne	Rainfed	2013	4210	0.81
13	Ikenne	Rainfed	2015	6575	0.68
14	Abuja	Rainfed	2015	6041	0.36

The AMMI biplot was used to obtain information on the hybrids that were the most suitable under each stress conditions as well as optimal environments and to investigate the stability of hybrids in the contrasting environments. Sequential path co-efficient analyses were performed to explain the causal relationships among traits under each research conditions as described by Mohammadi *et al*. (2003). The regression analysis was used to place the predictor traits into first, second, third and fourth order based on their individual contributions to the total variation in grain yield with minimized multicolinearity (Badu-Apraku *et al*., 2012a; 2014, Talabi *et al*., 2016). At first, all other traits were regressed on grain yield and those with significant contributions to grain yield at $P < 0.05$ were identified as first order traits. Subsequently, traits that were not identified as first-order traits were regressed on each of the first order traits to identify those with significant contributions to grain yield through the first-order traits and they were categorized as second-order traits. The procedure was repeated to identify traits in subsequent orders. The path coefficients were the standardized b-values from the output of the stepwise regression analysis (Mohammadi *et al*., 2003; Badu-Apraku *et al*., 2012a; 2014, Talabi *et al*., 2016). The stepwise multiple regression analysis tested the significance of the path coefficients using t-test at 0.05 level of probability and retained only traits with significant path coefficients and indicated the percentage of the variation they accounted for in the dependent variable.

The HGCAMT method proposed by Badu-Apraku *et al.* (2013b) was adopted for the grouping of the 30 early maturing maize.. The GCA effects of 10 traits that had significant mean squares across research conditions were standardized. The traits included grain yield, days to 50% silking and anthesis, ASI, plant and ear height, plant and ear aspects, root lodging and ears per plant.

Using SAS software version 9.3, the standardised GCA effects were used for the Ward‟s minimum variance cluster analysis to construct for the groupings of the inbred lines (SAS Institute, 2011).

5.3 Results

5.3.1 Performance of early maturing maize inbred lines under contrasting environments

The combined ANOVA of the 156 early maturing single cross hybrids evaluated across two locations (Mokwa and Abuja) under *Striga* infestation in 2013 and 2015, showed highly significant ($P < 0.01$) hybrid (G), environment (E) and hybrid x environment interaction (GEI) mean squares for all measured traits (Table 5.3). Significant ($P < 0.01$) sets and environment x sets interaction effects were obtained for most measured traits except sets mean squares for *Striga* damage at 8 WAP and environments x sets interactions mean squares for ASI and ears per plant (EPP). Similarly, the variation among male (GCA-male), female (GCA-female) in sets and the male x female interactions (SCA) were highly significant ($P < 0.01$) for all measured traits except SCA for ASI and EPP.

Table 5.3: Mean squares for grain yield and other agronomic traits of 156 early maturing maize hybrids screened under *Striga*-infested environments at Abuja and Mokwa in 2013 and 2015.

Source of variation	df	Grain yield (kg ha^{-1})	Days to 50% silking	Anthesis - silking Interval (days)	*Striga* damage score (scale 1-9)		Number of emerged *Striga* plants		Ear aspect	Ears per plant
					8 WAP	10 WAP	8 WAP	10 WAP		
Environment (E)	2	87669271.9**	2769.24**	45.18**	10.56**	2.82*	62.30**	22.92**	4.33**	1.46**
SET	5	3590873.0**	83.89**	9.80**	1.22ns	1.89*	17.77**	8.95**	2.23**	0.08**
E*SET	10	5133848.0**	17.07**	1.03ns	2.26**	1.26*	1.61**	1.74**	1.39**	0.03ns
REP(E*SET)	15	518716.4ns	4.82ns	2.44ns	0.46ns	0.71ns	0.67ns	0.42ns	0.57ns	0.02ns
BLOCK(E*REP)	72	1955079.9**	9.12**	2.74**	2.32**	2.01**	0.72**	0.57**	1.46**	0.01ns
HYBRID (G)	155	2895635.2**	18.79**	3.25**	3.08**	3.19**	2.56**	1.65**	1.68**	0.04**
GCA_M/SET	24	4989075.8**	23.03**	5.52**	5.12**	5.02**	3.88**	2.42**	2.13**	0.04**
GCA_F/SET	24	4731992.5**	33.47**	4.40**	5.69**	6.66**	3.36**	2.52**	3.80**	0.06**
SCA/SET	96	1320972.3**	7.78**	1.60ns	1.35**	1.06**	1.10**	0.75**	0.82**	0.02ns
G * E	310	1951558.3**	7.01**	2.18**	1.10**	1.07**	0.76**	0.64**	0.81**	0.03**
E*GCA_M/SET	48	2729848.9**	7.10**	2.56**	0.97ns	1.02**	0.90**	0.85**	0.86**	0.04**
E*GCA_F/SET	48	2374399.6**	7.85**	2.66**	1.26**	1.66**	1.10**	0.99**	1.01**	0.03**
E*SCA/SET	192	1404975.6**	5.63**	1.87ns	0.93*	0.87*	0.58**	0.45**	0.67**	0.02ns
Error	359	622139.0	3.67	1.60	0.72	0.67	0.43	0.33	0.43	0.02

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

Furthermore, interactions of the GCA-male and GCA-female with the environment were highly significant for yield and other traits except E x GCA-male for *Striga* damage at 8 WAP. Also, the SCA x environment interactions were significant ($P < 0.05$) for most measured traits except ASI, and EPP. The variation due to GCA-male and GCA-female were higher than those of SCA for all measured traits under *Striga* infestation.

Under drought conditions, highly significant effects were observed among hybrids, environments, hybrid x environment interactions, GCA-male, GCA-female, SCA, and the interactions of GCA-male, GCA-female and SCA with the environment, for all measured traits except SCA and the interactions of GCA-female and SCA with the environment for ASI (Table 5.4). The GCA-male and GCA-female mean squares were substantially larger than SCA effects for all traits under drought.

Under optimal environments, significant differences were observed among hybrids, environment, G x E interaction, GCA-male, GCA-female and GCA-male x E interaction effects for all traits (Table 5.5). However, the SCA effect, GCA-female x E interaction and SCA x E interaction mean squares were significant for all traits except SCA and GCA-female x E interaction mean square for ASI and SCA x E interaction effects for ASI, EPP and root lodging. The GCA-male and GCA-female effects were substantially larger than SCA effects for all traits.

Across the three research conditions (*Striga* infestation, drought and optimal growing conditions), ANOVA showed that variation due to hybrids, environments, GCA-male, GCA-female, SCA and their interactions were highly significant ($P < 0.01$) for grain yield and other agronomic traits common across the research environments (Table 5.6). The GCA-male and GCA-female effects were substantially larger than SCA effects for all traits.

Table 5.4: Mean squares for grain yield and other agronomic traits of 156 early maturing maize hybrids screened under drought environments at Ikenne and Bagauda in 2013 and at Ikenne, Bagauda and Minjibir in 2015

Source of variation	df	Grain Yield (kg ha^{-1})	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Plant height (cm)	Ear aspect (scale 1-9)	Root lodging	Plant aspect (scale 1-9)	Ears per plant	Stay green characteristic (scale 1-9)
Environment (E)	4	950272343.00**	3355.96**	5575.23**	492.03**	240290.02**	337.23**	40.91**	663.86**	19.98**	436.97**
SET	5	11609167.00**	137.26**	154.48**	5.29ns	805.28**	7.44**	1.74**	3.75**	0.16**	1.44ns
E * SET	20	10213470.00**	51.38**	46.49**	4.48*	2075.93**	2.50**	2.05**	3.37**	0.13**	3.86**
REP(ENV*SET)	25	8028967.00**	6.37**	7.93*	1.99ns	250.58ns	0.70*	0.46ns	1.34ns	0.04	0.78ns
BLOCK(E*REP)	122	5307794.00**	9.80**	15.81**	3.66**	604.30**	1.22**	0.60**	3.10**	0.08**	2.96**
HYBRIDS (G)	155	5374750.00**	20.10**	23.13**	3.63**	633.55**	2.03**	0.65**	2.35**	0.11**	2.76**
GCA_{M}/SET	24	6638086.00**	22.87**	23.67**	4.29*	860.34**	2.72**	0.75**	2.47**	0.15**	4.53**
GCA_{F}/SET	24	7505775.00**	22.77**	27.16**	4.51*	1130.53**	2.49**	0.76**	3.29**	0.11**	4.97**
SCA/SET	96	4239579.00**	11.41**	14.65**	3.09ns	442.93**	1.42**	0.54**	1.85**	0.09**	1.81**
G * E	620	4143954.00**	10.08**	10.99**	3.13**	469.39**	1.14**	0.60**	1.52**	0.06**	1.43**
ENV*GCA_{M}/SET	96	3853886.00**	13.76**	14.62**	3.40*	657.06**	2.19**	0.72**	1.81**	0.08**	1.97**
ENV*GCA_{F}/SET	96	4173701.00**	14.63**	16.63**	2.96ns	819.11**	1.51**	0.87**	2.08**	0.08**	1.41**
ENV*SCA/SET	384	3937195.00**	5.54**	6.70**	2.94ns	241.46*	0.63**	0.46**	1.12*	0.05**	1.09**
Error	592	3515561.00	3.66	4.88	2.66	207.60	0.46	0.35	0.93	0.04	0.78

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

Table 5.5: Mean squares for grain yield and other agronomic traits of 156 early maturing maize hybrids evaluated under optimal environments at Ikenne, and Mokwa in 2013 and 2015 and at Abuja in 2015

Source of variation	df	Grain Yield (kg ha^{-1})	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Plant height (cm)	Ear height (cm)	Root lodging	Husk cover (scale 1-9)	Plant aspect (scale 1-9)	Ear aspect (scale 1-9)	Ears r plant
Environment (E)	4	263742713.00**	149.46**	157.20**	9.51**	60394.10**	35942.13**	331.83**	227.90**	177.54**	116.51**	0.34**
SET	5	18872443.00**	80.39**	98.40**	1.33**	2138.22**	1657.50**	9.94**	1.91**	12.91**	2.40**	0.02
E*SET	20	4791105.00**	10.78**	13.82**	0.74**	362.94**	150.64**	3.69**	1.08**	1.38**	2.10**	0.01
REP(E*SET)	25	693839.00ns	1.85ns	1.72ns	0.31ns	77.28ns	68.72ns	0.79ns	0.31ns	0.40ns	0.29ns	0.01ns
BLOCK(E*REP)	122	1382316.00**	3.42**	3.32**	0.37ns	234.45**	120.92**	1.63**	0.33**	0.85**	0.46**	0.01*
HYBRIDS (G)	155	6541812.00**	12.81**	14.56**	0.79**	486.40**	399.53**	2.23**	0.61**	2.36**	1.45**	0.02**
GCA_M/SET	24	10693735.00**	19.11**	21.53**	1.42**	737.03**	657.69**	1.89*	0.59**	3.44**	1.83**	0.03**
GCA_F/SET	24	11581716.00**	18.54**	22.55**	1.14**	878.39**	773.25**	2.98**	1.31**	3.16**	1.89**	0.03**
SCA/SET	96	3032926.00**	5.95**	6.10**	0.47ns	237.80**	169.90**	1.55*	0.36**	1.06**	0.98**	0.02**
G * E	620	1664380.00**	3.32**	3.54**	0.45**	184.66**	112.81**	1.58**	0.40**	0.77**	0.68**	0.01*
E * GCA_M/SET	96	2141306.00**	4.18**	3.86**	0.68**	229.53**	163.52**	1.64**	0.51**	0.78**	0.92**	0.02**
E * GCA_F/SET	96	2410645.00**	3.95**	4.31**	0.42ns	253.04**	154.92**	1.68**	0.58**	0.77**	0.89**	0.02**
E * SCA/SET	384	1108390.00**	2.50**	2.67**	0.39ns	143.29**	85.08**	1.36ns	0.30**	0.73**	0.45**	0.01ns
Error	592	859535.00	1.71	1.85	0.37	97.47	64.29	1.18	0.24	0.42	0.30	0.01

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

Table 5.6: Mean squares for grain yield and other agronomic traits of 156 early maturing maize hybrids evaluated across *Striga*-infested, drought and optimal environments in 2013 and 2015

Source of variation	df	Grain yield (kg ha^{-1})	Days to 50% anthesis	Days to 50% silking	Anthesis-Silking Interval	Plant height (cm)	Ear height (cm)	Ear aspect (scale 1-9)	Root lodging (scale 1-9)	Husk cover (scale 1-9)	Ears per plant
Environment (E)	12	1015531669**	3374.00**	5529.64**	482.41**	161274.76**	78294.18**	174.69**	221.87**	570.89**	8.31**
SET	5	11060187**	232.03**	312.69**	9.19**	1048.72**	2467.27**	8.34**	8.92**	4.43**	0.08**
E * SET	60	4699875**	24.65**	24.81**	2.42**	1062.25**	580.56**	2.06**	2.90**	4.82**	0.07**
REP(E*SET)	65	651016**	3.50*	4.82*	1.45ns	157.86ns	83.210ns	0.51*	0.63ns	0.51ns	0.02ns
BLOCK(E*REP)	314	1363620**	6.53**	9.42**	2.17**	423.40**	195.86**	0.98**	1.12**	1.03**	0.04**
Hybrid (G)	155	6351613**	35.15**	42.34**	3.21**	882.02**	628.84**	2.98**	1.65**	2.15**	0.08**
GCA_M/SET	24	8195967**	46.14**	50.81**	4.91**	1362.82**	933.96**	3.33**	1.81**	2.66**	0.10**
GCA_F/SET	24	12572731**	51.68**	67.00**	5.10**	1862.97**	1379.15**	4.22**	1.65**	5.13**	0.11**
SCA/SET	96	3125655**	15.09**	16.51**	1.68ns	475.30**	258.92**	1.90**	1.13**	0.99**	0.06**
G * E	1860	1617195**	5.94**	7.21**	1.94**	317.06**	192.76**	0.93**	1.11**	1.13**	0.04**
E * GCA_M/SET	288	2442897**	7.73**	8.69**	2.30**	444.23**	252.49**	1.46**	1.14**	1.66**	0.05**
E * GCA_F/SET	288	2287304**	7.57**	9.54**	1.99**	495.45**	296.22**	1.30**	1.38**	1.90**	0.04**
E * SCA/SET	1152	9745151**	3.96**	5.10**	1.71*	193.15**	124.67**	0.58**	0.91**	0.58**	0.03**
Error	1544	617889	2.60	3.43	1.53	153.32	86.93	0.39	0.76	0.47	0.02

*, **, Significant at 0.05 and 0.01probability levels, respectively, and ns, not significant

5.3.2 Relative contributions of combining ability effects

The relative contributions of additive and dominance effects was determined as the proportion of GCA effects to the total genetic effects using the sum of squares. Under *Striga*-infested environments, the overall contributions of GCA (GCA-male plus GCA-female) sum of squares to the total variation among hybrids varied from 49% for stalk loding to 78% for ear height while that of SCA varied from 21% for ear height to 51% for stalk lodging (Table 5.7, Appendix 5.7a). The percentage contribution of the GCA-male sum of squares were larger than that of GCA-female for grain yield, ASI and number of emerged *Striga* plants at 8 WAP, while the contribution of GCA-female was greater than the GCA-male for days to 50% anthesis and silking, plant and ear heights, stalk lodging, husk cover, ear aspect, ears per plant, *Striga* damage at 8 and 10 WAP and number of emerged *Striga* plants at 10 WAP (Appendix 5.7b). GCA accounted for about 65% of the sum of squares for grain yield, 67% and 73% for *Striga* damage at 8 and 10 WAP, 62% each for number of emerged *Striga* plants at 8 and 10 WAP, respectively.

Under drought, the contribution of GCA to genotypic sum of squares ranged from 39% for stalk lodging to 65% for husk cover while that of SCA varied from 35% for husk cover to 61% for stalk lodging (Table 5.7, Appendix 5.7a). The percentage contribution of the GCA-male to the sum of squares were larger than those of GCA-female for days to anthesis, ear aspect and ears per plant while the contribution of the GCA-female was greater than the GCA-male for grain yield, days to silking, ASI, plant and ear heights, stalk and root lodging, husk cover, plant aspect and stay green characteristic (Appendix 5.7c). The contribution of SCA, GCA-male, and GCA-female to genotypic sum of squares for grain yield were 23, 36 and 41%, respectively. The contribution of GCA-male, GCA-female and SCA to genotypic sum of squares for stay-green characteristic were 27, 30 and 43.

Table 5.7: Proportion (%) of the sums of squares for crosses attributable to general (GCA), and specific combining ability (SCA) for grain yield and other agronomic traits of early white maize inbred lines.

Traits	*Striga*-infested			Drought			Optimum Condition		
	GCA		SCA	GCA		SCA	GCA		SCA
	male	female		male	female		male	female	
Grain yield	33.25	31.54	35.21	36.10	40.83	23.06	31.08	33.66	35.26
Days to anthesis	25.80	31.05	43.15	25.06	24.95	49.99	31.09	30.17	38.74
Days to silking	26.29	38.20	35.51	21.63	24.82	53.55	31.43	32.92	35.64
Anthesis-silking interval	33.81	26.92	39.27	20.29	21.33	58.37	32.16	25.77	42.07
Plant height	35.55	37.81	26.64	22.87	30.05	47.09	28.72	34.22	37.06
Ear height	33.98	44.42	21.60	11.72	30.73	57.55	31.16	36.64	32.20
Stalk lodging	22.94	25.68	51.38	12.49	26.78	60.74	16.14	30.86	53.00
Root lodging	-	-	-	20.36	20.71	58.94	17.06	26.88	56.06
Husk cover	30.76	31.91	37.33	24.66	40.31	35.04	17.76	39.23	43.00
Ear aspect	23.12	41.31	35.58	25.03	22.86	52.10	23.90	24.79	51.32
Plant aspect	-	-	-	18.77	24.99	56.24	31.71	29.20	39.09
Ears per plant	21.11	29.26	49.63	23.95	18.42	57.64	21.03	24.85	54.13
Striga damage rating at 8 WAP	31.60	35.11	33.29	-	-	-	-	-	-
Striga damage rating at 10 WAP	31.50	41.79	26.71	-	-	-	-	-	-
Number of emerged *Striga* plants at 8 WAP	33.35	28.88	37.77	-	-	-	-	-	-
Number of emerged *Striga* plants at 10 WAP	30.42	31.74	37.84	-	-	-	-	-	-
Stay green characteristics	-	-	-	27.04	29.65	43.32	-	-	-

GCA contributions to genotypic sum of squares varied from 44% for root lodging to 68% for ear height under optimal environments while SCA varied from 32% for ear height to 56% for root lodging (Table 5.7, Appendix 5.7a). In general, GCA was more important than SCA for grain yield under the three research conditions. However, for most measured traits, GCA was more important than SCA under *Striga* infestation, SCA was more important than GCA under drought and GCA was as important as SCA under optimal conditions.

5.3.3 General combining ability effects

The significant GCA-male effects for grain yield under *Striga* infestation ranged from -18 for TZdEI 315 to 996 for TZdEI 173 while significant GCA-female effects ranged from -20 for TZdEI 399 to 893 for TZdEI 268 (Table 5.8). Inbred lines TZdEI 173 had significant positive GCA-male and GCA-female effects for grain yield; TZdEI 260 had only significant positive GCA-male effects while TZdEI 352 had only significant GCA-female for grain yield. In contrast, inbreds TZEI 31 and TZdEI 84 both had significant negative GCA-male and GCA-female effects for grain yield while TZdEI 202 and TZdEI 378 had only significant negative GCA-male effect for grain yield (Table 5.8). Inbreds TZEI 31, TZdEI 84, TZEI 18 and TZdEI 202 both had significant positive GCA-male and GCA-female effects for *Striga* damage at 8 and 10 WAP while Inbreds TZdEI 173 and TZdEI 352 both had significant negative GCA-male and GCA-female effects for *Striga* damage at 8 and 10 WAP. The inbreds TZdEI 124 and TZdEI 131 had significant negative GCA-male effects for *Striga* damage at both 8 and 10 WAP. The inbred TZdEI 268 showed significant negative GCA-female effects for *Striga* damage at 8 WAP but significant negative GCA-female and GCA-male effects for *Striga* damage at 10 WAP.

Table 5.8: General combining ability effects of early maturing inbred lines evaluated under *Striga*-infested environments

Inbred line	Grain yield		Days to silking		*Striga* damage at 8WAP		*Striga* damage at10WAP		Number of emerged *Striga* plants 8WAP		Number of emerged *Striga* plants 10WAP	
	GCA_M	GCA_F	GCA_M	GCA_F	GCA_M	GCA_F	GCA_M	GCA_F	GCA_M	GCA_F	GCA_M	GCA_F
TZdEI 71	-443.53	197.11	0.21	-1.16*	0.55**	-0.03	0.49*	-0.07	-0.37*	-0.06	-0.32*	-0.1
TZdEI 124	325.70	40.81	-0.99*	-0.65	-0.41**	-0.21	-0.55**	-0.17	0.02	0.59**	0.00	0.37*
TZdEI 202	-711.23*	-422.78	0.78	1.12*	0.42**	0.60**	0.45*	0.39	0.00	-0.20	-0.12	-0.26
TZdEI 399	43.71	-20.20	1.08*	1.14*	-0.25	-0.63**	-0.31	-0.51*	0.54**	0.21	0.45**	0.30
TZdEI 260	785.34*	205.06	-1.09*	-0.53	-0314	0.27	-0.08	0.36	-0.19	-0.53**	-0.00	-0.30
TZdEI 268	449.57	893.59**	-0.55	-0.91*	-0.28	-0.71**	-0.54**	-0.62**	-0.67**	-0.35*	-0.56**	-0.32*
TZdEI 314	46.98	10.35	-0.79	-0.38	0.16	-0.34	003	-0.42	0.20	0.11	0.09	-0.13
TZdEI 396	212.68	77.92	0.87*	0.35	-0.46**	-0.31	-0.24	-0.22	-0.04	0.31	0.03	0.24
TZEI 7	-171.96	-481.62	-0.23	0.79	0.24	0.49*	0.16	0.58*	0.09	-0.12	0.07	-0.05
TZEI 31	-537.28*	-500.25*	0.71	0.15	0.67**	0.86**	0.59**	0.68**	0.42*	0.27	0.37*	0.25
TZdEI 315	-18.09	-152.17	-1.59**	-1.39**	0.13	0.25	0.21	-0.08	0.99**	0.65**	0.70**	0.49**
TZdEI 479	-369.27	-91.22	0.25	-1.02	0.13	0.12	0.27	0.52*	-0.85**	-0.54**	-0.53*	-0.32*
TZdEI 82	480.30	351.36	-0.62	-0.85	0.09	-0.01	-0.19	-0.25	0.04	-0.08	-0.10	-0.05
TZdEI 485	-246.67	-157.88	0.68	1.35*	-0.01	0.09	0.11	0.09	-0.51**	-0.63**	-0.37*	-0.57**
TZdEI 441	153.72	49.91	1.28*	1.91**	-0.34*	-0.45*	-0.39*	-0.28	0.41*	0.60*	0.31	0.45*
TZdEI 352	410.03	632.85*	0.49	1.28*	-0.75**	-0.64**	-0.59**	-0.89**	-0.05	0.14	-0.15	-0.06
TZdEI 84	-759.90*	-949.04**	-0.91*	-1.42**	0.45*	0.63*	0.47*	1.07**	-0.44*	-0.19	-0.32*	-0.22
TZdEI 280	358.73	-152.47	-0.71	-0.85	-0.05	0.06	0.04	0.14	-0.01	0.14	-0.06	0.16
TZdEI 357	-145.54	137.60	0.92*	0.41	-0.05	-0.41*	-0.13	-0.59*	0.25	0.16	0.22	0.39*
TZdEI 492	136.67	331.06	0.22	0.58	0.41*	0.36*	0.21	0.27	0.25	-0.25	0.30*	-0.27
TZdEI 98	-91.65	181.42	-0.01	-0.85	-0.29	-0.15	0.05	-0.13	-0.24	-0.07	-0.21	-0.18
TZdEI 157	-408.50	-163.55	0.33	1.45**	0.24	-0.19	0.21	0.11	0.46	0.24	0.42*	0.28
TZdEI 173	996.70**	671.98*	-1.941**	-1.78**	-0.83**	-0.62**	-0.99**	-0.76**	-0.06	-0.47*	-0.12	-0.38
TZdEI 283	-221.39	-233.95	0.89*	0.15	0.54**	0.21	0.35	0.24	-0.05	0.10	-0.04	0.06
TZEI 18	-275.16	-455.90	0.73	1.02*	0.34*	0.75**	0.38*	0.54*	-0.12	0.20	-0.05	0.22
TZdEI 105	194.83	-189.63	-0.88*	-0.74	-034*	-0.03	-0.32*	0.01	-0.03	-0.03	0.07	0.00
TZdEI 120	-57.93	134.39	-0.58	0.13*	0.16	0.27	0.08	-0.05	-0.30	-0.20	-0.35	-0.24
TZdEI 131	461.84	-315.13	-0.75	0.06	-0.64**	0.07	-0.55**	-0.05	0.03	0.09	0.12	0.02
TZdEI 264	-50.63	-21.88	1.391**	1.49**	0.33*	0.01	0.41*	0.31	0.12	-0.38	-0.04	-0.24
TZdEI 378	-548.11*	348.50	-0.94*	-0.4	0.49**	-0.33	0.38*	-0.32	0.18	0.52*	0.19	0.46*
SE ±	269.81	251..63	0.46	0.46	0.16	0.18	0.17	0.21	0.15	0.17	0.15	0.16

GCAm, GCA effects of the inbreds used as male parents, GCAf, GCA effects of the inbreds used as female parents, WAP, weeks after planting; *, **, Significant at 0.05 and 0.01probability levels, respectively.

However, TZdEI 441 had significant negative GCA-female and GCA-male effects for *Striga* damage at 8 WAP but only the GCA-male effect was significant for *Striga* damage at 10 WAP. In contrast, inbreds TZdEI 268, TZdEI 479 and TZdEI 485 had significant negative GCA-male and GCA-female effects for number of emerged *Striga* plants at 8 and 10 WAP while TZdEI 71, TZdEI 84 and TZdEI 120 had significant negative GCA-male effect for number of emerged *Striga* plants at 8 and 10 WAP. On the other hand, TZdEI 173 had significant negative GCA-female effect for number of emerged *Striga* plants at 8 and 10WAP. TZdEI 399, TZdEI 441 and TZdEI 264 showed significant positive GCA-male and GCA-female effects for days to 50% silking. Also, TZdEI 396, TZdEI 357 and TZdEI 283 had significant positive GCA-male effects while TZdEI 124, TZdEI 260, TZdEI 378 and TZdEI 105 had only significant negative GCA-male effect for days to silking. In contrast TZdEI 202, TZdEI 485, TZdEI 352, TZEI 18 and TZdEI 157 had only significant positive GCA-female effect for days to silking while TZdEI 71, TZdEI 268 and TZdEI 479 had only significant negative GCA-female effect (Table 5.8).

Under drought conditions, the significant GCA-male for grain yield varied from -737 for TZdEI 479 to 671 for TZdEI 492 while GCA-female varied from -574 for TZdEI 314 to 642 for TZEI 7 (Table 5.9). Inbred lines, TZdEI 492 and TZdEI 378 had positive and significant GCA effects (significant GCA-male and GCA-female) for grain yield. However, only the GCA-male effect for grain yield were significant and positive for TZdEI 260 and TZdEI 315. The inbred TZEI 7 had only significant positive GCA-female effect for grain yield.

Table 5.9: General combining ability effects of 30 early maturing maize inbred lines evaluated under drought environments

Inbred lines	Grain yield		ASI		Ear aspect		Plant aspect		Ears per plant		SGC	
	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf
TZdEI 71	-249.70	161.23	-0.05	0.00	0.09	-0.05	0.04	-0.06	-0.01	0.00	-0.15	-0.44*
TZdEI 124	-189.44	-408.51*	0.66*	0.24	0.20	0.24	0.14	0.36*	-0.01	-0.01	0.75**	0.54**
TZdEI 202	-43.88	-76.99	0.00	0.70	0.04	0.05	-0.12	-0.15	-0.02	0.01	-0.31	0.06
TZdEI 399	204.18	38.24	-0.08	-0.34	-0.09	-0.31	0.01	-0.12	0.01	-0.04	-0.09	-0.16
TZdEI 260	278.83*	286.02	-0.54*	-0.60*	-0.23	0.07	-0.08	-0.03	0.03	0.05	-0.21	0.02
TZdEI 268	12.29	-179.64	-0.58*	0.26	0.06	0.13	-0.13	-0.01	0.03	-0.02	0.08	0.07
TZdEI 314	60.65	-573.93**	-0.32	0.14	-0.29	0.34*	0.28	0.32	0.08*	0.01	0.20	0.69**
TZdEI 396	242.79	228.56	-0.06	-0.42	-0.10	-0.34*	-0.33	-0.36*	-0.03	0.03	-0.40	-0.57**
TZEI 7	-205.97	642.36**	0.38	0.01	0.34	-0.14	0.03	-0.05	-0.04	0.02	-0.14	-0.41*
TZEI 31	-109.76	-117.35	0.58*	0.00	-0.01	-0.01	0.15	0.12	-0.04	-0.04	0.28	0.23
TZdEI 315	472.63**	-113.36	-0.33	-0.34	-0.54*	0.08	-0.22	0.08	0.14	0.05	0.00	0.25
TZdEI 479	-736.72**	474.74**	0.03	0.28	0.43*	-0.01	0.36	0.14	-0.01	0.11	-0.03	0.03
TZdEI 82	115.65	-241.79	-0.26	0.03	-0.15	-0.24	-0.28	-0.23	0.01	-0.04	-0.49*	-0.47**
TZdEI 485	-97.46	-211.71	0.41	-0.26	0.41*	0.48	0.51**	0.65**	-0.13	-0.09*	0.86**	0.59**
TZdEI 441	245.90	92.12	0.15	0.28	-0.15	-0.30	-0.38*	-0.65**	-0.01	-0.03	-0.34	-0.41*
TZdEI 352	-230.27	176.22	0.15	-0.01	0.00	-0.14	-0.31	-0.10	-0.03	0.05	-0.05	-0.02
TZdEI 84	-131.27	-251.60	0.05	0.09	0.13	0.11	0.67**	0.39*	-0.03	-0.01	-0.03	0.08
TZdEI 280	-92.89	-386.16*	0.11	0.44*	-0.07	0.26	-0.22	-0.01	0.03	0.02	0.03	-0.24
TZdEI 357	-216.43	143.65	-0.07	-0.47*	0.06	-0.12	-0.01	0.02	-0.01	-0.05	0.01	-0.08
TZdEI 492	670.87**	317.88*	-0.23	-0.04	-0.14	-0.11	-0.15	-0.32	0.05	-0.01	0.03	0.26
TZdEI 98	-352.59*	19.44	-0.02	-0.35	0.26	-0.18	0.20	0.36*	-0.04	-0.02	0.31	0.27
TZdEI 157	92.57	88.88	-0.22	-0.17	-0.29	-0.10	-0.04	0.09	0.03	0.07	-0.15	-0.17
TZdEI 173	69.39	-7.28	-0.01	0.13	0.05	0.13	-0.14	-0.23	-0.06	0.00	0.14	0.05
TZdEI 283	-20.27	-306.09	0.16	0.15	0.17	0.34*	0.07	-0.13	0.07	-0.02	-0.15	0.09
TZEI 18	210.90	205.06	0.10	0.25	-0.20	-0.21	-0.11	-0.11	0.00	-0.04	-0.15	-0.25
TZdEI 105	-291.25*	-180.01	0.06	-0.29	0.07	0.12	0.14	0.05	-0.06	-0.08*	0.27	0.40*
TZdEI 120	132.18	27.77	0.34	-0.08	-0.31	-0.11	-0.01	-0.11	0.06	0.01	-0.29	-0.07
TZdEI 131	-358.47*	-183.96	0.01	0.24	0.11	0.27	0.04	0.09	-0.05	-0.01	0.09	0.21
TZdEI 264	72.55	-69.55	-0.36	0.08	-0.07	0.19	-0.26	0.25	0.02	0.01	-0.33	-0.43*
TZdEI 378	444.99**	405.75*	-0.06	0.06	0.18	-0.48**	0.11	-0.30	0.03	0.08*	0.27	-0.11
SE±	138.43	157.75	0.23	0.22	0.19	0.16	0.17	0.18	0.04	0.04	0.18	0.15

ASI, anthesis-silking interval; SGC, stay green characteristics, GCAm, GCA effects of the inbreds used as male parents, GCAf, GCA effects of the inbreds used as female parents SE, standard error.

Furthermore, TZdEI 260 had significant negative GCA-male and GCA-female effects for ASI. Inbreds TZdEI 124 andTZEI 31 had significant positive GCA-male effects for ASI while TZdEI 268 had significant negative GCA-male effects. Also, TZdEI 280 had significant positive GCA-female while TZdEI 357 had significant negative GCA-female effect for ASI. Positive values for the GCA-male and GCA-female effects for stay-green characteristic were observed for TZdEI 124 and TZdEI 485, only GCA-female effect for TZdEI 314 and TZdEI 105 indicate early senescence. In contrast, significant negative GCA-male and GCA-female values were observed in TZdEI 82, only GCA-female effect for TZdEI 71, TZdEI 396, TZdEI 441 and TZdEI 264 indicate delayed senescence. The lines with the poor values for plant and ear aspects were those with positive GCA-female and/or GCA-male effects (Table 5.9).

The GCA effects due to males within sets (GCA-male) for grain yield under optimal condition varied from -778 for TZdEI 98 to 782 for TZdEI 396 while the GCA effects due to females within sets (GCA-female) ranged from -1020 for TZdEI 124 to 955 for TZdEI 260 (Table 5.10). Under optimal conditions, Inbreds TZdEI 260, TZdEI 396, TZdEI 479 and TZdEI 173 had significant ($P < 0.5$) positive GCA for grain yield when used as either male or female parents whereas TZdEI 485, TZdEI 280 and TZdEI 283 had significant positive GCA effects for grain yield when used as male parent only. Similarly, TZdEI 71, TZdEI 492 and TZdEI 378 had significant positive GCA effects for grain yield only when used as female parent. In contrast, Inbreds TZEI 31 and TZdEI 120 had significant ($P < 0.5$) negative GCA-male and GCA-female effects for grain yield whereas TZdEI 71, TZdEI 315, TZdEI 352, TZdEI 98 and TZdEI 157 had significant negative GCA-male effect for grain yield while TZdEI 399, TZdEI 314, TZdEI 82 and TZdEI 84 had significant negative GCA-female effect for grain yield.

Table 5.10: General combining ability effects of early maturing maize inbred lines evaluated across optimal environments

INBREDS	Grain Yield		Days to anthesis		Days to silking		ASI		Plant aspect		Ear aspect		Ears per plant	
	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf	GCAm	GCAf
TZdEI 71	-556.78**	526.36*	0.37	-0.30	0.21	-0.40	-0.12	-0.12	0.24	-0.04	0.36**	0.03	-0.06**	0.00
TZdEI 124	-37.16	-1020.42**	0.06	0.12	-0.12	0.10	-0.24*	-0.03	0.11	0.05	0.21	0.21	-0.02	0.01
TZdEI 202	55.86	39.13	-0.51	0.04	-0.30	0.14	0.18	0.14	-0.14	-0.11	-0.19	-0.26*	0.03	0.04*
TZdEI 399	-222.98	-500.41*	0.87**	0.84**	1.05**	0.96**	0.20*	0.09	-0.13	-0.28*	-0.04	-0.13	0.01	-0.07**
TZdEI 260	761.06**	955.34**	-0.79**	-0.69*	-0.84**	-0.79**	-0.02	-0.08	-0.07	0.38*	-0.35*	0.15	0.04*	0.02
TZdEI 268	-17.26	-36.54	0.76*	0.44	0.65*	0.43	-0.14	-0.03	0.21	-0.16	-0.02	-0.03	0.00	-0.01
TZdEI 314	-52.52	-452.58*	-0.93**	-0.52*	-0.86**	-0.63*	0.08	-0.05	0.44**	0.37*	-0.08	0.04	-0.01	0.02
TZdEI 396	782.39**	690.16**	0.18	-0.04	-0.07	-0.18	-0.22*	-0.14	-0.54**	-0.03	-0.26*	-0.26*	0.01	0.02
TZEI 7	-336.56	319.83	-0.55*	-0.21	-0.32	-0.05	0.21*	0.15	0.10	-0.32*	0.34*	0.06	-0.02	-0.02
TZEI 31	-376.06*	-520.87*	0.54*	0.34	0.60*	0.43	0.07	0.07	-0.21	0.14	0.01	0.20	0.02	0.00
TZdEI 315	-463.86*	-84.24	-1.02**	-1.13**	-1.25**	-1.18**	-0.19	-0.04	-0.25	0.01	-0.09	0.10	0.00	-0.01
TZdEI 479	529.41*	461.19*	0.24	-0.75**	-0.09	-0.90**	-0.34**	-0.19*	0.64**	0.60**	0.15	-0.08	0.03	0.05
TZdEI 82	-327.16	-611.04**	-0.24	0.04	-0.26	0.06	-0.05	0.08	-0.26	-0.21	-0.11	0.15	-0.03	-0.03
TZdEI 485	609.08**	96.82	-0.22	0.38	-0.03	0.26	0.15	-0.16*	0.43**	0.40*	0.20	0.30*	0.00	-0.03
TZdEI 441	-347.46	137.27	1.24**	1.45**	1.63**	1.77**	0.44**	0.31**	-0.56**	-0.80**	-0.15	-0.47**	0.00	0.02
TZdEI 352	-488.81*	-78.45	0.71*	0.59*	0.88**	0.82**	0.18	0.25**	0.01	-0.01	0.27*	0.07	0.01	0.01
TZdEI 84	-287.01	-771.12**	-0.31	-0.65*	-0.23	-0.82**	0.06	-0.18*	0.17	0.16	0.33*	0.12	-0.01	-0.03
TZdEI 280	681.96**	77.55	-0.84**	-0.57*	-0.80**	-0.40	0.02	0.20*	0.02	0.19	-0.10	-0.08	0.01	0.01
TZdEI 357	-181.23	211.21	0.40	0.53*	0.22	0.40	-0.20*	-0.15	0.04	-0.10	-0.12	-0.06	0.00	0.02
TZdEI 492	275.08	560.82*	0.04	0.10	-0.07	-0.01	-0.06	-0.13	-0.23	-0.25	-0.38**	-0.05	-0.01	-0.01
TZdEI 98	-777.52**	152.63	0.58*	0.28	0.47	-0.03	-0.10	-0.27**	0.27	0.17	0.31*	0.04	-0.04*	-0.03
TZdEI 157	-477.91*	-361.73	0.54*	0.96**	0.31	0.84**	-0.16	-0.15	0.06	0.02	0.07	0.05	-0.01	0.00
TZdEI 173	469.32*	512.88*	-0.67*	-0.49	-0.86**	-0.60*	-0.17	-0.12	-0.34*	-0.05	-0.20	-0.13	0.01	0.01
TZdEI 283	651.95**	-387.14	-0.28	-0.59*	-0.05	-0.37	0.18	0.20	0.05	-0.14	-0.15	0.14	0.02	0.03
TZEI 18	134.16	371.62	-0.16	-0.29	0.14	-0.10	0.25*	0.22*	-0.03	-0.01	-0.03	-0.24*	0.03	-0.01
TZdEI 105	187.57	-212.33	0.25	-0.38	0.35	-0.50	0.14	-0.13	-0.38*	0.00	-0.11	0.04	0.01	-0.02
TZdEI 120	-437.84*	-398.64*	-0.49	0.01	-0.58*	-0.08	-0.09	0.01	0.08	-0.20	0.01	0.05	0.03	0.00
TZdEI 131	78.01	-176.89	-0.16	-0.02	-0.22	-0.09	-0.07	-0.02	-0.04	0.07	0.14	0.17	-0.03	-0.03
TZdEI 264	37.56	-103.33	0.66*	1.03**	0.66*	1.15**	-0.01	0.07	0.34*	0.38*	-0.10	0.24	0.00	0.01
TZdEI 378	134.70	681.07**	-0.26	-0.58*	-0.22	-0.48	0.02	0.04	0.00	-0.30*	0.05	-0.46**	-0.01	0.03
SE ±	185.10	196.39	0.26	0.25	0.25	0.26	0.10	0.08	0.14	0.14	0.12	0.12	0.02	0.02

GCA_m =GCA effects of the inbreds used as male parents, GCA_f = GCA effects of the inbreds used as a female parents, * and **significant at 5 and 1% probability levels, ASI, anthesis-silking interval

The inbred lines TZdEI 399, TZdEI 441, TZdEI 352 and TZdEI 264 displayed significant positive GCA-male and GCA-female effects for both days to anthesis and silking while inbreds TZdEI 260 and TZdEI 314 had significant negative GCA effects when used as either male or female parents for both days to anthesis and silking. Significant negative GCA-female effects for plant aspect were recorded for inbreds TZdEI 399, TZEI 7 and TZdEI 378, GCA-male for TZdEI 396, TZdEI 173 and TZdEI 105 and both GCA-male and GCA-female for TZdEI 441 while significant positive GCA effects for both GCA-male and GCA-female were observed for TZdEI 314, TZdEI 479, TZdEI 485 and TZdEI 264 (Table 5.10). Inbreds TZdEI 71, TZEI 7, TZdEI 352, TZdEI 84 and TZdEI 98 showed significant positive GCA-male for ear aspect while TZdEI 485 had significant positive GCA-female for ear aspect. In contrast, significant negative GCA-male effects of ear aspect was observed for TZdEI 260 and TZdEI 492 as well as GCA-female effects of ear aspect for TZdEI 202, TZdEI 441, TZEI 18 and TZdEI 378 and both GCA-male and GCA-female for TZdEI 396. The EPP had significant and positive GCA-male for inbred TZdEI 260, GCA-female for TZdEI 202 as well as significant negative GCA-male for TZdEI 71 and TZdEI 98, and GCA-female for TZdEI 399 (Table 5.10).

5.3.4 Performance and stability analysis of early maturing hybrids under *Striga*-infested, drought and optimal environments

Under *Striga* infestation, the mean grain yield of hybrids ranged from 1134 kg ha^{-1} for the *Striga* susceptible check, TZEI 26 x TZEI 5 to 5362 kg ha^{-1} for TZdEI 173 x TZdEI 280 with a mean of 3146 kg ha^{-1} (Table 5.11, Appendix 5.11). The highest yielding *Striga* resistant hybrid, TZdEI 173 x TZdEI 280 out-yielded the commercial hybrid check TZEI 60 x TZEI 86 by 152%.

Table 5.11: Grain yield and other agronomic traits of selected hybrids evaluated under artificial *Striga* infestation (STR) at Mokwa and Abuja and under optimal growing conditions (OPT) at Ikenne, Abuja and Mokwa in 2013 and 2015.

Hybrids	Grain yield (kg ha^{-1})		Days to 50% silking		SDR‡ (WAP)		NESP (WAP)		Ear aspect (scale 1 -9)		Ear per plant		BI
	STR	OPT	STR	OPT	8	10	8	10	STR	OPT	STR	OPT	
TZdEI 173 x TZdEI 352	4676	4347	58	53	1.67	2.33	2.64	2.79	3.67	4	0.87	0.96	11.05
TZdEI 173 x TZdEI 280	5362	6816	57	51	2.67	3.50	2.80	3.16	3.83	3.8	0.97	0.96	10.82
TZdEI 352 x TZdEI 315	4821	5969	60	52	2.50	3.17	3.26	3.36	4.17	4.05	1.05	0.94	10.31
TZdEI 71 x TZdEI 268	4432	7068	57	52	3.67	4.00	1.70	2.44	4.67	4.7	1.00	0.97	8.05
TZdEI 82 x TZdEI 260	4946	6856	55	50	3.33	4.67	2.24	3.04	3.83	4	0.96	0.99	7.61
TZdEI 260 x TZdEI 268	4193	6370	56	50	3.67	4.67	1.19	2.13	4.67	4.4	1.04	0.99	7.59
TZdEI 357 x TZdEI 82	4230	6246	58	51	3.00	3.50	2.40	3.09	4.67	4.1	0.97	0.99	7.58
TZdEI 314 x TZdEI 105	4385	5109	58	51	3.00	3.67	2.88	3.26	3.83	4.55	0.98	0.98	7.42
TZdEI 378 x TZdEI 173	4688	6272	58	52	2.50	3.50	3.38	3.74	4.33	4.05	0.90	0.97	7.34
TZdEI 268 x TZdEI 105	4215	4971	58	54	2.83	3.50	2.63	3.06	3.83	4.25	0.91	0.97	6.88
TZdEI 280 x TZdEI 485	3510	5880	62	52	3.33	4.17	1.20	1.93	5.33	4.6	1.02	0.96	6.77
TZdEI 268 x TZdEI 131	4681	5383	57	51	3.00	4.00	2.86	3.35	4.17	4.5	0.87	0.93	6.41
TZdEI 105 x TZdEI 173	3993	5448	57	51	2.83	3.33	2.94	3.19	4.50	4.45	0.93	0.98	6.39
TZdEI 352 x TZdEI 485	3814	6305	60	53	3.33	4.33	2.09	2.53	4.67	4.8	1.03	1.01	6.26
TZdEI 98 x TZdEI 352	4368	5868	61	54	2.67	3.67	2.81	3.17	4.17	4.3	0.83	0.97	6.15
TZdEI 441 x TZdEI 260	3821	7033	58	52	2.33	4.00	2.43	3.24	4.50	3.5	0.94	1.01	6.14
TZdEI 268 x TZdEI 120	4023	5581	58	51	3.17	4.33	2.69	2.98	4.50	4.35	1.02	1.08	6.12
TZdEI 485 x TZdEI 124	3415	5111	58	51	3.17	4.17	1.80	2.23	5.17	5.3	0.99	0.91	5.66
TZdEI 120 x TZdEI 173	4264	5388	59	52	3.83	4.00	2.90	3.10	4.50	4.2	0.98	0.95	5.57
TZdEI 492 x TZdEI 441	3963	6245	62	55	4.00	4.83	2.28	2.74	4.83	4.1	1.08	0.99	5.43
TZdEI 485 x TZdEI 260	3589	6442	59	51	3.83	5.00	1.33	2.23	4.83	4.9	1.07	0.93	5.39
TZdEI 124 x TZdEI 268	3440	3967	59	53	3.60	4.00	2.83	3.12	4.20	4.55	1.13	0.95	5.36
TZdEI 82 x TZdEI 399	3745	5910	57	51	2.67	3.83	2.78	3.31	4.33	4.15	0.92	0.98	5.13
TZdEI 479 x TZdEI 124	3482	6455	58	51	3.00	4.83	1.67	2.95	4.67	4.1	1.03	1.00	5.05
TZdEI 352 x TZdEI 82	4215	5881	61	52	3.17	4.00	3.06	3.31	4.83	4.05	0.88	1.01	4.90
Check 2 - TZEI 188 x TZEI 98	2681	5605	59	52	4.17	5.50	2.80	3.41	5.50	4.55	0.71	0.91	-4.53
Check 3 - TZEI 60 x TZEI 5	3143	6876	64	54	4.83	5.67	2.94	3.33	5.50	3.3	0.68	0.97	-4.73
TZdEI 105 x TZdEI 98	2151	4308	61	53	4.67	6.00	2.93	3.31	6.33	4.85	0.73	0.84	-7.09
TZEI 7 x TZdEI 378	2033	5921	62	51	5.17	6.00	3.31	3.73	5.83	4.45	0.81	0.93	-7.79
TZdEI 84 x TZdEI 485	1816	5731	59	52	5.67	6.33	2.25	2.71	5.83	4.8	0.75	0.98	-8.52
Check 1 - TZEI 60 x TZEI 86	2128	5333	62	53	5.00	6.17	3.01	3.58	5.67	4.65	0.67	0.98	-8.76
Check 5 - TZEI 2 x TZEI 87	1838	4167	61	52	5.17	6.17	3.24	3.64	6.00	5.175	0.74	0.91	-9.23
TZEI 31 x TZdEI 264	2108	5356	62	52	5.50	6.50	3.86	3.94	6.17	4.6	0.82	0.97	-9.24
Check 4 - TZEI 31 x TZEI 63	1961	4823	61	53	5.50	6.33	3.39	3.74	5.33	4.4	0.66	0.96	-10.73
Check 6 - TZEI 26 x TZEI 5	1134	4176	63	53	6.00	7.33	2.78	3.41	6.67	4.9	0.67	0.84	-14.14
Means	3146	5601	60	52	3.97	4.91	2.82	3.29	5.12	4.45	0.89	0.97	
Heritability	0.30	0.76	0.64	0.76	0.65	0.67	0.67	0.64	0.54	0.54	0.38	0.44	
SE±	343	312	0.86	0.46	0.37	0.36	0.30	0.25	0.29	0.19	0.06	0.04	

SDR: *Striga* Damage Rating at weeks after planting (WAP); NESP: Number of Emerged *Striga* Plants, BI: base index

Grain yield of the hybrids ranged from 579 kg ha^{-1} for TZdEI 314 x TZdEI 378 to 3601 kg ha^{-1} for TZdEI 479 x TZdEI 260 with a mean of 2307 kg ha^{-1} under drought and 2376 kg ha^{-1} for TZdEI 82 x TZdEI 71 to 7769 kg ha^{-1} for TZdEI 260 x TZdEI 396 with a mean of 5601 kg ha^{-1} under optimal growing environments (Table 5.12, Appendix 5.12). Under drought stress, the highest yielding hybrid TZdEI 479 x TZdEI 260, produced more grains than the commercial hybrid check TZEI 60 x TZEI 86 by 99% while the highest yielding hybrid, TZdEI 260 x TZdEI 396 under optimal growing condition out-yielded the commercial check TZEI 60 x TZEI 86 by 45%. Days to silking varied from 55 for TZdEI 260 x TZdEI 396 to 63 for TZdEI 485 x TZdEI 124 with a mean of 59. The average yield reduction of the hybrids was 44% and 59% under *Striga* infestation and drought conditions. The reduction in grain yield of the hybrids was accompanied by increased days to silking, ASI, bareness and poor ear aspect across *Striga* infested and drought stress environments, and poor plant aspect under drought environments (Tables 5.11 and 5.12, Appendix 5.11 and 5.12). The hybrid, TZdEI 173 x TZdEI 352 showed outstanding performance across the two stress environments using the IITA base index. Yield range across the three research conditions was 1748 kg ha^{-1} for TZdEI 82 x TZdEI 71 to 4976 kg ha^{-1} for TZdEI 260 x TZdEI 396 with a mean of 3768 kg ha^{-1} (Table 5.13).

Under *Striga* infestation, the heritability estimates varied from 0.30 for grain yield to 0. 67 for *Striga* damage at 10 WAP and number of emerged *Striga* plants at 8 WAP while under drought, the value ranged from 0.29 for plant height to 0.55 for grain yield. Under optimal growing condition, the heritability estimates ranged from 0.44 for ears per plant to 0.76 for grain yield and days to silking (Tables 5.11 and Tables 5.12). Across research conditions, heritability estimates ranged from 0.34 for root lodging to 0.84 for days to 50% anthesis and silking (Table 5.13).

Table 5.12: Grain yield and other traits of some hybrids evaluated under drought stress (DT) at Ikenne and Bagauda and under optimal growing conditions (OPT) at Ikenne, Abuja and Mokwa in 2013 and 2015.

Hybrids	Grain yield (kg ha^{-1})		Days to 50% silking		Plant height (cm)		Ear aspect (scale 1 - 9)		Plant aspect (1-9)		Ear per plant		SGC (1-9)	Base Index
	DT	OPT	DT	OPT	DT	OPT	DT	OPT	DT	OPT	DT	OPT		
TZdEI 479 x TZdEI 260	3601	6622	56	50	167.90	188.10	4.05	4.30	4.15	4.90	1.07	1.12	2.30	13.85
TZdEI 396 x TZdEI 264	3167	6018	58	53	169.40	180.70	4.35	4.30	3.65	5.65	0.96	0.99	2.40	9.20
TZdEI 378 x TZdEI 157	3086	5564	57	53	160.30	188.60	3.75	4.00	3.90	3.95	0.90	0.97	3.20	8.80
TZdEI 71 x TZdEI 396	3172	6601	56	51	165.00	188.90	3.90	4.15	3.80	3.35	0.73	1.02	2.10	7.79
TZdEI 157 x TZdEI 280	2880	5992	59	52	152.80	176.10	4.00	4.35	4.25	3.90	1.07	1.03	3.00	7.77
TZdEI 260 x TZdEI 396	3122	7769	55	50	159.10	197.10	4.65	4.60	3.75	4.40	0.87	0.98	2.80	7.57
TZdEI 399 x TZdEI 268	2443	4306	57	54	159.50	180.90	3.65	4.70	3.90	4.20	0.92	0.91	2.60	7.46
TZdEI 492 x TZdEI 315	3155	6010	57	51	158.90	178.40	3.85	4.20	4.20	3.25	0.82	0.90	3.40	6.91
TZdEI 396 x TZdEI 378	2909	6295	58	52	158.10	180.20	4.10	3.95	4.05	3.60	0.87	0.97	2.60	6.85
TZdEI 396 x TZdEI 131	2697	6680	55	50	164.10	192.50	4.35	4.15	4.15	3.60	0.82	0.98	2.50	6.82
TZdEI 396 x TZdEI 120	2742	5797	57	52	155.90	185.40	3.90	4.10	4.20	3.75	0.90	0.96	2.90	6.52
TZdEI 399 x TZdEI 314	2704	4891	56	51	151.60	181.80	3.95	4.40	4.35	4.40	0.94	0.92	3.20	6.42
TZdEI 314 x TZdEI 120	2796	4827	57	52	155.30	178.40	4.25	4.50	4.40	4.45	1.02	1.00	2.90	6.20
TZdEI 441 x TZdEI 71	2548	5153	58	53	163.60	191.00	3.85	4.35	3.75	3.70	0.82	0.93	2.20	5.96
TZEI 18 x TZdEI 84	2980	6045	58	53	154.00	176.60	4.15	4.15	4.10	3.55	0.82	0.93	2.50	5.89
TZdEI 71 x TZdEI 314	2606	6064	56	51	159.20	184.50	4.00	4.40	4.50	4.65	0.95	0.97	2.70	5.80
TZEI 7 x TZdEI 264	2681	5554	59	53	159.70	181.40	4.20	4.55	4.25	4.00	0.80	0.94	2.60	5.71
TZdEI 283 x TZdEI 492	2670	6352	58	52	152.10	179.10	4.15	3.85	4.45	3.40	0.98	1.07	3.20	5.66
TZdEI 260 x TZEI 31	2764	5847	57	52	157.80	185.00	4.25	4.80	4.40	4.20	0.99	1.01	3.30	5.50
TZdEI 173 x TZdEI 352	2545	4347	61	53	153.50	161.25	3.80	4.00	4.00	2.38	0.85	0.96	2.80	5.42
TZdEI 315 x TZdEI 399	2659	5759	56	52	150.70	179.70	4.05	4.15	4.40	3.85	0.89	1.03	3.10	5.39
TZdEI 98 x TZdEI 492	2791	5877	58	53	164.60	180.50	4.35	3.95	4.60	3.50	0.95	0.95	3.90	5.08
TZEI 18 x TZdEI 352	2789	5799	61	54	152.80	178.60	4.05	4.45	4.35	3.60	0.85	1.00	2.50	5.06
TZdEI 378 x TZEI 18	2810	5723	59	52	149.80	185.10	3.95	4.25	4.60	3.95	0.88	0.95	2.90	4.98
TZdEI 260 x TZEI 7	2735	5694	56	51	144.40	181.30	4.40	4.85	4.40	4.10	0.92	0.90	2.90	4.92
Check 1 - TZEI 60 x TZEI 86	1804	5333	58	53	148.00	183.70	5.00	4.65	4.70	4.20	0.81	0.98	3.50	-2.16
TZdEI 492 x TZdEI 485	2078	7723	60	52	142.90	196.40	5.40	4.10	5.00	4.10	0.55	0.99	4.90	-10.30
TZdEI 283 x TZdEI 352	1180	4043	61	53	145.60	182.80	5.75	5.05	4.95	4.15	0.63	0.99	4.00	-10.85
TZdEI 357 x TZdEI 479	1050	7058	62	53	126.20	198.50	5.65	4.30	5.75	4.50	0.63	1.05	3.60	-11.32
TZdEI 131 x TZdEI 98	1178	3290	61	54	147.70	174.20	5.70	5.30	5.40	4.95	0.65	0.82	4.10	-12.15
TZdEI 84 x TZdEI 479	839	5801	63	51	126.33	194.70	5.58	4.70	5.83	4.60	0.86	0.97	3.13	-12.46
TZdEI 280 x TZdEI 485	1229	5880	60	52	129.70	187.30	5.85	4.60	5.50	4.80	0.68	0.96	3.90	-12.87
TZdEI 485 x TZdEI 124	1582	5111	61	51	136.20	194.10	5.55	5.30	5.70	5.00	0.68	0.91	5.10	-13.01
TZdEI 82 x TZdEI 71	671	2376	63	53	146.13	161.80	5.44	6.00	5.56	5.25	0.46	0.80	3.78	-16.12
TZdEI 314 x TZdEI 378	579	4596	61	52	118.50	162.30	6.30	5.15	6.45	4.75	0.78	0.93	5.30	-17.36
Means	2307	5601	59	52	153.08	184.31	4.62	4.45	4.65	4.51	0.82	0.97	3.27	
Heritability	0.55	0.76	0.54	0.76	0.29	0.66	0.46	0.54	0.38	0.62	0.44	0.44	0.5	
SE±	638.02	311.50	0.75	0.46	4.97	3.38	0.23	0.19	0.34	0.22	0.07	0.04	0.3	

SGC, stay green characteristic.

Table 5.13: Grain yield and other traits of selected hybrids screened across *Striga*-infested, drought and optimal conditions at 13 environments in 2013 and 2015.

Hybrid	Grain yield (kg ha^{-1})	Days to 50% anthesis	Days to 50% silking	Anthesis-silking interval	Plant height (cm)	Ear aspect	Plant aspect	Root lodging	Husk cover	Ear per plant
TZdEI 260 x TZdEI 396	4976	53	54	1.00	172.08	4.63	4.08	1.67	3.56	0.93
TZdEI 173 x TZdEI 280	4782	53	55	1.23	165.35	4.06	3.78	1.54	3.06	0.93
TZdEI 71 x TZdEI 268	4777	55	55	0.54	168.77	4.75	4.40	1.97	3.27	0.98
TZdEI 173 x TZdEI 492	4765	55	56	1.46	158.92	3.98	3.80	1.31	3.27	0.96
TZdEI 479 x TZdEI 260	4715	53	54	0.85	171.73	4.37	4.53	1.23	3.85	1.07
TZdEI 441 x TZdEI 260	4657	55	56	1.54	170.58	4.00	3.53	1.20	3.00	0.91
TZdEI 82 x TZdEI 260	4625	52	53	1.15	164.04	4.19	3.80	1.55	3.17	0.95
TZdEI 71 x TZdEI 396	4540	53	55	1.42	174.23	4.25	3.58	1.35	3.13	0.88
TZdEI 396 x TZdEI 131	4499	53	54	0.73	172.88	4.46	3.88	2.11	3.23	0.91
TZdEI 492 x TZdEI 485	4480	55	57	1.88	164.27	4.88	4.55	1.26	3.77	0.82
TZdEI 378 x TZdEI 173	4452	55	56	1.42	165.00	4.31	4.05	1.25	3.50	0.89
TZdEI 98 x TZdEI 280	4402	54	55	1.23	174.88	4.54	4.45	1.52	3.52	0.90
Check 3 - TZEI 60 x TZEI 5	4379	57	59	1.92	174.69	4.21	3.75	1.22	3.52	0.84
TZdEI 396 x TZdEI 264	4379	55	56	1.35	170.69	4.40	4.65	1.71	3.23	0.98
TZdEI 352 x TZdEI 315	4360	55	57	1.69	169.23	4.12	3.88	1.75	3.19	0.98
TZdEI 357 x TZdEI 485	4357	56	57	1.92	167.23	4.92	4.45	1.15	3.77	0.83
TZEI 18 x TZdEI 357	4328	56	57	1.50	160.31	4.33	4.20	1.47	3.75	0.93
TZdEI 98 x TZdEI 352	4305	56	58	1.62	171.62	4.19	3.85	1.61	3.13	0.88
TZdEI 479 x TZdEI 124	4301	53	55	1.65	172.85	4.54	4.75	1.00	3.75	0.96
TZdEI 260 x TZdEI 314	4298	53	54	1.00	167.27	4.81	5.30	1.32	4.23	1.01
TZdEI 492 x TZdEI 315	4294	54	55	1.54	161.96	4.37	3.73	1.31	3.46	0.88
TZdEI 260 x TZdEI 268	4289	53	54	0.81	161.69	4.73	4.68	1.84	3.75	0.90
Check 2 - TZEI 188 x TZEI 98	3787	55	56	1.42	160.12	4.63	4.15	1.42	3.60	0.85
Check 1 - TZEI 60 x TZEI 86	3259	56	57	1.15	161.50	5.02	4.45	1.27	3.71	0.84
Check 4 - TZEI 31 x TZEI 63	3198	55	57	2.00	157.46	4.67	4.26	1.94	3.88	0.85
TZdEI 84 x TZdEI 441	3031	56	58	2.19	174.31	4.98	4.43	1.88	3.12	0.87
Check 5 - TZEI 2 x TZEI 87	2921	54	57	2.42	160.08	5.13	4.65	1.73	3.85	0.84
TZdEI 105 x TZdEI 98	2914	56	58	1.35	163.85	5.33	4.83	1.84	3.65	0.69
TZdEI 105 x TZdEI 157	2856	55	56	1.12	172.38	4.92	4.70	1.72	3.65	0.90
TZdEI 124 x TZEI 31	2782	54	57	2.19	165.58	5.10	4.68	2.33	3.90	0.88
TZdEI 283 x TZdEI 352	2642	56	58	1.92	160.19	5.38	4.55	1.57	3.75	0.84
Check 6 - TZEI 26 x TZEI 5	2588	56	58	2.08	153.46	5.50	4.75	1.95	3.96	0.76
TZdEI 314 x TZdEI 378	2474	57	58	1.27	135.62	5.75	5.60	2.22	4.37	0.84
TZdEI 131 x TZdEI 98	2230	57	59	1.92	157.27	5.58	5.18	1.76	3.94	0.75
TZdEI 82 x TZdEI 71	1748	57	59	1.83	152.88	5.73	5.39	1.64	3.86	0.72
Means	3768	55	56	2	164.86	4.67	4.34	1.66	3.55	0.89
Heritability	0.66	0.84	0.84	0.38	0.67	0.70	0.64	0.34	0.47	0.56
SE	165.02	0.34	0.39	0.26	2.63	4.86	0.21	0.21	0.14	0.03

The yield performance and stability of the selected 35 (best 25 and worst 10 hybrids using the base index) early maturing maize hybrids evaluated under drought, *Striga* infestation, optimal environments and across the three research conditions are presented in the AMMI biplots (Fig. 5.1, 5.2, 5.3 and 5.4). In the AMMI biplot, the grand mean for grain yield represents the vertical dotted line, while the horizontal dotted line (y ordinate) represents the interaction principal component axes 1 (IPCA1) value of zero. Hybrids located near the horizontal line have little interactions with the environment and are considered to be more stable than those farther apart. The farther a cultivar is to the right side of the grand mean line, the higher the grain yield.

Under *Striga* infestation, E (environment), G (hybrids), and the IPCA1 accounted for 6.76, 51.47, and 30.9% of the total variation in the sum of squares for grain yield, respectively, giving a total sum of 89.1%. This indicated that the biplot was effective in explaining both the main effects as well as in decomposing the G × E interaction under *Striga*-infested environments (Fig. 5.1). The hybrids 2 (TZdEI 173 x TZdEI 280), 5 (TZdEI 82 x TZdEI 260), 7 (TZdEI 357 x TZdEI 82), 8 (TZdEI 314 x TZdEI 105), 11 (TZdEI 280 x TZdEI 485), 13 (TZdEI 105 x TZdEI 173), 15 (TZdEI 98 x TZdEI 352), 16 (TZdEI 441 x TZdEI 260), 17 (TZdEI 268 x TZdEI 120) and 20 (TZdEI 492 x TZdEI 441) produced yields greater than the grand mean and had near zero IPCA1 score, indicating that they were stable under *Striga*-infested environments. The hybrids 1 (TZdEI 173 x TZdEI 352), 3 (TZdEI 352 x TZdEI 315), 7 (TZdEI 357 x TZdEI 82), 9 (TZdEI 378 x TZdEI 173), 10 (TZdEI 268 x TZdEI 105), 12 (TZdEI 268 x TZdEI 131), 19 (TZdEI 120 x TZdEI 173), 20 (TZdEI 492 x TZdEI 441), 23 (TZdEI 82 x TZdEI 399) and 25 (TZdEI 352 x TZdEI 82) produced yields greater than the grand mean but had

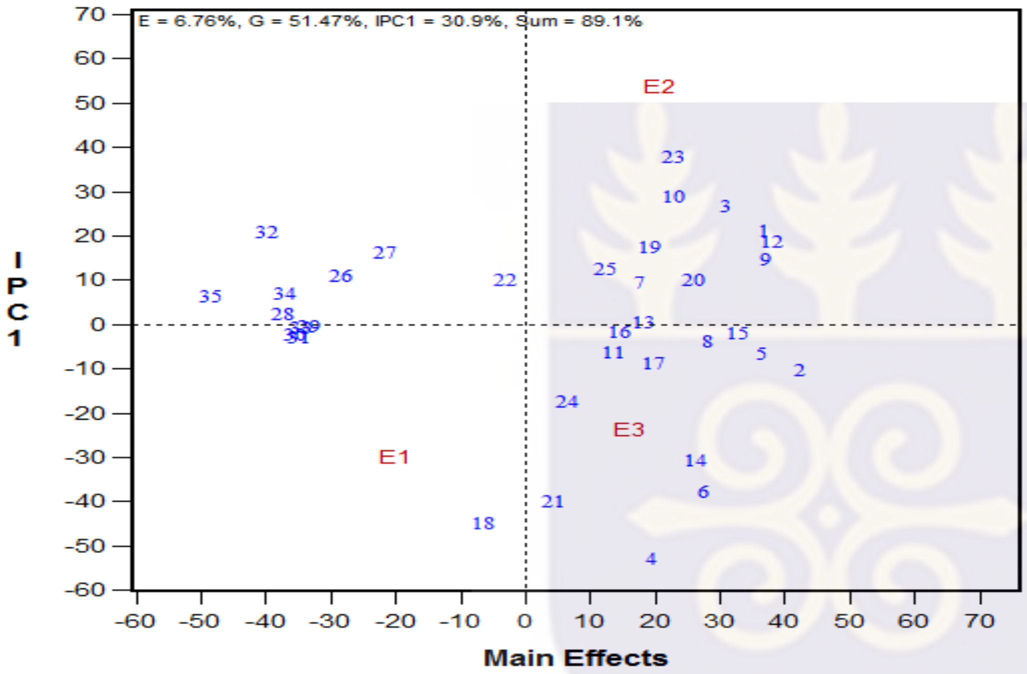


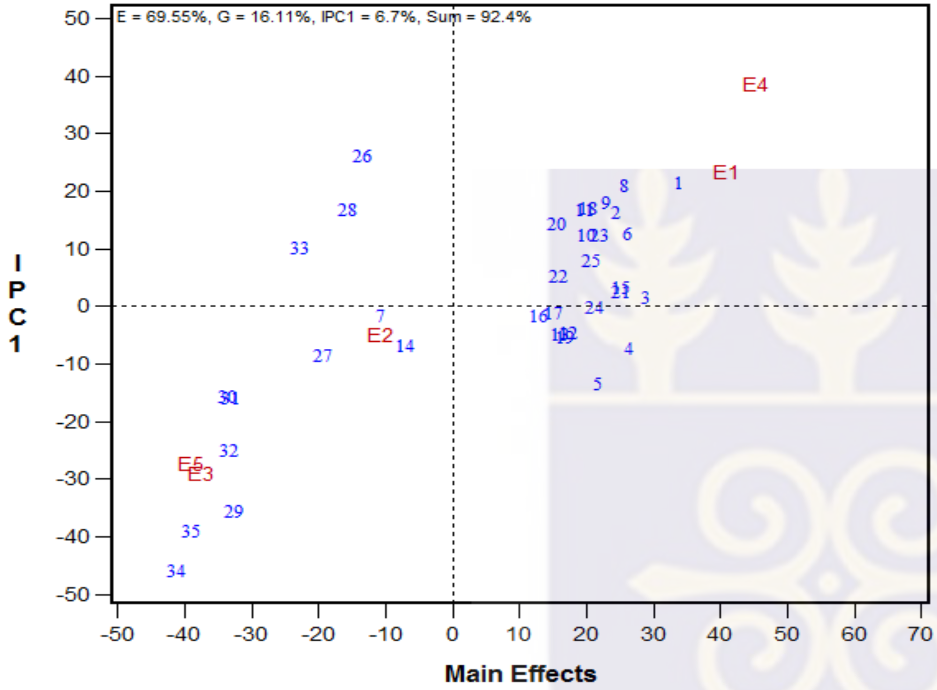
Figure 5.1: Mean performance and stability of selected early maturing maize hybrids in terms of grain yield as measured by principal components across three *Striga*-infested environments in Nigeria between 2013 and 2015.

E1 =Abuja, 2013; E2 = Mokwa, 2013; E3 = Abuja, 2015.

Entry	**Hybrid**
1	TZdEI 173 x TZdEI 352
2	TZdEI 173 x TZdEI 280
3	TZdEI 352 x TZdEI 315
4	TZdEI 71 x TZdEI 268
5	TZdEI 82 x TZdEI 260
6	TZdEI 260 x TZdEI 268
7	TZdEI 357 x TZdEI 82
8	TZdEI 314 x TZdEI 105
9	TZdEI 378 x TZdEI 173
10	TZdEI 268 x TZdEI 105
11	TZdEI 280 x TZdEI 485
12	TZdEI 268 x TZdEI 131
13	TZdEI 105 x TZdEI 173
14	TZdEI 352 x TZdEI 485
15	TZdEI 98 x TZdEI 352
16	TZdEI 441 x TZdEI 260
17	TZdEI 268 x TZdEI 120
18	TZdEI 485 x TZdEI 124
19	TZdEI 120 x TZdEI 173
20	TZdEI 492 x TZdEI 441
21	TZdEI 485 x TZdEI 260
22	TZdEI 124 x TZdEI 268
23	TZdEI 82 x TZdEI 399
24	TZdEI 479 x TZdEI 124
25	TZdEI 352 x TZdEI 82
26	TZEI 188 x TZEI 98
27	TZEI 60 x TZEI 5
28	TZdEI 105 x TZdEI 98
29	TZEI 7 x TZdEI 378
30	TZdEI 84 x TZdEI 485
31	TZEI 60 x TZEI 86
32	TZEI 2 x TZEI 87
33	TZEI 31 x TZdEI 264
34	TZEI 31 x TZEI 63
35	TZEI 26 x TZEI 5

positive interactions with IPCA1 indicating that they were adapted to high yield environments (E2) while hybrids 4 (TZdEI 71 x TZdEI 268), 6 (TZdEI 260 x TZdEI 268), 14 (TZdEI 352 x TZdEI 485), 21 (TZdEI 485 x TZdEI 260) and 24 (TZdEI 479 x TZdEI 124) yielded higher than the grand mean but showed strong negative interaction with IPCA1 indicating that they were adapted to low yield environments (E3).

Under drought, E (environment), G (hybrids), and the IPCA1 accounted for 69.55, 16.11, and 6.7% of the total variation in the sum of squares for grain yield, respectively giving a total sum of 92.4%. This indicated that the biplot was effective in explaining both the main effects as well as in decomposing the G × E interaction under drought environments (Fig. 5.2). The hybrids 3 (TZdEI 378 x TZdEI 157), 4 (TZdEI 71 x TZdEI 396), 12 (TZdEI 399 x TZdEI 314), 15 (TZEI 18 x TZdEI 84), 16 (TZdEI 71 x TZdEI 314), 17 (TZEI 7 x TZdEI 264), 19 (TZdEI 260 x TZEI 31), 21 (TZdEI 315 x TZdEI 399), 22 (TZdEI 98 x TZdEI 492), 24 (TZdEI 378 x TZEI 18), and 25 (TZdEI 260 x TZEI 7) produced yields greater than the grand mean and had near zero IPCA1 score, indicating that they were the most stable under drought environments. The hybrids 1 (TZdEI 479 x TZdEI 260), 8 (TZdEI 492 x TZdEI 315), 9 (TZdEI 396 x TZdEI 378), 2 (TZdEI 396 x TZdEI 264), 6 (TZdEI 260 x TZdEI 396), 10 (TZdEI 396 x TZdEI 131), 23 (TZEI 18 x TZdEI 352), 11 (TZdEI 396 x TZdEI 120), 18 (TZdEI 283 x TZdEI 492) and 20 (TZdEI 173 x TZdEI 352) produced yields greater than the grand mean but had positive interactions with IPCA1 indicating that they were adapted to high yield environments while hybrid 5 (TZdEI 157 x TZdEI 280) yielded higher than the grand mean but showed strong negative interaction with IPCA1 indicating that they were adapted to low yield environments.

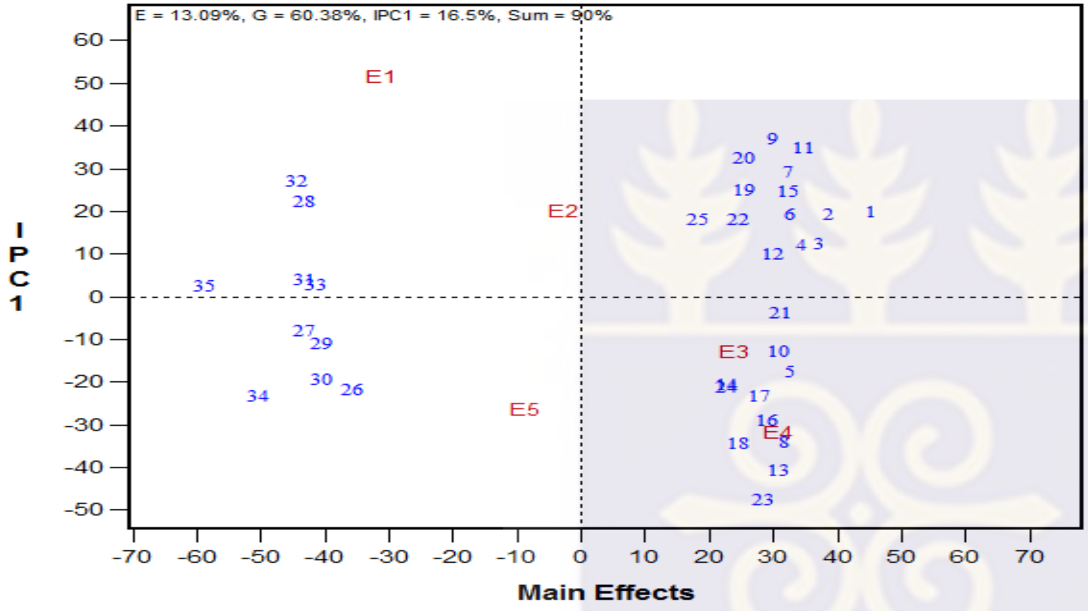


Entry	Hybrid
1	TZdEI 479 x TZdEI 260
2	TZdEI 396 x TZdEI 264
3	TZdEI 378 x TZdEI 157
4	TZdEI 71 x TZdEI 396
5	TZdEI 157 x TZdEI 280
6	TZdEI 260 x TZdEI 396
7	TZdEI 399 x TZdEI 268
8	TZdEI 492 x TZdEI 315
9	TZdEI 396 x TZdEI 378
10	TZdEI 396 x TZdEI 131
11	TZdEI 396 x TZdEI 120
12	TZdEI 399 x TZdEI 314
13	TZdEI 314 x TZdEI 120
14	TZdEI 441 x TZdEI 71
15	TZEI 18 x TZdEI 84
16	TZdEI 71 x TZdEI 314
17	TZEI 7 x TZdEI 264
18	TZdEI 283 x TZdEI 492
19	TZdEI 260 x TZEI 31
20	TZdEI 173 x TZdEI 352
21	TZdEI 315 x TZdEI 399
22	TZdEI 98 x TZdEI 492
23	TZEI 18 x TZdEI 352
24	TZdEI 378 x TZEI 18
25	TZdEI 260 x TZEI 7
26	TZdEI 352 x TZdEI 485
27	TZdEI 315 x TZdEI 124
28	TZdEI 492 x TZdEI 485
29	TZdEI 283 x TZdEI 352
30	TZdEI 357 x TZdEI 479
31	TZdEI 131 x TZdEI 98
32	TZdEI 280 x TZdEI 485
33	TZdEI 485 x TZdEI 124
34	TZdEI 82 x TZdEI 71
35	TZdEI 314 x TZdEI 378

Figure 5.2: Mean performance and stability of selected early maturing maize hybrids in terms of grain yield as measured by principal components across five drought environments in Nigeria between 2013 and 2015.

E1 = Bagauda, 2013; E2 = Ikenne, 2013/2014; E3 = Minjibir, 2015; E4 = Bagauda, 2015; E5 = Ikenne, 2015/2016.

Under optimal environments, the variation in grain yield attributable to E, G, and the IPCA1 were 13.09, 60.38, and 16.5%, respectively. The hybrids 3 (TZdEI 357 x TZdEI 485), 4 (TZdEI 98 x TZdEI 280), 10 (TZEI 18 x TZdEI 357), 12 (TZdEI 485 x TZdEI 202) and 21 (TZdEI 71 x TZdEI 396) produced yields greater than the grand mean and had near zero IPCA1 score, indicating their superior stability under optimal environments (Fig. 5.3). Hybrids 1 (TZdEI 260 x TZdEI 396), 2 (TZdEI 492 x TZdEI 485), 6 (TZdEI 71 x TZdEI 268), 7 (TZdEI 357 x TZdEI 479), 9 (TZdEI 492 x TZdEI 479), 11 (TZdEI 280 x TZdEI 479), 15 (TZdEI 260 x TZdEI 314), 19 (TZdEI 479 x TZdEI 71), 20 (TZdEI 479 x TZdEI 260), 22 (TZdEI 479 x TZdEI 124) and 25 (TZdEI 485 x TZdEI 260) yielded higher than the grand mean but showed strong positive interaction with IPCA1 indicating that they were adapted to high yield environments while hybrids 5 (TZdEI 173 x TZdEI 492), 8 (TZdEI 441 x TZdEI 260), 10 (TZEI 18 x TZdEI 357), 13 (TZEI 60 x TZEI 5), 14 (TZdEI 82 x TZdEI 260), 16 (TZdEI 173 x TZdEI 280), 17 (TZdEI 378 x TZdEI 283), 18 (TZdEI 396 x TZdEI 131), 23 (TZEI 18 x TZdEI 280) and 24 (TZEI 7 x TZdEI 105) yielded higher than the grand mean but showed strong negative interaction with IPCA1 indicating that they were adapted to low yield environments (Ikenne and Mokwa 2015).



Entry	Hybrid
1	TZdEI 260 x TZdEI 396
2	TZdEI 492 x TZdEI 485
3	TZdEI 357 x TZdEI 485
4	TZdEI 98 x TZdEI 280
5	TZdEI 173 x TZdEI 492
6	TZdEI 71 x TZdEI 268
7	TZdEI 357 x TZdEI 479
8	TZdEI 441 x TZdEI 260
9	TZdEI 492 x TZdEI 479
10	TZEI 18 x TZdEI 357
11	TZdEI 280 x TZdEI 479
12	TZdEI 485 x TZdEI 202
13	TZEI 60 x TZEI 5
14	TZdEI 82 x TZdEI 260
15	TZdEI 260 x TZdEI 314
16	TZdEI 173 x TZdEI 280
17	TZdEI 378 x TZdEI 283
18	TZdEI 396 x TZdEI 131
19	TZdEI 479 x TZdEI 71
20	TZdEI 479 x TZdEI 260
21	TZdEI 71 x TZdEI 396
22	TZdEI 479 x TZdEI 124
23	TZEI 18 x TZdEI 280
24	TZEI 7 x TZdEI 105
25	TZdEI 485 x TZdEI 260
26	TZdEI 399 x TZdEI 268
27	TZEI 31 x TZdEI 120
28	TZEI 26 x TZEI 5
29	TZEI 2 x TZEI 87
30	TZdEI 105 x TZdEI 157
31	TZdEI 283 x TZdEI 352
32	TZdEI 124 x TZdEI 268
33	TZdEI 124 x TZEI 31
34	TZdEI 131 x TZdEI 98
35	TZdEI 82 x TZdEI 71

Figure 5.3: Mean performance and stability of selected early maturing maize hybrids in terms of grain yield as measured by principal components across five optimal environments in Nigeria between 2013 and 2015.

E1 = Ikenne, 2013; E2 = Mokwa, 2013; E3 = Ikenne, 2015; E4 = Mokwa, 2015; and E5 = Abuja, 2015.

Across research environments, the variation in grain yield attributable to E, G, and the IPCA1 were 68.5, 13.74, and 6%, respectively, giving a sum of 88.2%. The hybrids 2 (TZdEI 173 x TZdEI 280), 3 (TZdEI 173 x TZdEI 492), 5 (TZdEI 441 x TZdEI 260), 7 (TZdEI 82 x TZdEI 260), 8 (TZdEI 71 x TZdEI 396), 10 (TZdEI 396 x TZdEI 131), 12 (TZdEI 396 x TZdEI 264), 13 (TZdEI 98 x TZdEI 352), 15 (TZdEI 157 x TZdEI 352), 17 (TZEI 18 x TZdEI 357), 20 (TZdEI 268 x TZdEI 378), 21 (TZdEI 157 x TZdEI 280), 23 (TZdEI 492 x TZdEI 441) and 24 (TZEI 60 x TZEI 5) produced yields greater than the average mean and had near zero IPCA1 score, indicating their superior stability across research environments (Fig. 5.4). Hybrids 11 (TZdEI 378 x TZdEI 173), 16 (TZdEI 352 x TZdEI 315) and 22 (TZdEI 82 x TZdEI 399) yielded higher than the grand mean but showed strong positive interaction with IPCA1 indicating that they were adapted to high yield environments while hybrids 1 (TZdEI 260 x TZdEI 396), 4 (TZdEI 71 x TZdEI 268), 6 (TZdEI 479 x TZdEI 260), 9 (TZdEI 98 x TZdEI 280), 14 (TZdEI 492 x TZdEI 485), 18 (TZdEI 357 x TZdEI 485), 19 (TZdEI 479 x TZdEI 124) and 25 (TZdEI 260 x TZdEI 268) yielded higher than the grand mean but showed strong negative interaction with IPCA1 indicating that they were adapted to low yield environments**.**

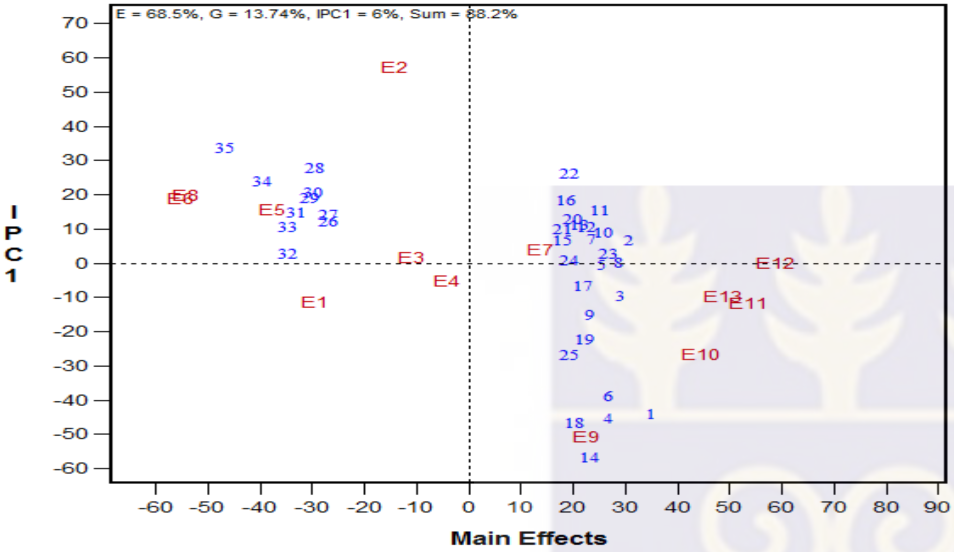


Figure 5.4: Mean performance and stability of selected early maturing maize hybrids in terms of grain yield as measured by principal components across eight stressed and five non-stressed environments in Nigeria between 2013 and 2015.

E1 = Abuja Striga-infested, 2013; E2 = Mokwa Striga-infested, 2013; E3 = Abuja Striga-infested, 2015; E4 = Bagauda drought, 2013; E5 = Ikenne drought, 2013/2014; E6 = Minjibir drought, 2015; E7 = Bagauda drought, 2015; E8 = Ikenne drought, 2015/2016; E9 = Ikenne optimal, 2013; E10 = Mokwa optimal, 2013; E11 = Ikenne optimal, 2015; E12 = Mokwa optimal, 2015; E13 = Abuja optimal; 2015.

Entry	Hybrid
1	TZdEI 260 x TZdEI 396
2	TZdEI 173 x TZdEI 280
3	TZdEI 173 x TZdEI 492
4	TZdEI 71 x TZdEI 268
5	TZdEI 441 x TZdEI 260
6	TZdEI 479 x TZdEI 260
7	TZdEI 82 x TZdEI 260
8	TZdEI 71 x TZdEI 396
9	TZdEI 98 x TZdEI 280
10	TZdEI 396 x TZdEI 131
11	TZdEI 378 x TZdEI 173
12	TZdEI 396 x TZdEI 264
13	TZdEI 98 x TZdEI 352
14	TZdEI 492 x TZdEI 485
15	TZdEI 157 x TZdEI 352
16	TZdEI 352 x TZdEI 315
17	TZEI 18 x TZdEI 357
18	TZdEI 357 x TZdEI 485
19	TZdEI 479 x TZdEI 124
20	TZdEI 268 x TZdEI 378
21	TZdEI 157 x TZdEI 280
22	TZdEI 82 x TZdEI 399
23	TZdEI 492 x TZdEI 441
24	Check 3 - TZEI 60 x TZEI 5
25	TZdEI 260 x TZdEI 268
26	TZEI 31 x TZdEI 131
27	TZdEI 84 x TZdEI 441
28	TZdEI 105 x TZdEI 157
29	Check 5 - TZEI 2 x TZEI 87
30	TZdEI 124 x TZEI 31
31	TZdEI 283 x TZdEI 352
32	Check 6 - TZEI 26 x TZEI 5
33	TZdEI 314 x TZdEI 378
34	TZdEI 131 x TZdEI 98
35	TZdEI 82 x TZdEI 71

5.3.5 Relationship between performance of parental inbred lines and their hybrids

The average mid and high parent heterosis values for grain yield (267% and 191%) were higher under drought than under *Striga*-infested environments (96% and 73%). Negative values for mid and high parent heterosis were recorded for the flowering traits (days to 50% silking and anthesis) under *Striga* and drought environments; stay green characteristic and ear aspect only under drought. On the other hand, positive mid and high parent heterosis values were recorded for the *Striga* traits and ear aspect under *Striga*-infested environments (Table 5.14).

5.3.6 Interrelationship between traits under the different research conditions

Significant phenotypic correlations were obtained between grain yield and other traits under *Striga* infestation (Table 5.15). The phenotypic correlation (r_p) between number of emerged *Striga* plants and grain yield was (-0.07*) at 8 WAP and (0.06*) at 10 WAP, indicating that genotypes with fewer number of emerged *Striga* plants yielded higher than those with more number of emerged *Striga* plants. Significant positive genotypic correlations (r_g) were obtained between the number of emerged *Striga* plants at 8 WAP and at 10 WAP (0.95**) and between host plant damage at 8 and 10 WAP (0.99**). Also, large genotypic correlations existed among several other traits. Grain yield had moderately high positive, genotypic correlation with EPP (0.47*), PHT (0.54*), and EHT (0.53**). In contrast, grain yield had small negative genotypic correlation with the flowering traits, and number of emerged *Striga* plants at 8 and 10 WAP.

Table 5.14: Average mid and high parent heterosis for grain yield and other agronomic traits under *Striga*-infested and drought environments

Traits	Mid-parent heterosis (%)		High parent heterosis (%)	
	Striga infested	Drought	*Striga* infested	Drought
Grain yield	96.2	266.58	73.07	191.15
Days to anthesis	-2.95	-7.08	-4.27	-8.37
Days to silking	-2.28	-5.25	-3.76	-6.39
Ear aspect	9.35	-12.46	15.26	-5.50
Plant aspect	-	-5.19	-	5.67
Ears per plant	3.97	23.93	-2.59	14.18
Striga damage rating at 8 WAP	1.62	-	8.94	-
Striga damage rating at 10 WAP	5.22	-	13.45	-
Number of emerged *Striga* plants at 8 WAP	93.21	-	238.39	-
Number of emerged *Striga* plants at 10 WAP	48.9	-	94.23	-
Stay green characteristics	-	-21.56	.	-13.37

Table 5.15: Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficients for grain yield and other agronomic traits evaluated under artificial *Striga* infestation in Mokwa and Abuja in 2013 and 2015.

TRAIT	YIELD	DA	DS	ASI	PHT	EHT	SDR1	SDR2	NESP1	NESP2	SL	HC	EASP	EPP
YIELD		0.05	-0.06	-0.20	0.54**	0.53**	-0.95**	-0.95**	0.25	0.13	0.41	-1.00**	-1.00**	0.47*
DA	-0.08*		0.96**	0.60*	0.05	0.39*	0.02	0.08	0.01	0.05	-0.50	0.13	0.04	-0.27
DS	-0.11**	0.65**		0.79**	0.07	0.46**	0.14	0.20	0.01	0.08	-0.50	0.28*	0.16	-0.47**
ASI	-0.07*	0.05	0.79**		0.14	0.55*	0.33	0.37	0.02	0.14	-0.28	0.52*	0.32	-0.77*
PHT	0.19**	-0.11**	-0.11**	-0.04		0.75**	-0.55**	-0.65**	-0.13	-0.11	0.63	-0.53**	-0.44**	0.16
EHT	0.20**	-0.01	-0.03	-0.03	0.64**		-0.45**	-0.49**	0.19	0.17	1.00	-0.50**	-0.40**	-0.01
SDR1	-0.42**	0.14**	0.25**	0.21**	-0.35**	-0.33**		0.95**	0.07	0.09	0.21	1.00**	0.83**	-0.58**
SDR2	-0.45**	0.10*	0.20**	0.17**	-0.38**	-0.35**	0.78**		0.00	0.04	0.24	1.00**	0.92**	-0.63**
NESP1	-0.07*	-0.05	-0.01	0.03	0.03	0.13**	0.07	0.10*		0.99**	0.54	0.06	0.10	-0.17
NESP2	-0.06*	-0.05	-0.02	0.01	-0.01	0.12**	0.07	0.14**	0.89**		0.76	0.08	0.09	-0.27
SL	-0.15**	-0.11**	-0.11**	-0.03	0.12**	0.05	0.11**	0.12**	0.07*	0.04		1.00	0.01	-0.74
HC	-0.22**	0.04	0.12**	0.12**	-0.26**	-0.14**	0.52**	0.65**	0.14**	0.19**	-0.01		1.00**	-0.89**
EASP	-0.48**	0.12**	0.19**	0.15**	-0.25**	-0.23**	0.61**	0.64**	0.13**	0.11**	0.17**	0.44**		-0.78**
EPP	0.21**	-0.13**	-0.16**	-0.11**	0.09**	0.07*	-0.32**	-0.33**	-0.15**	-0.12**	-0.15**	-0.18**	-0.28**	

DA, days to anthesis; DS, days to silking; ASI, anthesis-silking interval; PHT, plant height; EHT, ear height; SDR1, Striga damage at 8 weeks after planting; SDR2, Striga damage at 10 weeks after planting; NESP1, number of emerged Striga plants at 8 weeks after planting, NESP2, number of emerged Striga plants at 10 weeks after planting; SL, stalk lodging; HC, husk cover; EASP, ear aspect; EPP, ears per plant; *, **, Significant at 0.05 and 0.01probability levels, respectively, Significant large negative genetic correlation was also obtained with *Striga* damage at 8 and 10 WAP. Large-to-moderately large and significant genetic correlation coefficients were also observed between plant height (PHT) and ear height (EHT); days to anthesis and days to silking as well as ASI; days to silking and ASI; ASI and EHT, husk cover (HC) and *Striga* damage at 8 and 10 WAP, and husk cover and ear aspect.

Under drought, significant phenotypic correlations were obtained between grain yield and all measured traits except root and stalk lodging (Table 5.16). The phenotypic correlation between grain yield and stay green characteristic (SGC) was r_p= -0.12*, ASI r_p= -0.08*, EPP r_p= 0.16**, PASP r_p= -0.26**, and EASP r_p= -0.32** indicating that the variation in grain yield explained by these traits was very small. The values for genotypic correlations were generally larger than the phenotypic correlations. Grain yield showed significant negative genetic correlations with plant aspect (r_g= -0.91**), ear aspect (r_g= -1.00**), SGC (r_g= -0.80**) and significant positive genetic correlations with ears per plant (r_g= 0.99**). Other large-to-moderately large and significant genotypic correlation coefficients (r_g) observed were days to anthesis with days to silking; days to silking with ASI, EASP, EPP and SGC; ASI with EASP and SGC; PHT with HC, PASP, EASP and SGC; HC with PASP, EASP and SGC; PASP with EASP, EPP and SGC; EASP with EPP and SGC; and EPP with SGC.

Table 5.16: Estimates of genotypic (above diagonal) and phenotypic (below diagonal) correlation coefficient for grain yield and other agronomic traits of maize inbred lines evaluated under drought stress in Bagauda, Ikenne and Minjibir in 2013 and 2015.

	Yield	DA	DS	ASI	PLHT	EHT	RL	SL	HC	PASP	EASP	EPP	SGC
Yield		-0.17	-0.33	-0.82	0.50	1.00	-1.00	-1.00	-0.74*	-0.91**	-1.00**	0.99**	-0.80**
DA	-0.17**		0.97**	0.29	0.07	0.54	0.44	0.19	0.07	0.24	0.47*	-0.49**	0.33
DS	-0.20**	0.84**		0.51*	-0.11	0.24*	0.46	0.22	0.22	0.30	0.58**	-0.61**	0.45**
ASI	-0.08*	-0.17**	0.40**		-0.79	-1.00	0.33	0.02	0.71	0.37	0.70*	-0.71	0.74*
PHT	0.22**	-0.44**	-0.45**	-0.08*		-0.38	-0.48	-0.59	-0.57*	-0.72**	-0.96**	0.27	-0.66**
EHT	0.15**	-0.39**	-0.37**	-0.01	0.68**		-1.00	-0.77	0.98	-0.96	-1.00	-0.22	-0.75
RL		-0.06*	-0.05	0.02	0.10**	0.07*		-1.00	0.70	0.64	0.20	0.29	-0.10
SL	0.03	-0.07*	-0.15**	-0.15**	0.07*	0.05	0.22**		1.00	1.00	0.12	-0.48	0.90
HC	-0.21**	0.28**	0.29**	0.05	-0.48**	-0.22**	-0.13**	-0.01		0.60**	1.00**	-0.44*	0.89**
PASP	-0.26**	0.33**	0.34**	0.05	-0.47**	-0.28**	0.00	0.01	0.49**		0.73**	-0.54**	0.80**
EASP	-0.32**	0.19**	0.27**	0.17**	-0.37**	-0.08*	0.04	-0.03	0.42**	0.42**		-0.71*	0.59**
EPP	0.16**	-0.25**	-0.29**	-0.10**	0.30**	0.21**	0.02	0.03	-0.23**	-0.24**	-0.28**		-0.60**
SGC	-0.12**	0.05	0.12**	0.12**	-0.24**	-0.01	0.00	0.08*	0.38**	0.36**	0.44**	-0.17**	

DA, days to anthesis; DS, days to silking; ASI, anthesis-silking interval; PLHT, plant height; EHT, ear height; RL, root lodging; SL, stalk lodging; HC, husk cover; PASP, plant aspect; EASP, ear aspect; EPP, ears per plant SGC, stay green characteristic; *, **, Significant at 0.05 and 0.01probability levels, respectively,

5.3.6.1. Relative importance of secondary traits to grain yield under *Striga* infestation and drought

Under drought, the stepwise multiple regression analysis identified EASP, EHT, DYSK, PASP and PLHT as the important traits with significant direct contribution to grain yield. These traits explained about 72% of the variation in grain yield (Fig. 5.5). Among the five primary traits, ear aspect had the highest direct effect (-0.786) on grain yield. Only EHT and PLHT had positive direct effects on grain yield. Six traits (HC, EPP, STGR, DA, SL, ASI) were identified in the second-order, only DA contributed indirectly to yield through four of the five first-order traits. Also, days to 50% anthesis had the highest positive indirect contribution through days to 50% silking. The indirect contribution of the remaining five secondary traits are clearly illustrated in Fig. 5.5. Only root lodging was identified in the third-order as having positive indirect contribution through stalk lodging.

In the *Striga* environments, EASP and RAT 2 were identified by step-wise multiple regression analysis as the primary traits, accounting for 80% of the total variation in grain yield (Fig. 5.6). Six traits (RAT 1, HUSK, EPP, PLHT, CO_1, and CO_2) were identified as the second order contributors to grain yield with RAT 1 and EPP being the only secondary traits that contributed indirectly to grain yield through all the primary traits. Four traits were grouped into third order and only ear height and days to 50% silking contributed indirectly to yield through four of the six secondary traits. Only DA was identified in the fourth order having indirect effect through three of the third-order traits.

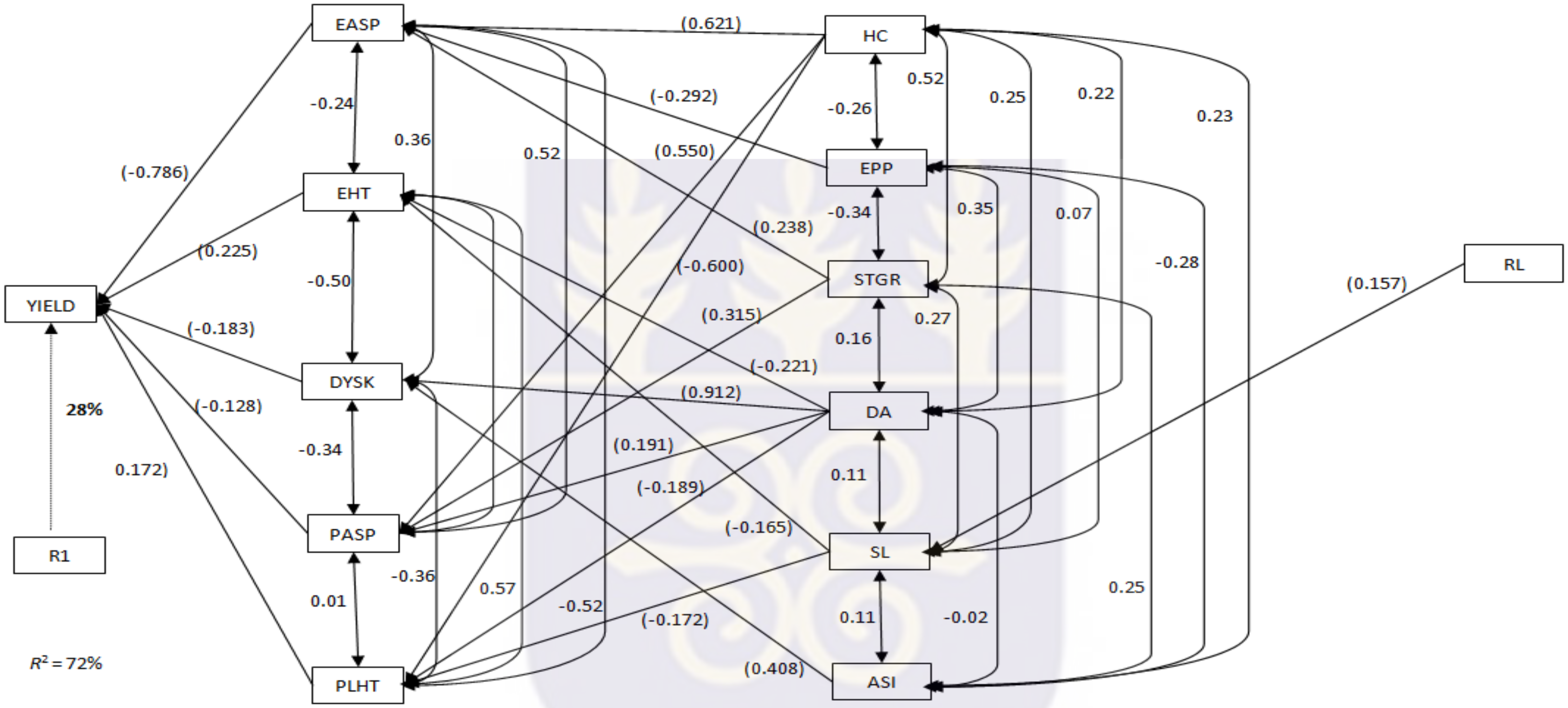


Figure 5.5: Path analysis diagram displaying relationship of measured traits of early maturing inbred lines screened under drought at Ikenne, Minjibir and Bagauda, 2013 and 2015.

Bold value is the residual effect; values in parenthesis are direct path coefficients while other values are correlation coefficients. R1 is residual effects; ASI, anthesis-silking interval; DA, days to 50% anthesis; DYSK, days to 50% silking; EASP, ear aspect; EPP, ears per plant; HC, husk cover; PASP, plant aspect; PLHT, plant height; EHT, ear height; RL, root lodging; SL, stalk lodging; STGR, stay green characteristic and YIELD, grain yield

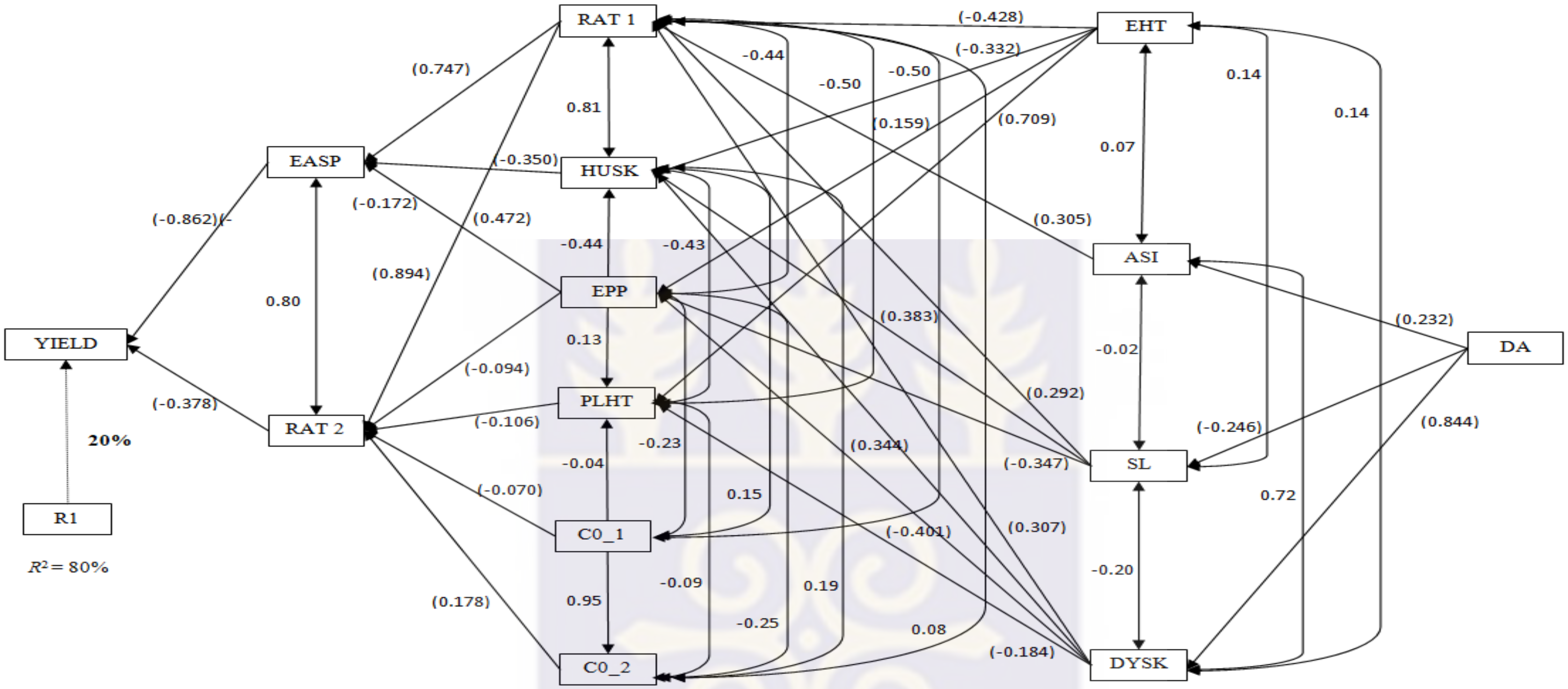


Figure 5.6: Path analysis diagram displaying relationship of measured traits of early maturing inbred lines screened under artificial Striga infestation at Abuja and Mokwa, 2013 and 2015.

Bold value is the residual effect; values in parenthesis are direct path coefficients while other values are correlation coefficients. R1 is residual effects; ASI, anthesis-silking interval; DA, days to 50% anthesis; DYSK, days to 50% silking; EASP, ear aspect; EPP, ears per plant; HUSK, husk cover; PASP, plant aspect; PLHT, plant height; EHT, ear height; RAT 1 and RAT 2, Striga damage score at 8 and at 10 WAP; CO_1 and CO_2, number of emerged Striga plants at 8 and at 10 WAP; RL, root lodging; SL, stalk lodging and YIELD, grain yield

5.3.7 Heterotic grouping of the early maturing inbred lines

The result of the dendogram constructed based on the HGCAMT (Fig. 5.7), showed four heterotic groups. Group 1 consisted of TZdEI 71, TZdEI 98, TZdEI 378 and TZdEI 479. group 2 comprised of TZdEI 124, TZdEI 131, TZdEI 84, TZdEI 314, TZdEI 280, TZdEI 485, TZdEI 202, TZdEI 352, TZEI 7, TZEI 31, TZdEI 283, TZEI 18 and TZdEI 264, group 3 is made up of TZdEI 399, TZdEI 268, TZdEI 120, TZdEI 357, TZdEI 157, TZdEI 396, TZdEI 82, TZdEI 105 and TZdEI 441 ; while TZdEI 260, TZdEI 315, TZdEI 492 and TZdEI 173 constituted group 4 (Fig 5.7). Group 1 and 2 comprises of lines with varied reaction to *Striga* and drought. About 55% and 44% of white lines in group 3 were tolerant to *Striga* and drought, while group 4 had 25% and 50% *Striga* resistant and drought tolerant lines.

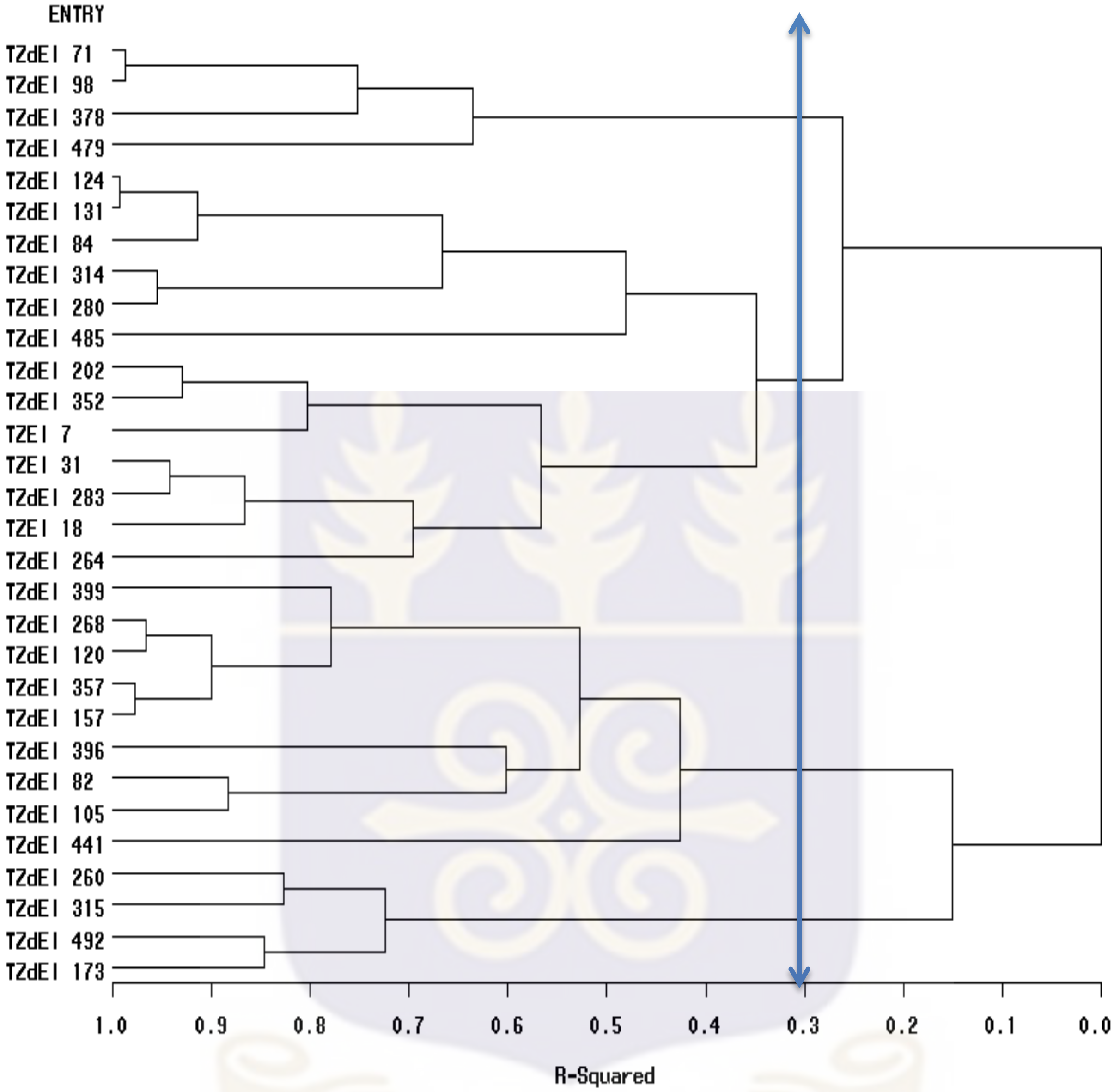


Figure 5.7: Dendrogram of 30 early maturing maize inbreds constructed from GCA effects of multiple traits (HGCAMT) using cluster analysis based on Ward's minimum variance across research environments.

5.4 Discussion

The significant genotypic mean squares for most measured traits under *Striga* infestation, and all traits under drought stress and optimal growing conditions indicated that there was large genetic variation among the hybrids which should allow progress from selection for *Striga* resistance, induced drought stress tolerance and improved grain yield under the three contrasting environments. The significant mean squares of the environment for all traits under *Striga* infestation, drought and optimal growing conditions indicate that the environments were unique in discriminating among the hybrids and highly variable, implying the need for testing in more than one environment over several years for each of the contrasting environments as reported by Badu-Apraku *et al.* (2007a, 2011a).

The significant genotype x environment interaction mean squares for grain yield, *Striga* damage and number of emerged *Striga* plants under *Striga* infestation is an indication that the hybrids varied in their response to *Striga* infestation at the different sites suggesting that the biotypes of *S. hermonthic*a at the different sites could be different. Several authors in WCA have reported similar result (Yallou *et al.*, 2009; Menkir *et al.*, 2010; Badu-Apraku and Lum, 2010; Badu-Apraku *et al.*, 2010). The highly significant interactions between genotype x environment for grain yield and other traits under drought and optimal growing environments was an indication that the environment influenced the expression of the hybrids in the different drought environments for the traits. This provided a justification for evaluating the hybrids across the two distinct environments in an effort to identify those with consistent performance across the environments. These results are consistent with the findings of Badu-Apraku *et al.* (2011b) and Badu-Apraku and Oyekunle (2012). The average yield reduction of the hybrids under *Striga* infestation was 44% relative to performance under optimal environments. This is quite similar to the results of Badu-Apraku *et al.* (2004a) and Ifie *et al*. (2015) who reported yield reduction of 42% and 44%, respectively, under similar conditions. However, it is lower than the 53.7% reported by Adetimirin *et al.* (2000), 68% by Kim *et al.* (2002), 65% by Badu-Apraku *et al.* (2010) and 55% by Akaogu *et al*. (2012). It is, however, higher than the yield reduction of 23% reported by Badu-Apraku *et al.* (2011b). The yield reduction of 47% suggested that the intensity of infestation in this study was high enough to allow the identification of hybrids that possessed genes for *Striga* resistance/tolerance.

Despite the high severity of infestation in this study, the novel *Striga* resistance genes from the wild relatives of maize, *Zea diploperennis,* in the genotypes allowed them to suppress the emergence of the *Striga* plants and produced high yields. The high yield of the hybrids under *Striga* infestation was accompanied by reduced number of emerged *Striga* plants as well as reduced *Striga* damage. Also, the average yield reduction of 59% under drought indicated that the levels of drought imposed during flowering and grain-filling were severe enough to allow selection for drought tolerance among the hybrids. The yield reduction observed under drought was within the range reported by other researchers (Nesmith and Ritchie, 1992; Badu-Apraku *et al*., 2011b; Akaogu *et al*., 2017). Under drought, the reduction in grain yield was accompanied by a decrease in ASI, barrenness, stay green characteristic, and poor plant and ear aspects. These results are consistent with those of earlier scientists (Bolanos *et al*., 1993; Edmeades *et al*., 1995) who reported that ears per plant and ASI are important secondary traits when selecting for drought tolerance and yield potential in tropical maize.

The relatively high heritability (> 60%) obtained for days to 50% anthesis and silking, ear height, *Striga* damage rating, number of emerged *Striga* plants and ear aspect under *Striga* infestation; grain yield, days to silking and anthesis, plant height, plant and ear aspect under optimal conditions indicated that these traits could be easily transferred and direct phenotypic selection could also be done since additive gene action was more important in the inheritance of the traits more than the non-additive genetic effects. On the other hand, the relatively low heritability estimates obtained for grain yield, plant height, ear and plant aspect, ears per plant under drought; grain yield, anthesis-silking interval and ears per plant under *Striga*-infested indicated that direct phenotypic selection for these traits may not be effective suggesting the use of indirect selection or secondary traits to determine the underlying genetic merits of the traits as suggested by Mhike *et al*. (2011).

The significant GCA-male, GCA-female and SCA for grain yield and other agronomic traits except for ASI under *Striga* infestation suggested that the performance of the inbreds differed when used as either male or female parents in hybrid combinations. This also suggested that additive and non-additive gene actions were important in the inheritance of grain yield and other measured traits under *Striga* infestation. The high GCA over SCA mean squares for *Striga* damage and number of emerged *Striga* plants under *Striga* infestation indicated that additive gene action was more important in controlling both host plant damage and number of emerged *Striga* plants. The results of this study are, in part, contradictory to the findings of Gethi and Smith (2004), Badu-Apraku *et al*. (2007a) who showed that non-additive gene action was more important than additive gene action in controlling the inheritance of host plant damage, while additive gene action was more important in controlling the number of emerged *Striga* plants. Furthermore, the findings of this study are contradictory to the results of Kim (1994), Akanvou *et al*. (1997); Badu-Apraku *et al*. (2007b) who reported that additive gene action controlled *Striga* damage while non-additive gene action controlled the number of emerged *Striga* plants. The discrepancy in this results and those of the earlier authors may be attributed to the fact that the early maturing inbreds used in the present study were derived from two diverse germplasm sources, which might possess some genes with different modes of action for *Striga* resistance.

Under drought and optimal growing condition, the significant GCA-male, GCA-female and SCA for grain yield and other agronomic traits except SCA for ASI, was an indication that the inbred lines responded differently when used as either male or female parents in hybrid combinations. This implied that additive and non-additive gene actions were important in the inheritance of grain yield and most measured traits except ASI. These results revealed consistent trends in the mode of gene action controlling the inheritance of resistance to *Striga* and tolerance to drought in the set of early maturing inbred lines studied. Additive gene action was more important than non-additive gene action for grain yield and most measured traits observed under both stresses. Similar results have been reported for resistance to *Striga* and tolerance to drought in early white (Badu-Apraku *et al.*, 2011b) and extra-early maturing maize inbreds (Badu-Apraku and Oyekunle, 2012, Akaogu *et al.*, 2012, 2017). This implied that appreciable breeding progress could be made using breeding methods which capitalize on additive gene action such as the S_1 family recurrent selection, backcrossing and hybridization for the development of drought tolerant cultivars, and synthetics as well as for population improvement. This is in support of the results of Vasal *et al*. (1992) and Zambezi *et al*. (1994).

The significant GCA-male x environment and GCA-female x environment interactions for grain yield and most measured traits under *Striga* infestation and drought, indicated that there is significant variation in the combining ability of the lines across the *Striga* and drought environments. This suggested that the selection of *Striga* resistant/tolerant and drought tolerant hybrids would be more reliable if based on performance across a range of *Striga* environments. The significant SCA x environment interaction effects for grain yield, days to 50% anthesis, *Striga* damage, number of emerged *Striga* plants and ear aspect indicated that the response of the hybrids with respect to these traits varied in the *Striga* infested environments. This result is consistent with those of Badu-Apraku *et al.* (2013b). Similarly, the significant SCA x environment interactions for grain yield and other agronomic traits except ASI under drought indicated that the expression of these traits in specific hybrids would vary in the different drought environments. This is also consistent with the findings of several authors (Badu-Apraku and Oyekunle 2012).

In this study, the percentage contributions of GCA-male and GCA-female effects did not significantly vary for grain yield and other traits under *Striga*-infested, drought and optimal growing conditions which implied that maternal or cytoplasmic genes did not have any influence on these traits. Derera *et al*. (2008) reported maternal effects for grain yield under drought, and anthesis-silking interval, prolificacy and ear aspect under drought and non-drought environments in maize hybrids. Similarly, Jumbo and Carena (2012) reported maternal effects for ear height in elite early maturing maize population hybrids. Furthermore, Ifie (2013) reported maternal effects for days to silking and paternal effects for ears per plant in early maturing maize hybrids under *Striga* infested environments.

Inbred lines TZdEI 268, TZdEI 352 and TZdEI 173 had superior positive GCA (GCA-male and/or GCA-female) effects for grain yield under *Striga* infestation indicating that the inbred lines contributed to higher grain yield in their hybrids under *Striga* infestation. TZdEI 492 and TZdEI 378 had superior positive GCA effects for grain yield under drought environments suggesting that the inbred lines contributed to higher grain yield of their hybrids under drought while TZdEI 260, TZdEI 396, TZdEI 479 and TZdEI 173 had superior positive GCA effects for grain yield under optimal environments. These inbred lines are expected to contribute higher grain yield to their hybrids under optimal environments. The inbred lines identified with significant positive GCA effects for grain yield would likely contribute favorable alleles in a recurrent selection program and such lines could be used as parents to form a synthetic population that could be improved for *Striga* resistance and drought tolerance if the heterotic orientations are taken into consideration to avoid mixing up of heterotic groups. Subsequently, new inbred lines with improved levels of *Striga* resistance and drought tolerance could be extracted from the improved populations following cycles of recurrent selection.

Using the base indices, TZdEI 173 x TZdEI 352 showed good performance under both *Striga* infestation and drought stress. This result is interesting and encouraging as *Striga* and drought stress occur simultaneously in the savannas of WCA and farmers in the sub-region are requesting hybrids with combined resistance/tolerance to the two stress factors. The superior yielding hybrids identified in this study should be evaluated extensively in contrasting environments in multi-location and on-farm trials to confirm the superior performance and release to farmers in WCA for production.

The mid-parent and high parent heterosis values for grain yield were higher under drought than under *Striga*-infested environments. The average mid- and high- parent heterosis for grain yield was 96% and 73% under *Striga* infestation; 267% and 191% under drought. The positive values obtained for grain yield indicated that the hybrids produced more grain yield than their inbred parents. Negative mid- and high- parent heterosis values obtained for days to 50% anthesis and silking indicate that the hybrids flowered earlier than their corresponding inbred parents under both drought and *Striga*-infested environments. This is in support of the results of Meseka *et al.* (2006), who reported negative heterotic values for days to silking and positive values for plant height and grain yield under low and high nitrogen environments. Also, the positive mid- and high- parent heterosis for *Striga* damage and number of emerged *Striga* plants at 8 and at 10 WAP indicated that the hybrids suffered higher *Striga* damage and allowed the emergence of more *Striga* plants than their corresponding parental lines.

Another objective of this study was to examine the relationships among the measured traits under the contrasting environments. Phenotypic and genotypic correlation analysis provides information on the type, strength and direction of the relationship between a pair of traits. In contrast, sequential path analysis provides information on cause and effect relationships among traits by identifying traits with significant contributions to grain yield and ranking them as first and second order traits in decreasing order of their relative importance in explaining the observed variation in grain yield. The traits identified in the first order are considered as traits of value, while the second order traits are considered as traits of potential importance (Badu-Apraku *et al*., 2014; Talabi *et al*., 2016). In this study, phenotypic and genotypic correlations as well as sequential path analysis were employed to provide an insight into the inter-trait relationships among the measured traits. The significant genotypic correlation suggested that there was genetic relationship between most of the traits studied. The negative genotypic correlations between grain yield and days to silking and anthesis as well as *Striga* damage at 8 and 10 WAP were expected because *Striga* affects the growth and development and grain yield of infested plants. The negative correlations between grain yield and flowering traits could be due to the intensity of artificial *Striga* infestation on the hybrids. The significant negative phenotypic correlations between grain yield and *Striga* damage at 8 and 10 WAP suggested a negative relationship between the two traits. This result corroborated the findings of Amusan *et al*. (2008), Badu-Apraku *et al*. (2012a) and Karaya *et al*. (2012). The positive phenotypic and genotypic correlations between *Striga* damage at 8 and 10 WAP and number of emerged *Striga* plants at 8 and at 10 WAP suggested that either of the parameters will suffice as a selection parameter for the evaluation of genotypes for *Striga* resistance. Considering the resources and time involved in taking *Striga* damage and number of emerged *Striga* plants, this result suggested that the data for these traits may be taken at either 8 or 10 WAP without any serious loss of precision. This result is consistent with the findings of Badu-Apraku (2007).

The high negative genotypic and moderate phenotypic correlations between grain yield and *Striga* damage at 8 and 10 WAP suggested that selection for high grain yield and *Striga* resistance under artificial *Striga* infestation could be realized in the breeding program. The positive phenotypic and genotypic correlations obtained between *Striga* damage and number of emerged *Striga* plants at 8 WAP, on one hand, *Striga* damage and number of emerged *Striga* plants at 10 WAP on the other, suggested that *Striga* resistance was not controlled by the number of *Striga* plants attached to the host and that several genes regulate *S. hermonthica* emergence and severity of host plant damage in maize. This result corroborated the findings of other researchers Kim (1994); Akanvou *et al*. (1997) and Badu-Apraku (2007). The generally low phenotypic and genetic correlations between grain yield and the number of emerged *Striga* plants implied that the two traits were genetically independent and could be improved separately. This results suggested that *Striga* damage should be preferred to number of emerged *Striga* plants for selection for high grain yield and *Striga* resistance/tolerance because of the high heritability estimates and the negative phenotypic and genotypic correlations between grain yield and *Striga* damage at 8 and 10 WAP.

However, for maximum gain from selection for increased grain yield and resistance to *Striga*, a combination of host plant damage and number of emerged *Striga* plants should be used to improve the two traits simultaneously. Similar findings in *Sorghum bicolor* was reported by

Haussmann *et al*. (2000). Selection for host damage and number of emerged *Striga* plants could be effectively carried out simultaneously using an appropriate selection index under *Striga*-infested and non-infested environments. Overall, grain yield had significant phenotypic correlations with all the traits used in computation of the base indices for selection of *Striga* resistant varieties.

Under drought environments, the negative genotypic and phenotypic correlations between grain yield and flowering traits as well as the stay green characteristic suggested that the level of drought stress imposed was very severe and high enough to elicit differences between the germplasm in terms of tolerance and susceptibility to drought. In this study, the strong genotypic correlation between grain yield and ASI, PASP, EASP as well as SGC justified their addition in the IITA base index for increased yield under drought conditions.

Ear aspect was identified as the most important trait contributing to the differences in grain yield under *Striga*-infested and drought, thus, confirming its reliability as a secondary trait for indirect selection under the both research conditions.

It is striking to note that five hybrids (TZdEI 173 x TZdEI 280, TZdEI 82 x TZdEI 260, TZdEI 98 x TZdEI 352, TZdEI 441 x TZdEI 260, and TZdEI 492 x TZdEI 441) were identified by AMMI biplots as high yielding and stable across the research environments as well as under *Striga* infestation. Also three hybrids (TZdEI 396 x TZdEI 264, TZdEI 71 x TZdEI 396 and TZdEI 157 x TZdEI 280) were identified among the top 25 highest yielding under drought environments as well as across research conditions. In addition, TZdEI 71 x TZdEI 268, TZdEI 260 x TZdEI 396 and TZdEI 173 x TZdEI 280 were selected based on their yield performance across contrasting environments. These hybrids should be extensively tested in on-farm trials in WCA to confirm the consistency in performance and vigorously promoted for adoption and commercialization to contribute to food security and improved livelihoods of resource poor farmers in the sub-region.

The set of inbreds were classified into four heterotic groups using the GCA effects of multiple traits. The inbreds in each heterotic group may be recombined to form *Striga* resistant and drought tolerant populations which could be improved through recurrent selection.

5.5 Conclusions

A total of 156 single cross hybrids were screened under *Striga* infested, drought and optimal environments in an effort to determine their combining abilities and the mode of gene action conditioning *Striga* resistance and tolerance to drought, classify the inbred lines into heterotic groups, identify outstanding hybrids with consistent performance across the three contrasting environments and examine the trait relationships. *Striga* infested, drought and optimal environments were highly variable and unique in discriminating among the hybrids. The genetic differences among the hybrids was enough to allow the selection of *Striga* resistant/tolerant and drought tolerant hybrids. The preponderance of GCA over SCA mean squares for most of the traits under *Striga*-infested and optimal environments indicated that additive gene action was more important than non-additive gene action for the measured traits although both GCA and SCA effects accounted for the differences among the 156 hybrids evaluated in this study. In contrast both additive and non-additive gene action were important for yield and other agronomic traits under drought environments. The maternal or cytoplasmic genes did not have any influence on the inheritance of grain yield and other agronomic traits under the contrasting research conditions (*Striga*-infested, drought and optimal growing environment).

Three inbred lines (TZdEI 268, TZdEI 479 and TZdEI 485) with significant negative GCA (GCA-male and GCA-female) effects for number of emerged *Striga* plants under *Striga* infestation would be useful in contributing favorable alleles for breeding for *Striga* resistance in tropical germplasm. Inbreds TZdEI 173 and TZdEI 352 had significant positive GCA effects for grain yield and produced one of the highest yielding hybrids under *Striga* infestation indicating they would contribute favourable alleles for breeding for improved grain yield under *Striga*. The inbreds, TZdEI 492 and TZdEI 378 with significant positive GCA (GCA-male and GCA-female) effects for grain yield and TZdEI 479 with significant positive GCA-female and TZdEI 260 with significant positive GCA-male for grain yield under drought would be useful in contributing favorable alleles for breeding for tolerance to drought. These lines identified as outstanding under both stresses, could contribute favourable alleles when used in breeding for high grain yield under drought and *Striga* infestation.

The additive main effects and multiplicative interaction analysis identified TZdEI 173 x TZdEI 280, TZdEI 173 x TZdEI 492, TZdEI 441 x TZdEI 260, TZdEI 82 x TZdEI 260, TZdEI 71 x TZdEI 396, TZdEI 396 x TZdEI 131, TZdEI 396 x TZdEI 264, TZdEI 98 x TZdEI 352, TZdEI 157 x TZdEI 352, TZEI 18 x TZdEI 357, TZdEI 268 x TZdEI 378, TZdEI 157 x TZdEI 280, TZdEI 492 x TZdEI 441 and TZEI 60 x TZEI 5 as the highest yielding and stable hybrids across the three contrasting research environments. These hybrids should be tested in multi-location and on-farm trials to confirm the consistency in performance and promoted for release and commercialization in the sub-region. These hybrids will be useful in *Striga* endemic and drought prone areas of the sub-region. High yielding hybrids (TZdEI 173 x TZdEI 352, TZdEI 173 x TZdEI 280, TZdEI 352 x TZdEI 315, TZdEI 71 x TZdEI 268, TZdEI 82 x TZdEI 260, TZdEI 260 x TZdEI 268, TZdEI 357 x TZdEI 82, TZdEI 314 x TZdEI 105, TZdEI 378 x TZdEI 173, TZdEI 268 x TZdEI 105 and TZdEI 268 x TZdEI 131) with reduced *Striga* emergence and host plant damage were identified.

The sequential path analyses identified ear aspect as the most reliable secondary trait for indirect selection for grain yield under both *Striga*-infested and drought conditions. The significant phenotypic correlation between grain yield with *Striga* damage at 8 and 10 WAP, number of emerged *Striga* plants at 8 and 10 WAP, and ears per plant justified their inclusion in the base index as secondary traits for indirect selection for grain yield under *Striga* infested environments. Also, the significant genotypic and phenotypic correlation between grain yield and anthesis-silking interval, plant aspect, ear aspect and stay green characteristic justified their addition in the base index for selection for grain yield under drought environments.

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1. General Conclusions

Striga hermonthica parasitism, stem borers, low inherent soil feritilty and recurrent drought, are the major limiting factors to maize production and productivity in the savanna agro-ecologies of WCA which have the highest yield potential because of high incoming solar radiation, low night temperature and low severity of pest and diseases. Severe yield reduction is obtained when the stresses occur simultaneously in the field. The genetic relatedness of the 36 early maturing maize inbred lines with the novel *Striga* resistance genes from the wild relatives *Zea diploperennis* were assessed using SNP markers. The mode of inheritance to *Striga* resistance in an early maturing tropical maize inbred line, TZdEI 352 containing genes for *Striga* resistance from *Zea diploperennis* was determined using generation mean analysis. A total of 156 single cross hybrids generated using the NC II design were evaluated under *Striga*-infested, drought and optimal growing conditions in Nigeria for two years. The objectives were to determine the genetic diversity, mode of inheritance and combining ability for grain yield and heterotic groups of the early maturing maize inbreds under contrasting environments, identify high yielding and stable hybrids with combined *Striga* resistance and drought tolerance genes.

The findings of this study are summarized as follows:

There was correspondence between the cluster analysis and population structure analysis in grouping the early maturing inbred lines into four distinct classes using the information based on their genetic distance.

Based on the base indices as selection criteria, 42% and 50% of the inbred lines were identified as drought tolerant and *Striga* resistant respectively while 22% of the lines combined resistance/tolerance to both *Striga* and drought.

Inheritance study showed that epistasis played an important role in *Striga* resistance genes from *Zea diploperennis* in tropical maize. Also, resistance to *Striga hermonthica* is site/location specific.

Striga parasistism reduced grain yield by 47% relative to yield under optimal environments suggesting that the level of infestation was high enough to elucidate hybrids that possessed novel *Striga* resistance genes from the wild relative *Zea diploperennis.* The grain yield reduction of hybrids under drought was 59% of the optimal environments indicating that the drought stress imposed from 4 weeks after planting till physiological maturity was adequate to elicit the genetic variation among the hybrids.

General combining ability (GCA) effects were greater than specific combining ability (SCA) effects for most traits under *Striga*-infested and optimal growing conditions suggesting that additive gene action was more important than non-additive gene action in the 30 early maturing inbreds. In addition, additive gene action was as important as non-additive gene action under drought conditions.

Broad sense heritability ranged from 30% for grain yield to 67% for days to anthesis, *Striga* damage at 10 WAP and number of emerged *Striga* plants at 8 WAP under *Striga* infestation, and 29% for plant height to 55% for grain yield under drought. This result indicated that many of these traits can be readily transmitted from the parents to their offspring and direct phenotypic selection can be done since there was preponderance of additive gene effects for most of the measured traits.

The 30 inbred lines were classified into four heterotic groups based on the GCA effects of multiple traits of the inbreds.

Inbred lines TZdEI 173, TZdEI 352, TZdEI 268, TZdEI 479 and TZdEI 485 showed significant positive GCA effects for grain yield and significant negative GCA effects for number of emerged *Striga* plants under *Striga* infestation while inbreds TZdEI 492, TZdEI 378, TZdEI 479 and TZdEI 260 showed positive GCA effects for grain yield under drought. These inbred lines would contribute favorable alleles for *Striga* resistance and drought tolerance which could be introgressed into the breeding populations of national maize programs of West and Central Africa for improvement.

Maternal or cytoplasmic genes did not have any influence on the inheritance of grain yield and other agronomic studied traits under *Striga*-infested, drought and optimal growing environments.

6.2 Recommendations

The findings from this study will help plant breeders understand how to use the inbred lines in other breeding activities such as selecting parental lines for hybrid seed production, classification into heterotic groups and creating a core set of germplasm.

The schemes used in this study can be exploited by other breeder for efficient parental lines and hybrid production under drought, *Striga*-infested and optimal growing conditions in the sub-region.

The inbred lines identified with combined resistance/tolerance to *Striga* and drought would contribute favourable alleles for introgression of genes for resistance/tolerance to both stresses in hybrid production, population improvement and inbred lines recycling.

The ten hybrids (TZdEI 173 x TZdEI 280, TZdEI 82 x TZdEI 260, TZdEI 98 x TZdEI 352, TZdEI 441 x TZdEI 260, TZdEI 492 x TZdEI 441, TZdEI 396 x TZdEI 264), (TZdEI 71 x TZdEI 396, TZdEI 157 x TZdEI 280, TZdEI 71 x TZdEI 268, and TZdEI 260 x TZdEI 396) identified as high yielding and stable under the individual research conditions and across environments should be tested extensively in on-farm trials to confirm the consistency of performance and promoted for release and commercialization in the sub-region. Also, they would be useful as female parents for the development of three-way or double cross hybrids.

The inbred lines that showed positive GCA effects for grain yield under *Striga*-infested and drought environments as well as negative GCA effects for *Striga* damage, number of emerged *Striga* plants and stay green characteristics could be used in pedigree selection to develop synthetic populations and high yielding hybrids with combined resistance/tolerance to *Striga* and drought.

Inbred TZdEI 352 was identified as a tester and could be used in classifying other tropical early maturing inbred lines into heterotic groups.

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APPENDICES

Appendix 5.11: Performance of 156 single cross hybrids under *Striga* infestation (STR) and optimal (OPT) environment

Hybrid	**Grain yield (kg ha^{-1})**		***Striga* damage**		***Striga* emergence**		**Ear aspect**		Base Index
	STR	**OPT**	**8 WAP**	**10 WAP**	**8 WAP**	**10 WAP**	**STR**	**OPT**	
TZdEI 399 x TZEI 7	3881	5297	2.83	3.67	2.66	3.49	4.50	4.45	4.40
TZdEI 378 x TZdEI 98	3966	4969	2.50	4.17	3.62	3.91	4.67	4.55	4.24
TZdEI 173 x TZdEI 492	4495	7184	3.83	4.50	3.37	3.77	3.83	3.55	3.92
TZdEI 314 x TZdEI 131	3306	5131	3.00	4.00	2.99	3.45	4.67	4.60	3.89
TZdEI 399 x TZdEI 396	3609	5298	2.50	4.17	3.06	3.65	4.33	4.25	3.85
TZdEI 98 x TZdEI 357	3845	4760	3.00	4.17	3.30	3.69	4.83	4.50	3.85
TZdEI 82 x TZdEI 124	3661	5205	3.50	4.00	2.41	2.86	5.00	4.60	3.78
TZdEI 173 x TZdEI 357	3781	5737	3.50	4.33	3.02	3.51	4.67	4.30	3.76
TZdEI 352 x TZdEI 441	3997	5331	3.83	4.00	2.69	3.17	4.50	4.55	3.71
TZdEI 396 x TZdEI 131	3867	6680	3.00	4.17	3.61	3.94	5.17	4.15	3.71
TZdEI 71 x TZdEI 314	3753	6064	3.17	4.17	2.92	3.22	4.83	4.40	3.71
TZdEI 357 x TZdEI 77	3483	7058	3.83	4.83	1.81	3.11	4.50	4.30	3.57
TZdEI 283 x TZdEI 280	3780	5856	3.17	4.17	3.13	3.50	4.67	4.65	3.39
TZdEI 157 x TZdEI 352	3963	5840	2.83	4.17	3.40	3.56	4.50	4.25	3.30
TZdEI 357 x TZdEI 441	3634	5471	3.00	3.50	2.83	3.49	4.67	4.30	3.27
TZdEI 268 x TZdEI 378	3616	5988	3.33	4.67	3.03	3.37	4.33	4.25	2.97
TZdEI 98 x TZdEI 492	3868	5877	3.50	4.17	3.30	3.57	4.83	3.95	2.96
TZdEI 264 x TZdEI 173	3814	5330	3.17	4.50	3.07	3.38	5.00	4.65	2.78
TZdEI 260 x TZdEI 396	3411	7769	4.17	5.00	1.45	2.70	4.67	4.60	2.72
TZdEI 492 x TZdEI 82	4101	6253	4.67	5.00	2.47	2.69	4.33	4.40	2.71
TZdEI 77 x TZdEI 260	3394	6622	4.17	5.33	1.71	2.42	5.00	4.30	2.59
TZdEI 399 x TZdEI 268	3041	4306	3.17	4.00	2.59	3.12	4.50	4.70	2.55
TZdEI 396 x TZdEI 264	3680	6018	3.67	4.50	3.49	3.71	4.67	4.30	2.52
TZdEI 124 x TZdEI 396	3684	5731	3.33	4.33	3.65	3.83	5.33	4.45	2.47
TZdEI 202 x TZdEI 268	3129	6187	4.17	4.50	2.28	2.82	5.00	4.15	2.33
TZdEI 71 x TZdEI 396	3404	6601	3.00	4.50	2.74	3.26	5.00	4.15	2.31
TZdEI 492 x TZdEI 211	3080	7723	3.83	5.17	1.57	2.50	5.33	4.10	2.12
TZdEI 120 x TZdEI 98	3560	4811	3.83	4.50	2.32	2.78	4.67	4.60	1.93
TZdEI 314 x TZdEI 120	3109	4827	3.83	4.67	2.81	3.06	5.00	4.50	1.41
TZdEI 124 x TZdEI 314	3314	4574	3.33	4.50	3.77	4.09	5.17	4.50	1.28
TZdEI 211 x TZdEI 71	2903	6043	4.17	5.17	1.83	2.46	5.17	4.60	1.20
TZdEI 268 x TZdEI 264	3737	5330	4.33	5.17	2.65	3.07	5.00	4.25	1.10
TZdEI 280 x TZdEI 82	3738	6046	4.33	4.83	2.49	3.23	5.17	4.40	1.06
TZdEI 260 x TZdEI 314	2860	6823	4.17	5.50	1.82	2.48	5.17	4.90	0.96
TZdEI 357 x TZdEI 211	2993	7311	3.50	4.83	2.32	3.38	5.17	4.60	0.87
TZdEI 131 x TZdEI 173	3532	5971	3.50	4.50	3.31	3.58	5.00	4.35	0.76
TZdEI 441 x TZdEI 399	3045	5359	3.50	4.50	3.29	3.77	5.17	4.40	0.67
TZdEI 283 x TZdEI 84	3054	5557	3.67	4.83	3.34	3.54	5.17	4.35	0.54
TZdEI 77 x TZdEI 202	2443	5410	4.33	5.33	1.45	1.96	5.17	4.60	0.48
TZdEI 157 x TZdEI 492	3451	5624	3.83	4.83	3.32	3.87	4.50	4.05	0.38
TZdEI 211 x TZdEI 399	2579	4897	3.83	4.67	2.10	2.61	5.00	5.20	0.34
TZdEI 315 x TZdEI 399	3291	5759	4.00	4.33	3.85	4.07	4.83	4.15	0.34
TZdEI 315 x TZdEI 124	2876	5380	4.17	4.50	2.55	2.92	5.00	5.40	0.17
TZdEI 315 x TZdEI 260	3191	5816	4.00	5.00	3.19	3.79	5.17	4.40	-0.18
TZdEI 396 x TZdEI 120	3055	5797	4.00	4.83	3.05	3.19	5.00	4.10	-0.20
TZdEI 314 x TZdEI 264	2947	5200	3.83	5.00	3.35	3.46	5.17	3.95	-0.23

Appendix 5.11 continued. Performance of 156 single cross hybrids under *Striga* (STR) infestation and optimal (OPT) environments.

Hybrid	**Grain yield (kg ha^{-1})**		***Striga* damage**		***Striga* emergence**		**Ear aspect**		Base Index
	STR	**OPT**	**8 WAP**	**10 WAP**	**8 WAP**	**10 WAP**	**STR**	**OPT**	
TZdEI 399 x TZdEI 314	2991	4891	4.00	4.67	3.12	3.50	5.33	4.40	-0.27
TZdEI 441 x TZdEI 124	3210	5604	3.33	4.17	3.55	3.76	5.33	4.20	-0.42
TZdEI 157 x TZdEI 84	2747	4849	3.50	5.00	2.85	3.46	5.67	4.80	-0.52
TZEI 18 x TZdEI 352	3326	5799	3.83	5.00	3.19	3.67	5.00	4.45	-0.55
TZdEI 396 x TZdEI 105	2884	5624	3.67	5.00	3.43	3.95	5.67	4.40	-0.66
TZdEI 98 x TZdEI 280	3107	7225	4.33	5.83	2.32	2.57	5.17	4.30	-0.74
TZdEI 280 x TZdEI 77	2812	6891	4.50	5.33	1.93	2.54	5.00	4.30	-0.77
TZdEI 84 x TZdEI 441	2568	4732	3.50	5.00	2.81	3.08	5.67	4.70	-0.79
TZdEI 202 x TZdEI 396	2944	6066	4.33	4.67	2.81	3.13	5.67	3.90	-0.81
TZdEI 441 x TZdEI 71	2762	5153	4.17	5.17	2.63	3.00	5.00	4.35	-0.87
TZdEI 357 x TZdEI 315	2795	5476	4.33	4.67	3.44	3.78	5.33	4.40	-0.97
TZdEI 260 x TZEI 31	3348	5847	4.17	5.17	3.15	3.64	5.00	4.80	-0.97
TZdEI 264 x TZdEI 98	2957	4723	3.33	4.83	2.96	3.42	5.17	4.80	-0.99
TZEI 18 x TZdEI 357	3036	6897	3.83	4.33	3.53	3.87	5.33	3.80	-1.06
TZdEI 131 x TZEI 18	2623	5337	4.17	5.00	2.57	3.21	5.33	4.50	-1.13
TZdEI 280 x TZdEI 441	3054	5940	3.67	5.00	3.39	3.99	5.00	3.85	-1.13
TZdEI 283 x TZdEI 492	3294	6352	4.50	5.33	3.16	3.76	4.83	3.85	-1.14
TZdEI 315 x TZdEI 202	2573	5198	4.00	5.00	3.35	3.81	5.83	4.50	-1.30
TZdEI 264 x TZdEI 283	2709	5490	4.67	5.67	1.78	2.30	5.50	5.40	-1.36
TZdEI 264 x TZEI 18	2952	5484	4.17	5.67	2.77	3.12	5.50	4.65	-1.37
TZdEI 124 x TZEI 31	2892	3880	4.33	5.00	3.30	3.54	5.17	5.00	-1.38
TZdEI 315 x TZdEI 71	2322	5445	4.33	5.17	2.15	2.61	5.83	5.00	-1.54
TZdEI 157 x TZdEI 280	3395	5992	4.00	5.00	3.36	3.88	4.50	4.35	-1.59
TZdEI 173 x TZdEI 84	2068	6026	4.33	5.17	0.99	2.16	5.17	5.00	-1.63
TZdEI 77 x TZdEI 399	2573	5517	4.00	5.50	2.53	3.22	4.83	4.80	-1.67
TZEI 7 x TZdEI 264	3078	5554	4.50	5.67	2.88	3.06	5.83	4.55	-1.69
TZdEI 105 x TZEI 18	3020	5717	4.17	5.00	3.16	3.55	5.33	4.40	-1.73
TZEI 31 x TZdEI 131	2975	4549	4.00	4.67	3.15	3.64	5.33	5.10	-1.82
TZdEI 283 x TZdEI 352	2740	4043	4.33	5.50	2.89	3.37	5.33	5.05	-1.87
TZdEI 492 x TZdEI 315	3319	6010	5.00	5.67	3.21	3.66	5.50	4.20	-1.87
TZdEI 98 x TZdEI 84	2742	4456	4.83	5.17	3.12	3.38	5.17	4.00	-2.00
TZdEI 283 x TZdEI 357	2984	5527	4.50	5.00	3.15	3.41	4.83	4.20	-2.12
TZdEI 82 x TZdEI 202	2277	5717	4.67	5.33	2.43	2.78	5.50	4.30	-2.33
TZdEI 399 x TZEI 31	2365	5183	4.00	4.83	3.52	4.17	5.33	4.30	-2.43
TZdEI 77 x TZdEI 71	2667	6638	4.33	6.00	1.81	2.55	5.33	4.50	-2.54
TZdEI 157 x TZdEI 357	2648	5093	4.00	5.17	3.45	3.90	5.67	4.15	-2.55
TZEI 31 x TZdEI 120	2971	4180	5.00	5.50	2.96	3.20	5.17	4.75	-2.58
TZdEI 82 x TZdEI 71	2143	2376	5.00	5.33	1.60	2.50	5.67	6.00	-2.59
TZdEI 378 x TZdEI 157	2785	5564	3.83	4.67	4.19	4.32	5.33	4.00	-2.71
TZdEI 124 x TZEI 7	2862	4600	4.00	5.17	3.33	3.70	5.50	5.20	-2.74
TZEI 7 x TZdEI 105	2644	6443	4.00	5.00	3.07	3.49	5.50	4.40	-2.76
TZEI 7 x TZdEI 131	3285	5702	4.00	5.17	3.16	3.67	5.50	4.40	-2.77
TZdEI 120 x TZdEI 283	2804	4990	4.67	5.33	3.25	3.43	5.17	4.06	-2.83
TZdEI 260 x TZEI 7	3201	5694	4.83	5.33	3.65	3.96	5.50	4.85	-2.93

Appendix 5.11 continued: Performance of 156 single cross hybrids under *Striga* infestation (STR) and optimal (OPT) environments.

Hybrid	**Grain yield (kg ha^{-1})**		***Striga* damage**		***Striga* emergence**		**Ear aspect**		Base Index
	STR	**OPT**	**8 WAP**	**10 WAP**	**8 WAP**	**10 WAP**	**STR**	**OPT**	
TZEI 7 x TZdEI 105	2644	6443	4.00	5.00	3.07	3.49	5.50	4.40	-2.76
TZEI 7 x TZdEI 131	3285	5702	4.00	5.17	3.16	3.67	5.50	4.40	-2.77
TZdEI 120 x TZdEI 283	2804	4990	4.67	5.33	3.25	3.43	5.17	4.06	-2.83
TZdEI 260 x TZEI 7	3201	5694	4.83	5.33	3.65	3.96	5.50	4.85	-2.93
TZdEI 120 x TZdEI 157	2724	5042	4.50	5.17	3.40	3.64	5.33	4.65	-3.14
TZdEI 396 x TZdEI 378	2708	6295	4.33	5.17	3.59	3.85	5.00	3.95	-3.16
TZdEI 84 x TZdEI 77	1903	5801	4.33	6.17	1.21	2.38	6.00	4.70	-3.17
TZdEI 202 x TZEI 7	2204	5498	4.33	5.17	1.78	2.30	5.50	4.80	-3.20
TZdEI 105 x TZdEI 283	2925	5473	4.33	5.50	3.25	3.73	5.17	4.20	-3.23
TZdEI 105 x TZdEI 157	2270	4102	3.83	5.00	3.46	3.79	5.50	4.90	-3.34
TZdEI 378 x TZdEI 283	2901	6742	4.83	5.33	3.50	3.86	5.83	3.50	-3.50
TZdEI 280 x TZdEI 315	2571	5527	4.17	5.67	3.67	4.01	5.33	4.50	-3.55
TZdEI 71 x TZEI 7	2980	5096	4.83	5.33	2.98	3.35	6.00	5.10	-3.57
TZdEI 84 x TZdEI 315	2849	5164	4.33	6.17	3.37	3.59	6.00	4.40	-3.58
TZdEI 84 x TZdEI 82	2565	4540	5.00	6.00	1.36	2.06	6.33	4.40	-3.71
TZdEI 131 x TZdEI 157	2502	4940	4.33	5.33	3.76	3.73	5.50	4.75	-3.86
TZdEI 441 x TZdEI 202	2426	5558	3.67	5.17	2.98	3.22	5.50	4.15	-3.88
TZEI 18 x TZdEI 280	3171	6448	4.67	5.33	3.53	3.87	5.50	3.95	-3.91
TZdEI 120 x TZEI 18	2627	4407	4.50	5.50	2.99	3.41	5.33	4.70	-4.19
TZdEI 378 x TZEI 18	2709	5723	4.67	5.50	3.81	4.01	5.50	4.25	-4.37
TZdEI 264 x TZdEI 157	2984	4833	4.67	5.67	3.37	4.17	5.50	4.45	-4.41
TZdEI 131 x TZdEI 98	2214	3290	4.17	5.50	2.87	3.09	5.83	5.30	-4.47
TZEI 188 x TZEI 98	2681	5605	4.17	5.50	2.80	3.41	5.50	4.55	-4.53
TZEI 18 x TZdEI 84	2611	6045	5.00	5.83	2.67	3.17	5.67	4.15	-4.67
TZEI 60 x TZEI 5	3143	6876	4.83	5.67	2.94	3.33	5.50	3.30	-4.73
TZdEI 71 x TZEI 31	2403	5519	4.83	5.50	3.27	3.65	6.00	4.30	-5.16
TZEI 7 x TZdEI 120	2357	5027	5.00	5.83	2.62	3.26	5.50	4.65	-5.73
TZEI 31 x TZdEI 105	2651	5540	5.00	6.00	3.47	4.04	5.83	4.25	-5.83
TZdEI 314 x TZdEI 378	2109	4596	4.83	5.33	3.05	3.57	5.83	5.15	-5.92
TZEI 31 x TZdEI 378	2598	5138	5.00	5.50	3.54	3.86	5.33	4.35	-6.09
TZdEI 211 x TZdEI 202	1740	6885	4.67	5.83	1.65	2.35	5.83	4.20	-6.25

Appendix 5.12: Performance of 156 single cross hybrid under drought (DT) and optimal (OPT) environments

Hybrid	**Grain yield (kg ha-^{1})**		**Days to silking**		**Ear aspect**		**Ears per plant**		**SGC**	**BI**
	DT	**OPT**	**DT**	**OPT**	**DT**	**OPT**	**DT**	**OPT**		
TZdEI 479 x TZdEI 260	3601	6622	56	50	4.05	4.30	1.07	1.12	2.30	13.85
TZdEI 396 x TZdEI 264	3167	6018	58	53	4.35	4.30	0.96	0.99	2.40	9.20
TZdEI 378 x TZdEI 157	3086	5564	57	53	3.75	4.00	0.90	0.97	3.20	8.80
TZdEI 71 x TZdEI 396	3172	6601	56	51	3.90	4.15	0.73	1.02	2.10	7.79
TZdEI 157 x TZdEI 280	2880	5992	59	52	4.00	4.35	1.07	1.03	3.00	7.77
TZdEI 260 x TZdEI 396	3122	7769	55	50	4.65	4.60	0.87	0.98	2.80	7.57
TZdEI 399 x TZdEI 268	2443	4306	57	54	3.65	4.70	0.92	0.91	2.60	7.46
TZdEI 492 x TZdEI 315	3155	6010	57	51	3.85	4.20	0.82	0.90	3.40	6.91
TZdEI 396 x TZdEI 378	2909	6295	58	52	4.10	3.95	0.87	0.97	2.60	6.85
TZdEI 396 x TZdEI 131	2697	6680	55	50	4.35	4.15	0.82	0.98	2.50	6.82
TZdEI 396 x TZdEI 120	7038	5797	57	52	3.90	4.10	0.90	0.96	2.90	6.52
TZdEI 399 x TZdEI 314	2704	4891	56	51	3.95	4.40	0.94	0.92	3.20	6.42
TZdEI 314 x TZdEI 120	2796	4827	57	52	4.25	4.50	1.02	1.00	2.90	6.20
TZdEI 441 x TZdEI 71	2548	5153	58	53	3.85	4.35	0.82	0.93	2.20	5.96
TZEI 18 x TZdEI 84	2980	6045	58	53	4.15	4.15	0.82	0.93	2.50	5.89
TZdEI 71 x TZdEI 314	2606	6064	56	51	4.00	4.40	0.95	0.97	2.70	5.80
TZEI 7 x TZdEI 264	2681	5554	59	53	4.20	4.55	0.80	0.94	2.60	5.71
TZdEI 283 x TZdEI 492	2670	6352	58	52	4.15	3.85	0.98	1.07	3.20	5.66
TZdEI 260 x TZEI 31	2764	5847	57	52	4.25	4.80	0.99	1.01	3.30	5.50
TZdEI 173 x TZdEI 352	2545	4347	61	53	3.80	4.00	0.85	0.96	2.80	5.42
TZdEI 315 x TZdEI 399	2659	5759	56	52	4.05	4.15	0.89	1.03	3.10	5.39
TZdEI 98 x TZdEI 492	2791	5877	58	53	4.35	3.95	0.95	0.95	3.90	5.08
TZEI 18 x TZdEI 352	2789	5799	61	54	4.05	4.45	0.85	1.00	2.50	5.06
TZdEI 378 x TZEI 18	2810	5723	59	52	3.95	4.25	0.88	0.95	2.90	4.98
TZdEI 260 x TZEI 7	2735	5694	56	51	4.40	4.85	0.92	0.90	2.90	4.92
TZdEI 441 x TZdEI 260	2702	7033	59	52	4.20	3.50	0.79	1.01	2.70	4.77
TZEI 7 x TZdEI 378	5924	5921	58	51	4.25	4.45	0.97	0.93	2.80	4.61
TZdEI 82 x TZdEI 399	2733	5910	58	51	4.20	4.15	0.82	0.98	2.40	4.48
TZdEI 71 x TZdEI 268	2692	7068	57	52	4.85	4.70	0.99	0.97	3.40	4.33
TZdEI 157 x TZdEI 492	2740	5624	60	54	4.00	4.05	0.82	0.98	3.00	4.11
TZdEI 357 x TZdEI 441	2804	5471	60	54	4.20	4.30	0.68	0.96	2.70	3.99
TZdEI 131 x TZdEI 283	2479	5853	56	52	4.60	4.40	0.98	0.97	3.10	3.97
TZdEI 82 x TZdEI 260	2202	6856	56	50	4.60	4.00	0.89	0.99	2.30	3.97
TZEI 188 x TZEI 98	2642	5605	58	52	4.20	4.55	0.87	0.91	2.80	3.91
TZdEI 98 x TZdEI 352	2706	5868	60	54	4.10	4.30	0.83	0.97	3.10	3.89
TZdEI 157 x TZdEI 357	2430	5093	60	55	4.65	4.15	0.96	1.00	2.50	3.67
TZdEI 264 x TZEI 18	2666	5484	60	54	4.30	4.65	0.83	1.00	2.80	3.57
TZdEI 268 x TZdEI 378	2962	5988	58	53	4.45	4.25	0.83	0.96	3.30	3.44
TZEI 31 x TZdEI 105	2527	5540	57	53	4.30	4.25	0.82	0.97	3.20	3.29
TZdEI 352 x TZdEI 315	2487	5969	60	52	4.15	4.05	0.97	0.94	3.10	3.26
TZdEI 260 x TZdEI 314	2635	6823	56	50	4.50	4.90	1.01	1.02	3.80	3.13
TZdEI 173 x TZdEI 280	2511	6816	56	51	4.45	3.80	0.87	0.96	3.20	3.12
TZdEI 378 x TZdEI 283	2611	6742	58	51	4.15	3.50	0.93	0.99	2.90	3.09

Appendix 5.12 continued. Performance of 156 single cross hybrids under drought (DT) and optimal environments.

Hybrid	Grain yield (kg ha^{-1})		Days to silking		Ear aspect		Ears per plant		SGC	BI
	DT	OPT	DT	OPT	DT	OPT	DT	OPT		
TZEI 7 x TZdEI 120	2888	5027	57	50	4.20	4.65	0.88	0.99	2.40	3.05
TZdEI 202 x TZdEI 268	2707	6187	59	52	4.35	4.15	0.87	1.03	3.30	3.03
TZdEI 173 x TZdEI 492	5609	7184	58	52	4.50	3.55	0.93	1.02	3.30	2.91
TZEI 18 x TZdEI 357	2534	6897	59	53	4.25	3.80	0.88	1.04	3.60	2.77
TZdEI 82 x TZdEI 202	2184	5717	56	51	4.30	4.30	0.90	0.99	2.70	2.74
TZEI 60 x TZEI 5	2612	6876	60	54	4.35	3.30	0.81	0.97	3.40	2.62
TZdEI 357 x TZdEI 315	2453	5476	59	53	4.20	4.40	0.86	1.03	3.40	2.54
TZdEI 399 x TZdEI 396	2450	5298	58	53	4.55	4.25	0.75	0.88	2.70	2.49
TZdEI 352 x TZdEI 82	2440	5881	60	52	4.25	4.05	0.84	1.01	2.60	2.41
TZdEI 82 x TZdEI 124	2177	5205	56	51	4.40	4.60	0.81	0.97	2.70	2.40
TZdEI 98 x TZdEI 280	2356	7225	55	52	4.40	4.30	0.87	0.93	3.60	2.30
TZdEI 378 x TZdEI 98	2308	4969	58	53	4.25	4.55	0.94	1.08	3.50	2.13
TZdEI 105 x TZdEI 173	2425	5448	59	51	4.38	4.45	0.78	0.98	3.75	2.12
TZdEI 283 x TZdEI 84	2671	5557	57	53	4.50	4.35	0.83	1.03	3.30	2.00
TZdEI 120 x TZdEI 173	2450	5388	59	52	4.45	4.20	0.80	0.95	3.00	1.99
TZdEI 268 x TZdEI 264	2311	5330	60	53	4.75	4.25	0.97	0.97	2.90	1.97
TZdEI 315 x TZdEI 71	2386	5445	55	49	4.90	5.00	0.87	0.90	3.10	1.95
TZdEI 120 x TZEI 18	2525	4407	59	54	4.35	4.70	0.79	1.08	3.20	1.93
TZdEI 479 x TZdEI 71	2368	6638	60	51	5.10	4.50	1.05	1.01	3.10	1.83
TZdEI 124 x TZdEI 396	2271	5731	57	51	4.40	4.45	0.91	1.03	3.30	1.73
TZEI 31 x TZdEI 264	2583	5356	59	52	4.55	4.60	0.77	0.97	3.10	1.70
TZdEI 131 x TZdEI 157	2272	4940	58	52	4.35	4.75	0.86	0.94	3.40	1.64
TZdEI 202 x TZdEI 396	2289	6066	59	52	4.55	3.90	0.87	0.99	2.60	1.63
TZdEI 485 x TZdEI 202	2212	6885	58	51	5.25	4.20	0.75	1.00	2.40	1.49
TZdEI 492 x TZdEI 82	2109	6253	59	53	4.80	4.40	0.82	0.97	2.60	1.44
TZdEI 84 x TZdEI 315	2471	5164	58	50	4.45	4.40	0.87	0.98	3.60	1.35
TZEI 18 x TZdEI 492	2467	5733	60	54	4.30	4.10	0.75	0.91	2.70	1.34
TZdEI 264 x TZdEI 98	2076	4723	60	54	4.70	4.80	0.89	0.95	2.70	0.93
TZdEI 441 x TZdEI 399	2359	5359	61	54	4.90	4.40	0.77	0.99	2.80	0.92
TZEI 31 x TZdEI 378	2597	5138	58	52	4.45	4.35	0.84	0.99	3.70	0.90
TZdEI 71 x TZEI 31	2443	5519	58	51	4.65	4.30	0.79	0.96	2.70	0.89
TZdEI 283 x TZdEI 357	2103	5527	59	52	4.70	4.20	0.86	0.94	3.00	0.87
TZEI 7 x TZdEI 131	2283	5702	58	52	4.55	4.40	0.78	0.93	3.10	0.86
TZdEI 260 x TZdEI 268	2266	6370	57	50	5.10	4.40	0.72	0.99	2.80	0.65
TZdEI 357 x TZdEI 82	2318	6246	59	51	4.65	4.10	0.77	0.99	2.90	0.52
TZdEI 399 x TZEI 31	2415	5183	58	52	4.10	4.30	0.76	0.89	3.50	0.52
TZdEI 268 x TZdEI 120	2432	5581	60	51	4.35	4.35	0.76	1.08	2.80	0.39
TZdEI 202 x TZdEI 314	2250	5417	57	51	4.25	4.05	0.89	0.94	3.40	0.17
TZdEI 124 x TZdEI 314	2200	4574	57	51	4.40	4.50	0.89	0.93	3.40	0.16
TZdEI 378 x TZdEI 173	2486	6272	59	52	4.55	4.05	0.80	0.97	3.80	0.08
TZdEI 120 x TZdEI 157	2262	5042	59	52	4.35	4.65	0.80	0.93	3.30	0.07
TZdEI 264 x TZdEI 157	2161	4833	61	54	4.55	4.45	0.83	0.95	2.50	0.02
TZdEI 124 x TZdEI 268	2045	3967	58	53	4.90	4.55	0.92	0.95	3.80	0.01
TZdEI 399 x TZEI 7	2271	5297	60	53	4.75	4.45	0.74	0.93	2.70	-0.06
TZdEI 315 x TZdEI 202	2048	5198	58	50	4.95	4.50	0.91	1.00	3.20	-0.08

Appendix 5.12 continued. Performance of 156 single cross hybrids under drought (DT) and optimal (OPT) environments.

Hybrid	Grain yield (kg ha^{-1})		Days to silking		Ear aspect		Ears per plant		SG C	BI
	DT	OPT	DT	OPT	DT	OPT	DT	OPT		
TZdEI 314 x TZdEI 264	2368	5200	59	52	4.45	3.95	0.76	1.00	3.70	-0.14
TZdEI 98 x TZdEI 357	2459	4760	60	54	4.15	4.50	0.71	0.93	3.60	-0.17
TZEI 31 x TZdEI 120	2551	4180	59	52	4.40	4.75	0.88	0.97	3.90	-0.23
TZEI 31 x TZEI 63	2317	4823	60	53	4.55	4.40	0.86	0.96	3.67	-0.26
TZdEI 202 x TZEI 31	2310	5263	59	52	4.35	4.20	0.81	1.08	3.30	-0.30
TZdEI 492 x TZdEI 441	2481	6245	61	55	4.80	4.10	0.82	0.99	3.60	-0.33
TZEI 18 x TZdEI 280	2560	6448	60	52	4.20	3.95	0.70	0.97	3.40	-0.39
TZdEI 120 x TZdEI 98	2208	4811	58	51	4.45	4.60	0.86	0.95	4.00	-0.45
TZdEI 283 x TZdEI 280	2151	5856	59	53	4.60	4.65	0.80	1.04	2.90	-0.68
TZdEI 105 x TZEI 18	2071	5717	58	52	4.60	4.40	0.81	0.94	3.60	-0.73
TZdEI 120 x TZdEI 283	1967	4990	59	53	4.90	4.06	0.83	1.05	3.00	-0.87
TZdEI 396 x TZdEI 105	2375	5624	58	52	4.25	4.40	0.74	0.99	3.10	-0.99
TZdEI 280 x TZdEI 82	1919	6046	57	52	4.70	4.40	0.81	0.95	2.40	-1.06
TZdEI 71 x TZEI 7	1985	5096	57	51	4.90	5.10	0.81	0.95	2.40	-1.19
TZdEI 479 x TZdEI 124	2639	6455	57	51	4.90	4.10	0.86	1.00	3.90	-1.26
TZdEI 173 x TZdEI 357	2314	5737	60	53	4.55	4.30	0.70	1.03	3.30	-1.26
TZdEI 202 x TZEI 7	2151	5498	57	51	5.30	4.80	0.86	0.96	3.20	-1.61
TZEI 7 x TZdEI 105	2183	6443	60	52	4.75	4.40	0.82	0.95	3.40	-1.82
TZdEI 441 x TZdEI 124	2068	5604	59	52	4.75	4.20	0.85	0.97	3.40	-2.06
TZdEI 105 x TZdEI 157	1955	4102	59	52	4.60	4.90	0.83	0.96	3.70	-2.07
TZdEI 157 x TZdEI 84	2148	4849	60	53	4.55	4.80	0.81	0.94	3.30	-2.15
TZEI 60 x TZEI 86	1804	5333	58	53	5.00	4.65	0.81	0.98	3.50	-2.16
TZdEI 173 x TZdEI 84	2376	6026	58	52	5.35	5.00	0.83	0.98	3.60	-2.56
TZEI 2 x TZEI 87	2327	4167	58	52	4.55	5.18	0.82	0.91	3.70	-2.63
TZdEI 315 x TZdEI 260	1755	5816	57	50	5.10	4.40	0.85	1.00	3.20	-2.70
TZdEI 479 x TZdEI 399	2389	5517	60	51	5.15	4.80	0.92	0.95	3.80	-2.75
TZdEI 441 x TZdEI 202	1960	5558	60	53	4.95	4.15	0.69	1.01	3.10	-2.79
TZdEI 105 x TZdEI 283	2181	5473	57	53	4.85	4.20	0.73	0.94	3.70	-2.82
TZdEI 485 x TZdEI 71	1955	6043	58	51	5.30	4.60	0.84	0.97	3.30	-3.00
TZdEI 280 x TZdEI 315	1925	5527	59	50	5.05	4.50	1.03	1.04	3.70	-3.04
TZdEI 268 x TZdEI 105	2162	4971	59	54	4.85	4.25	0.66	0.97	3.70	-3.18
TZdEI 314 x TZdEI 131	2091	5131	58	51	4.50	4.60	0.79	1.01	3.60	-3.20
TZdEI 131 x TZEI 18	2256	5337	60	53	4.85	4.50	0.72	0.95	3.60	-3.40
TZdEI 131 x TZdEI 173	2169	5971	58	51	4.90	4.35	0.78	0.99	3.70	-3.42
TZdEI 280 x TZdEI 441	2090	5940	60	53	5.10	3.85	0.74	0.94	3.10	-3.46
TZdEI 264 x TZdEI 173	2089	5330	60	52	5.00	4.65	0.61	0.96	3.30	-3.80
TZdEI 98 x TZdEI 84	2091	4456	59	50	4.10	4.00	0.75	1.07	3.10	-3.80
TZdEI 314 x TZdEI 105	2044	5109	57	51	4.85	4.55	0.83	0.98	4.30	-3.84

Appendix 5.12 continued. Performance of 156 single cross hybrids under drought (DT) and optimal environments.

Hybrid	**Grain yield (kg ha^{-1})**		**Days to silking**		**Ear aspect**		**Ears per plant**		**SGC**	**BI**
	DT	**OPT**	**DT**	**OPT**	**DT**	**OPT**	**DT**	**OPT**		
TZdEI 352 x TZdEI 479	1627	6174	60	53	5.30	4.90	0.85	1.03	3.40	-3.99
TZEI 26 x TZEI 5	1872	4176	59	53	5.40	4.90	0.72	0.84	3.00	-4.02
TZdEI 268 x TZdEI 131	1982	5383	60	51	4.90	4.50	0.85	0.93	4.00	-4.03
TZdEI 479 x TZdEI 202	2554	5410	57	50	4.90	4.60	0.72	0.99	3.30	-4.08
TZdEI 124 x TZEI 7	1920	4600	57	51	4.90	5.20	0.76	0.98	3.60	-4.57
TZdEI 264 x TZdEI 283	1934	5490	60	54	5.40	5.40	0.93	1.05	3.40	-4.63
TZdEI 485 x TZdEI 399	2057	4897	60	53	5.40	5.20	0.72	0.96	3.70	-5.07
TZdEI 84 x TZdEI 441	1656	4732	61	54	4.85	4.70	0.79	0.94	3.10	-5.26
TZdEI 492 x TZdEI 479	1894	6908	61	53	5.00	4.90	0.77	0.98	4.00	-5.33
TZdEI 84 x TZdEI 485	1985	5731	60	52	4.80	4.80	0.61	0.98	3.50	-5.60
TZEI 31 x TZdEI 131	1902	4549	59	53	4.90	5.10	0.66	0.89	3.60	-5.70
TZdEI 357 x TZdEI 485	2221	7311	59	53	5.10	4.60	0.64	0.98	4.20	-5.81
TZdEI 84 x TZdEI 82	1919	4540	59	53	5.25	4.40	0.62	0.86	4.25	-6.38
TZdEI 280 x TZdEI 479	1035	6891	59	52	5.00	4.30	0.68	1.02	2.90	-7.06
TZdEI 485 x TZdEI 260	2312	6442	59	51	5.05	4.90	0.63	0.93	4.70	-7.33
TZdEI 105 x TZdEI 98	1741	4308	60	53	5.20	4.85	0.51	0.84	4.10	-8.49
TZdEI 124 x TZEI 31	1612	3880	60	53	5.15	5.00	0.74	0.99	4.10	-9.58
TZdEI 352 x TZdEI 485	2128	6305	60	53	5.30	4.80	0.66	1.01	5.00	-9.63
TZdEI 315 x TZdEI 124	1763	5380	57	51	5.55	5.40	0.80	0.94	4.90	-9.73
TZdEI 492 x TZdEI 485	2078	7723	60	52	5.40	4.10	0.55	0.99	4.90	-10.30
TZdEI 283 x TZdEI 352	1180	4043	61	53	5.75	5.05	0.63	0.99	4.00	-10.85
TZdEI 357 x TZdEI 479	1050	7058	62	53	5.65	4.30	0.63	1.05	3.60	-11.32
TZdEI 131 x TZdEI 98	1178	3290	61	54	5.70	5.30	0.65	0.82	4.10	-12.15
TZdEI 84 x TZdEI 479	839	5801	63	51	5.58	4.70	0.86	0.97	3.13	-12.46
TZdEI 280 x TZdEI 485	1229	5880	60	52	5.85	4.60	0.68	0.96	3.90	-12.87
TZdEI 485 x TZdEI 124	1582	5111	61	51	5.55	5.30	0.68	0.91	5.10	-13.01
TZdEI 82 x TZdEI 71	671	2376	63	53	5.44	6.00	0.46	0.80	3.78	-16.12
TZdEI 314 x TZdEI 378	579	4596	61	52	6.30	5.15	0.78	0.93	5.30	-17.36

Appendix 5.13: Performance of the 156 single cross hybrids across *Striga* infested, drought and optimal conditions at 13 environments in 2013 and 2015

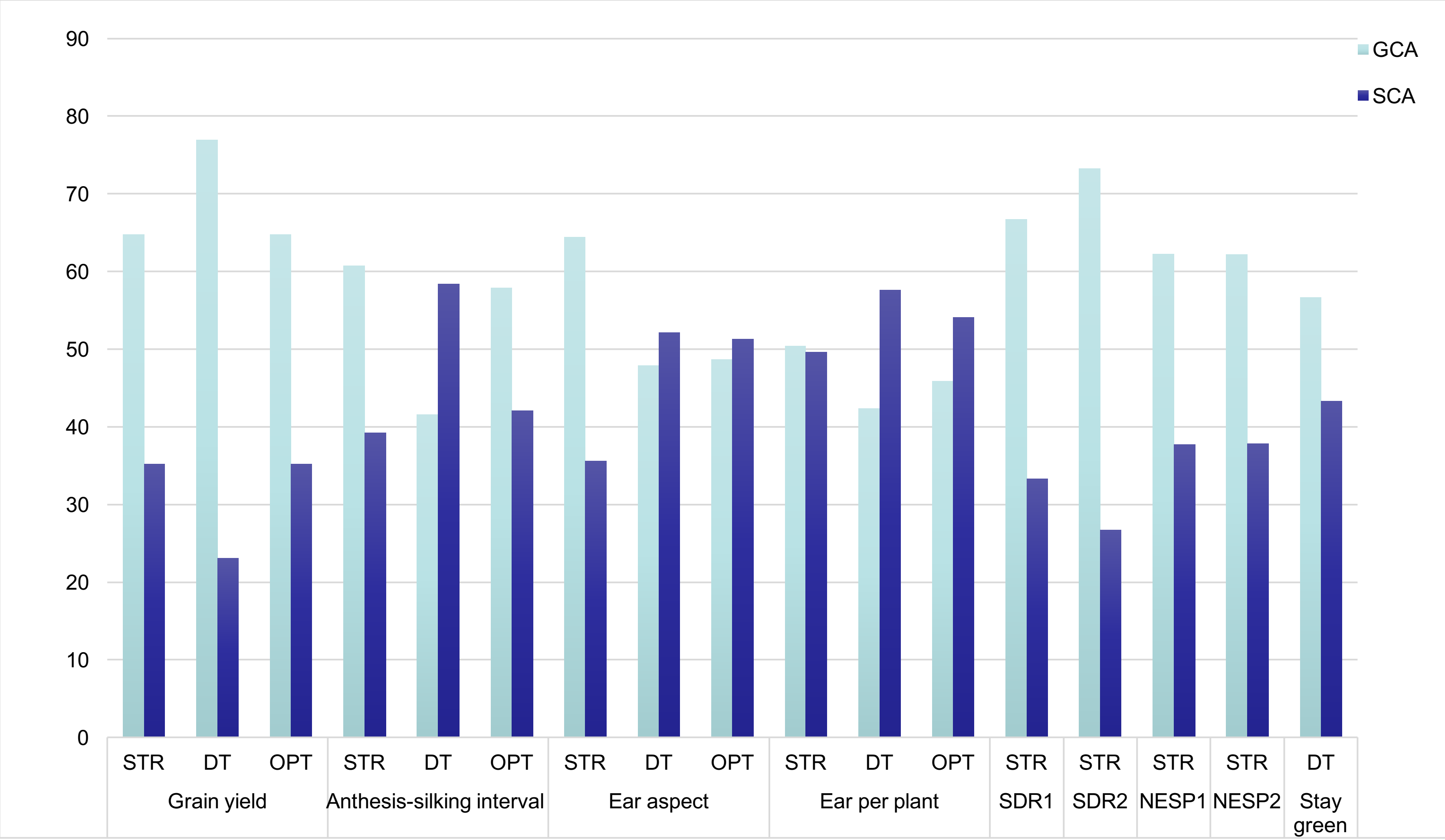
Hybrid	**Grain yield (kg ha^{-1})**	**Days to silking**	**Anthesis -silking interval**	**Plant height (cm)**	**Ear aspect**	**Plant aspect**	**Ears per plant**
TZdEI 268 x TZdEI 378	4278	56	1.50	161.58	4.35	4.28	0.91
TZdEI 378 x TZdEI 283	4272	56	1.96	164.92	4.29	4.00	0.94
TZdEI 492 x TZdEI 441	4255	58	2.20	170.27	4.54	3.50	0.94
TZdEI 357 x TZdEI 82	4229	56	1.27	170.35	4.44	4.20	0.90
TZdEI 283 x TZdEI 492	4229	56	1.46	163.00	4.19	3.93	1.00
TZdEI 492 x TZdEI 479	4225	58	1.62	166.19	4.96	4.45	0.90
TZdEI 98 x TZdEI 492	4224	56	0.85	169.23	4.31	4.05	0.94
TZEI 18 x TZdEI 280	4206	57	1.96	152.69	4.40	4.33	0.82
TZdEI 157 x TZdEI 280	4201	57	1.46	160.38	4.25	4.08	0.99
TZdEI 82 x TZdEI 399	4196	55	1.69	170.50	4.21	3.88	0.91
TZdEI 485 x TZdEI 260	4195	56	1.15	162.00	4.94	5.55	0.85
TZdEI 396 x TZdEI 378	4166	56	1.35	163.81	4.25	3.83	0.91
TZdEI 71 x TZdEI 314	4160	54	1.00	169.23	4.35	4.58	0.94
TZdEI 202 x TZdEI 268	4143	56	1.35	168.00	4.42	4.10	0.96
TZdEI 157 x TZdEI 352	4141	58	1.62	169.46	4.33	3.93	0.90
TZdEI 492 x TZdEI 82	4131	57	1.23	165.85	4.54	3.83	0.90
TZdEI 352 x TZdEI 82	4124	57	2.04	172.58	4.31	3.85	0.92
TZdEI 352 x TZdEI 485	4124	58	2.27	161.85	4.96	5.00	0.88
TZdEI 479 x TZdEI 71	4080	56	1.08	162.15	4.92	4.73	0.98
TZdEI 260 x TZEI 31	4079	55	1.35	165.42	4.63	4.30	0.97
TZEI 18 x TZdEI 352	4076	59	1.88	160.65	4.42	3.98	0.91
TZEI 18 x TZdEI 84	4075	56	1.96	162.42	4.50	3.83	0.86
TZdEI 105 x TZdEI 173	4073	55	0.67	176.58	4.44	3.97	0.90
TZdEI 157 x TZdEI 492	4012	58	1.38	168.58	4.13	4.00	0.90
TZdEI 268 x TZdEI 120	4012	56	1.58	168.65	4.38	4.18	0.94
TZdEI 315 x TZdEI 399	4000	55	1.38	161.04	4.27	4.13	0.96
TZdEI 357 x TZdEI 441	3985	58	1.85	177.88	4.35	3.63	0.81
TZdEI 396 x TZdEI 120	3985	56	1.12	165.23	4.23	3.98	0.92
TZdEI 120 x TZdEI 173	3984	56	1.23	164.31	4.37	4.08	0.90
TZdEI 173 x TZdEI 357	3980	57	1.77	165.35	4.48	4.20	0.89
TZdEI 260 x TZEI 7	3974	55	1.65	157.92	4.83	4.25	0.90
TZdEI 378 x TZdEI 157	3970	56	1.08	168.58	4.21	3.93	0.92
TZdEI 131 x TZdEI 173	3944	55	1.69	165.23	4.71	4.20	0.87
TZdEI 283 x TZdEI 280	3942	57	1.92	166.62	4.63	4.00	0.91
TZdEI 202 x TZdEI 396	3939	56	1.58	177.96	4.56	3.78	0.92
TZdEI 268 x TZdEI 131	3937	56	1.42	168.27	4.58	4.38	0.88
TZdEI 124 x TZdEI 396	3937	55	1.31	171.04	4.63	4.10	0.96
TZEI 7 x TZdEI 105	3928	56	1.73	170.58	4.79	3.90	0.87
TZdEI 357 x TZdEI 479	3922	58	1.00	158.04	4.87	5.13	0.88
TZdEI 280 x TZdEI 82	3915	56	2.23	163.58	4.69	3.98	0.87

Appendix 5.13 continued. Performance of the hybrids across *Striga*-infested, drought and optimal conditions in 13 environments in 2013 and 2015.

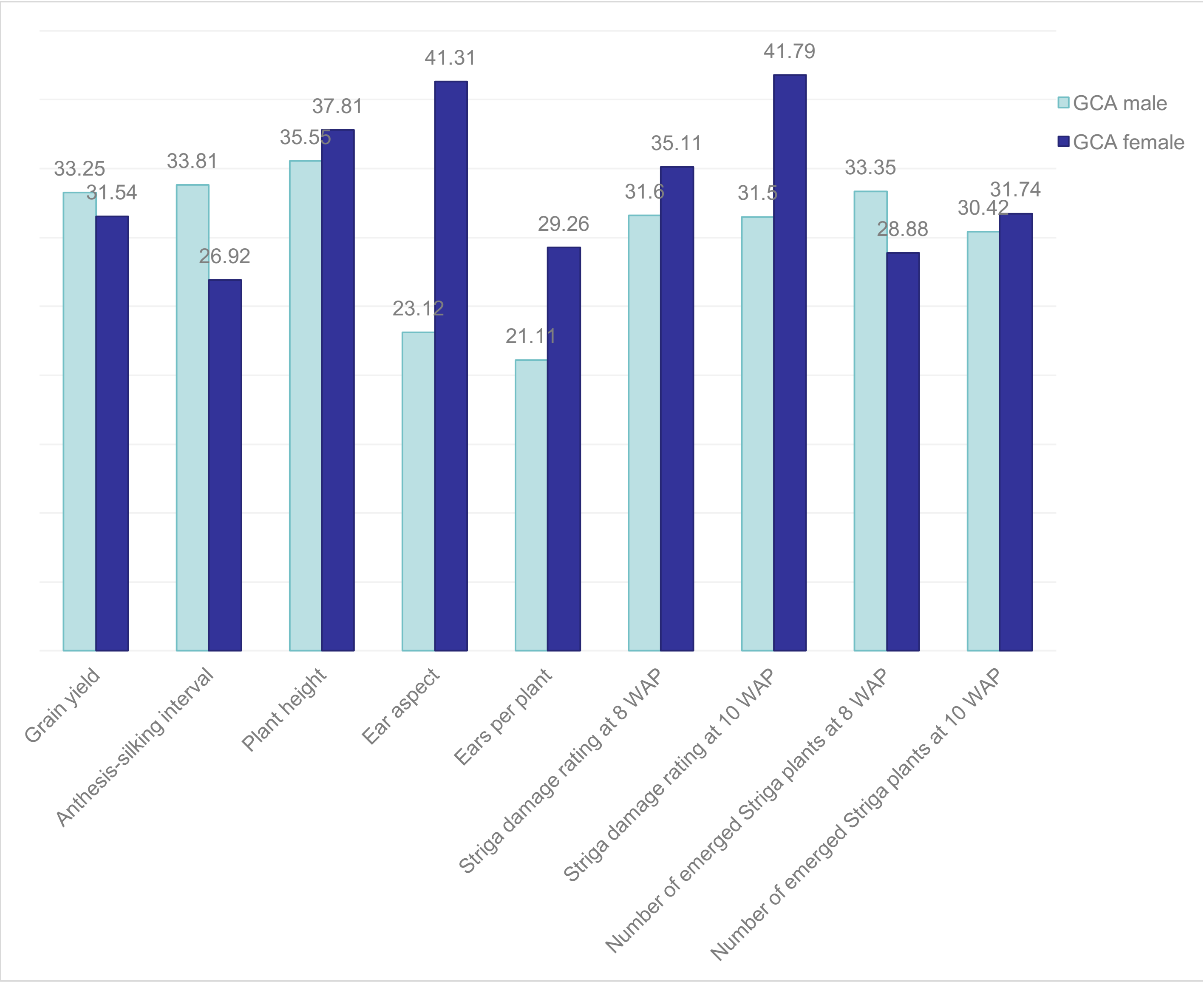
Hybrid	Grain yield (kg ha^{-1})	Days to silking	Anthesis -silking interval	Plant height (cm)	Ear aspect	Plant aspect	Ears per plant
TZdEI 378 x TZEI 18	3905	57	1.81	161.31	4.42	4.28	0.91
TZdEI 485 x TZdEI 202	3900	56	1.23	165.31	4.98	4.53	0.84
TZEI 7 x TZdEI 264	3876	58	1.73	164.42	4.71	4.13	0.87
TZdEI 283 x TZdEI 84	3872	56	2.00	174.54	4.60	4.05	0.94
TZEI 7 x TZdEI 131	3870	56	1.68	168.08	4.71	4.23	0.82
TZdEI 131 x TZdEI 283	3865	55	1.46	170.00	4.65	4.33	0.95
TZdEI 352 x TZdEI 441	3844	60	1.85	164.38	4.60	3.93	0.86
TZdEI 399 x TZEI 7	3822	57	1.46	167.50	4.58	4.15	0.83
TZdEI 399 x TZdEI 396	3822	57	1.27	163.73	4.38	3.93	0.83
TZdEI 268 x TZdEI 264	3800	57	1.27	156.58	4.62	4.53	0.95
TZdEI 264 x TZEI 18	3791	58	2.12	153.92	4.71	4.38	0.91
TZEI 188 x TZEI 98	3787	56	1.42	160.12	4.63	4.15	0.85
TZdEI 280 x TZdEI 441	3775	57	1.92	161.46	4.60	3.80	0.85
TZdEI 314 x TZdEI 105	3767	55	1.54	165.62	4.50	4.40	0.93
TZEI 18 x TZdEI 492	3754	58	1.96	149.19	4.46	4.33	0.82
TZdEI 485 x TZdEI 71	3746	56	1.15	173.42	5.00	4.65	0.92
TZdEI 396 x TZdEI 105	3742	56	1.46	171.00	4.63	4.85	0.89
TZdEI 202 x TZdEI 314	3721	55	1.85	162.19	4.42	4.38	0.91
TZEI 31 x TZdEI 105	3717	56	1.42	172.85	4.63	4.15	0.88
TZdEI 264 x TZdEI 173	3717	57	1.23	159.50	4.87	4.45	0.80
TZdEI 268 x TZdEI 105	3714	57	1.19	165.92	4.38	4.35	0.84
TZdEI 378 x TZdEI 98	3714	56	1.15	167.62	4.46	4.38	0.99
TZdEI 173 x TZdEI 84	3709	56	1.58	170.92	5.17	4.63	0.90
TZdEI 441 x TZdEI 124	3700	57	1.85	176.69	4.67	4.15	0.88
TZdEI 357 x TZdEI 315	3698	57	1.58	172.58	4.54	3.98	0.95
TZdEI 280 x TZdEI 479	3697	56	1.50	165.73	4.73	4.70	0.86
TZEI 7 x TZdEI 378	3697	56	1.65	157.23	4.69	4.03	0.92
TZdEI 173 x TZdEI 352	3694	57	1.29	161.25	3.83	3.28	0.89
TZdEI 105 x TZEI 18	3691	56	1.46	164.19	4.69	4.28	0.87
TZdEI 82 x TZdEI 124	3686	54	0.96	170.15	4.62	4.00	0.89
TZdEI 441 x TZdEI 399	3675	58	1.77	172.54	4.77	3.80	0.89
TZdEI 315 x TZdEI 260	3648	54	1.15	155.35	4.85	4.45	0.93
TZdEI 314 x TZdEI 120	3648	55	1.19	162.58	4.52	4.43	1.00
TZdEI 352 x TZdEI 479	3638	58	1.77	168.15	5.00	4.68	0.92
TZdEI 479 x TZdEI 399	3635	56	1.38	155.85	4.94	5.33	0.93
TZdEI 479 x TZdEI 202	3627	54	2.27	168.46	4.85	5.15	0.89
TZdEI 283 x TZdEI 357	3620	57	1.35	171.31	4.54	3.95	0.89
TZdEI 105 x TZdEI 283	3618	56	1.96	167.73	4.67	4.28	0.83
TZdEI 71 x TZEI 31	3611	55	1.54	162.92	4.83	4.28	0.87
TZdEI 98 x TZdEI 357	3610	57	1.42	169.58	4.44	4.30	0.85

Appendix 5.13 continued. Performance of 156 single cross hybrids across Striga infested, drought and optimal conditions in 13 environments in 2013 and 2015.

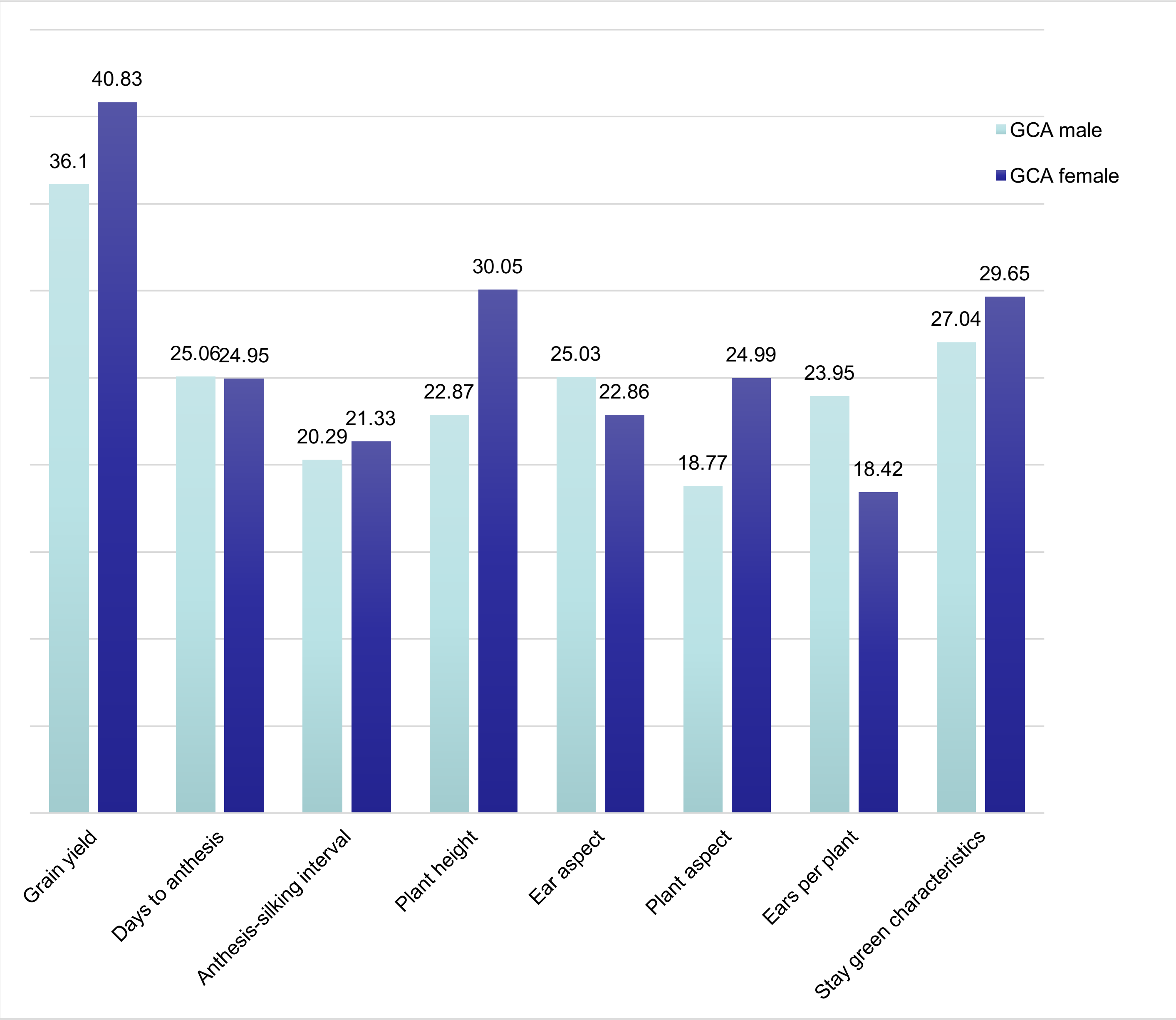
Hybrid	Grain yield (kg ha^{-1})	Days to silking	Anthesis -silking interval	Plant height (cm)	Ear aspect	Plant aspect	Ears per plant
TZdEI 399 x TZdEI 314	3605	55	1.12	162.50	4.44	4.38	0.93
TZdEI 84 x TZdEI 315	3597	54	1.31	164.19	4.79	4.28	0.92
TZEI 7 x TZdEI 120	3597	55	1.73	164.19	4.67	4.85	0.90
TZdEI 314 x TZdEI 264	3590	57	1.38	151.15	4.42	4.45	0.90
TZEI 31 x TZdEI 378	3572	56	1.69	155.27	4.62	4.45	0.88
TZdEI 441 x TZdEI 71	3571	57	1.58	174.58	4.31	3.73	0.89
TZdEI 82 x TZdEI 202	3570	55	1.81	168.73	4.58	4.05	0.95
TZdEI 315 x TZdEI 71	3548	53	0.81	163.00	5.15	4.80	0.89
TZdEI 280 x TZdEI 485	3544	58	2.35	154.88	5.25	5.15	0.87
TZEI 31 x TZdEI 264	3541	57	1.65	155.50	4.94	4.45	0.86
TZdEI 314 x TZdEI 131	3541	55	1.65	166.38	4.58	4.75	0.92
TZdEI 131 x TZEI 18	3530	57	1.85	159.04	4.83	4.43	0.86
TZdEI 120 x TZdEI 98	3524	56	1.27	171.46	4.56	4.28	0.89
TZdEI 157 x TZdEI 357	3503	59	1.46	165.38	4.69	4.45	0.96
TZdEI 264 x TZdEI 283	3480	59	2.12	154.73	5.42	5.35	0.97
TZdEI 399 x TZEI 31	3468	56	1.73	161.62	4.46	4.05	0.86
TZdEI 441 x TZdEI 202	3465	58	2.27	178.04	4.77	3.78	0.82
TZdEI 280 x TZdEI 315	3460	55	1.88	150.81	4.90	4.40	1.01
TZdEI 202 x TZEI 7	3450	55	2.15	171.81	5.15	4.20	0.88
TZdEI 202 x TZEI 31	3442	57	1.77	166.00	4.67	4.08	0.93
TZdEI 120 x TZdEI 157	3439	57	1.65	162.42	4.69	4.30	0.87
TZdEI 71 x TZEI 7	3412	55	1.69	156.12	5.23	4.40	0.86
TZdEI 315 x TZdEI 124	3411	54	1.58	168.42	5.37	5.18	0.88
TZdEI 84 x TZdEI 485	3387	56	1.69	170.54	5.04	4.90	0.78
TZdEI 264 x TZdEI 157	3385	59	1.50	153.15	4.73	4.70	0.88
TZdEI 84 x TZdEI 479	3385	56	1.55	161.45	5.30	5.06	0.92
TZdEI 124 x TZdEI 314	3371	55	1.23	164.81	4.62	4.53	0.92
TZdEI 315 x TZdEI 202	3364	55	1.35	161.58	4.98	4.33	0.97
TZdEI 485 x TZdEI 124	3362	56	1.42	161.96	5.37	5.35	0.84
TZdEI 131 x TZdEI 157	3347	56	1.04	168.88	4.77	4.35	0.90
TZdEI 157 x TZdEI 84	3328	58	1.50	171.54	4.90	4.80	0.88
TZdEI 264 x TZdEI 98	3322	58	1.35	159.62	4.85	4.73	0.89
TZdEI 399 x TZdEI 268	3301	56	1.19	168.23	4.25	4.05	0.91
TZdEI 84 x TZdEI 82	3280	57	1.13	169.33	5.17	4.25	0.76
TZEI 31 x TZdEI 120	3276	56	1.69	159.12	4.71	4.58	0.92
TZdEI 120 x TZEI 18	3273	57	1.88	154.85	4.71	4.35	0.90
TZdEI 485 x TZdEI 399	3270	58	1.46	158.88	5.23	5.08	0.86
TZEI 60 x TZEI 86	3259	57	1.15	161.50	5.02	4.45	0.84
TZEI 31 x TZEI 63	3198	57	2.00	157.46	4.67	4.26	0.85
TZdEI 120 x TZdEI 283	3191	58	1.38	157.13	4.69	4.17	0.92
TZEI 31 x TZdEI 131	3168	57	1.54	167.62	5.08	4.83	0.78
TZdEI 124 x TZEI 7	3167	54	1.85	158.62	5.15	4.63	0.86
TZdEI 124 x TZdEI 268	3094	56	0.72	164.12	4.62	4.50	0.97
TZdEI 98 x TZdEI 84	3046	56	1.13	164.08	4.33	5.33	0.91



Appendix 5.7a. Percentage contribution of GCA and SCA under *Striga*, drought and optimal growing environments



Appendix 5.7b. Additive variance due to male and female for yield and other agronomic traits under *Striga* infestation



Appendix 5.7c. Additive variance due to male and female for yield and other agronomic traits under drought